Industrial Electrical Engineering and Automation

Visualisation of network loading and the impact of solar power at secondary substations in Lund.

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Abstract

Electrical power distribution is currently seeing both challenges and opportunities. On one hand, the digitisation of measurement data and modern measurement devices enable deeper analysis and planning of the grid. On the other hand, the expansion of privately owned photovoltaic systems and the customers' desire to produce their own electricity is an inevitable challenge that distribution companies may face in the very near future. The distribution network companies have a need of analysing and dimensioning with the ever growing number of connected solar power installations in mind. The purpose of this project is to create a proof of concept tool that visualises the historical consumption data to give an overview of the network load and whether the existing capacity is adequate for future scenarios of more connected solar power installations.

This project was carried out at the distribution network company Kraftringen in Lund, Sweden, with the use of power consumption data of several secondary substations in the span of almost a year. Using the Qlik Sense platform an user interface was created to visualise in detail the hourly power consumption for each and every secondary substation over 2018 excluding December. Raw consumption data was then filtered and processed to give the most useful analysis of the network loading. Through calculation using weather data from SMHI and a data-sheet from a solar plant model provided by the distribution company, a solar power production profile was created. This profile was then imported to the Qlik Sense app to visualise the impact it has on the network based on the number of installations and the amount of power they produce.

The findings indicate that most secondary substations in Lund have much capacity remaining for load increase at their current state but can be put to their limit as the photovoltaic systems become more efficient and the customers being more willing to utilise them. The calculation of solar power profile is reasonable to represent average consumers in a network and it's possible to predict the impact of future solar power installations on the network. Furthermore, the calculation of tax reduction limit for producing customers provides economical value and hopefully even more incentives to utilise solar power. The visualisation tool is a proof of concept that can have other uses with future installations of new measurement devices as more data can be gathered and analysed. An example is voltage and current data that can be used to analyse the impact of photovoltaic systems in other aspects than just the load.

Acknowledgements

Contents

1 Introduction

1.1 Background

There has been a surge of interest for private solar energy production in Sweden as well as other developed countries in recent years. Earlier experience in Germany, a major solar energy producer with similar solar irradiation profile as Sweden, indicates that mass-integration of photovoltaic plants into low-voltage grids has potential to cause major grid disruption[1]. The expansion of photovoltaic systems connected to the low-voltage grids may also require network reinforcement in form of larger cables and transformers[2]. Therefore knowing the impact of solar plants connected to the grid is important for the dimensioning of a network which is traditionally designed for electrical flow to the customers, not other way around.

A proposal referred to the Swedish Council on Legislation for consideration regarding electricity meters appeared in 2016. This proposal suggested that as of 1st of July 2017 every owner of the grid is required, not just obligated as before, by law to measure and calculate the electricity that is transferred and be able to present this for users without extra charge. This law is part of the development of moving to smarter grids, and one of the suggestions brought up was the requirement to make hourly measurements which then created a need for updated regulations and laws in regard to electricity meters. This was the foundation to investigate what possible regulations would need to be implemented along with moving towards a smarter grid. It was also assumed that this would decrease the energy consumption of the users. Changing all of the current electricity meters may take time and therefore each company has until 2025 to do so. Kraftringen is currently, as of 2020, undergoing this change [3].

Kraftringen is an energy company in Sweden with the ambition to lead the development of renewable energy production, distribution and consumption. One important milestone is to eliminate the use of fossil fuel which the company have already done in the production of electric power. However there are works to be done to be completely fossil-free in production and consumption and solar power is an important part of the development.

1.2 Goals

The goal of this master thesis is to design an analysis tool that makes it convenient for Kraftringen to look at the hourly consumption from connected customers in a network. The hourly consumption data is presented graphically and in detail for every day of the year from which the load on the transformers can be analysed. The next step is creating a hypothetical solar power profile and add it to the existing load so the impacts of additional solar power production on the network can be analysed.

1.3 Problem statement

The successful project should be able to answer the following questions:

- Are the visualisations useful for the analysis of the hourly consumption and strain on the network?

- What impact do customers with solar panels have on the network?

- In Sweden, private owners of solar power production can get tax reductions if they meet the right conditions, and one of the conditions limits the amount of produced electricity. Can this visualisation tool be used to find the limit for each customer?

1.4 Delimitations

Since the main focus of this thesis is power consumption data, no data for voltage, current or reactive power will be analysed. Power consumption data is only for the year of 2018, excluding December. Due to technical limitations only data from 11 secondary substations are imported to Qlik Sense. While this is enough for a proof of concept, its practical use is somewhat limited. The solar power production profile is based on one solar panel model from 2008. This is fine because only the production is used in the analysis and not size or cost. The concept is meant to work in general, even with data from other measurement systems but the focus here is data from Kraftringen and compatibility with the Qlik Sense platform.

1.5 Related works

Landis+gyr has a tool that helps to manage the grid through gathered data and presents it in a visual way with load profiles of substations [4], but our thesis will focus on the city of Lund using the historical consumption data to create our own analysis over the grid/substations/solar energy. The software interface will however be used as a main inspiration for our project.
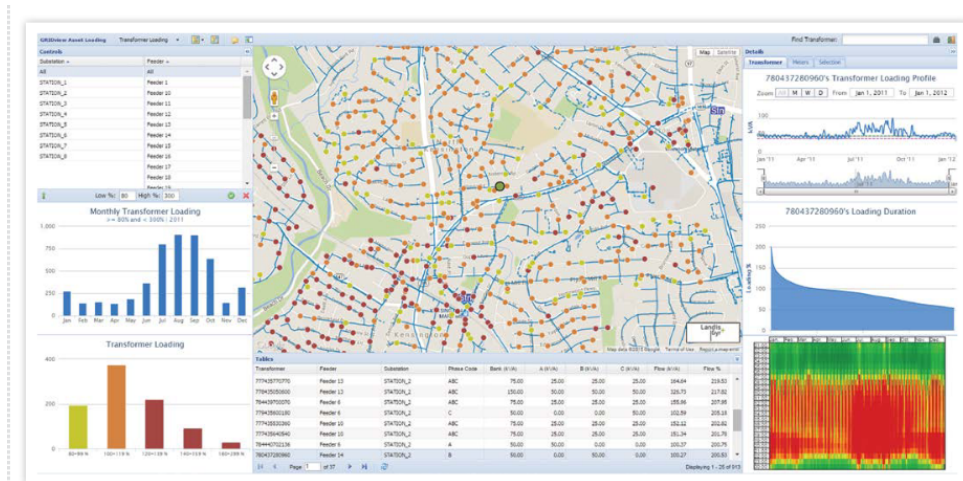

Figure 1: Inspiration from an analysing tool from Landis+gyr [4]

Oscar Ingvarsson's thesis touches on the subject of network and measuring different things as well as aggregated electricity meter data, but it has a focus on electric vehicles [5]. Our thesis will instead focus on, what's been stated already, active power and solar energy.

2 Theory

Throughout the thesis the topics of power distribution network and solar power will be explored. Amongst them there will be focus on network topology, power in general and solar power production. Either an overview or in depth theoretical explanations of these topics will be presented in this section.

2.1 Network topology

As network topology in Sweden is relevant to this work it is explained here.

The power system is traditionally a top down system with highest being the generation plants (hydro, nuclear, etc..) that produce power and transfer it to the 400kV transmission lines. The amount of power produced matches the demand of the end consumers who are lowest down in the hierarchy (see Figure 2) plus network losses. In between are the distribution levels which consist of regional and local grids all the way down to low-voltage distribution network or directly to connected consumers. The secondary substations are the closest link between the consumers and distribution network. This ensures a one way flow power transmission according to the classical "Source-Load" circuit model. However, this system is undergoing a transformation in recent years into a more decentralised distribution network due to growth of renewable energy production in the form of wind and photovoltaic power systems.

The structure of the power system can change depending on the country, and in Sweden it is structured in the following way [6]:

1. Power generation (wind, hydro, nuclear etc)

2. From the generation this is transmitted through the National grid operated at 400kV and 220kV

3. The national grid is then branched out to regional grids operated in the range of 40kV to 130kV

4. From the regional grid local grids are supplied and are operated under 40kV, generally at 20kV or 11kV

5. Transformers then bring down the voltage to 400V (line-to-line) at the secondary substations,

6. From the secondary substations the power is then distributed to customers connected to them

The visualisations in this thesis is based on data collected at point 6 in the list above. Figure 2 depicts the power system hierarchy and also shows where in the network this is done in a different way than above.
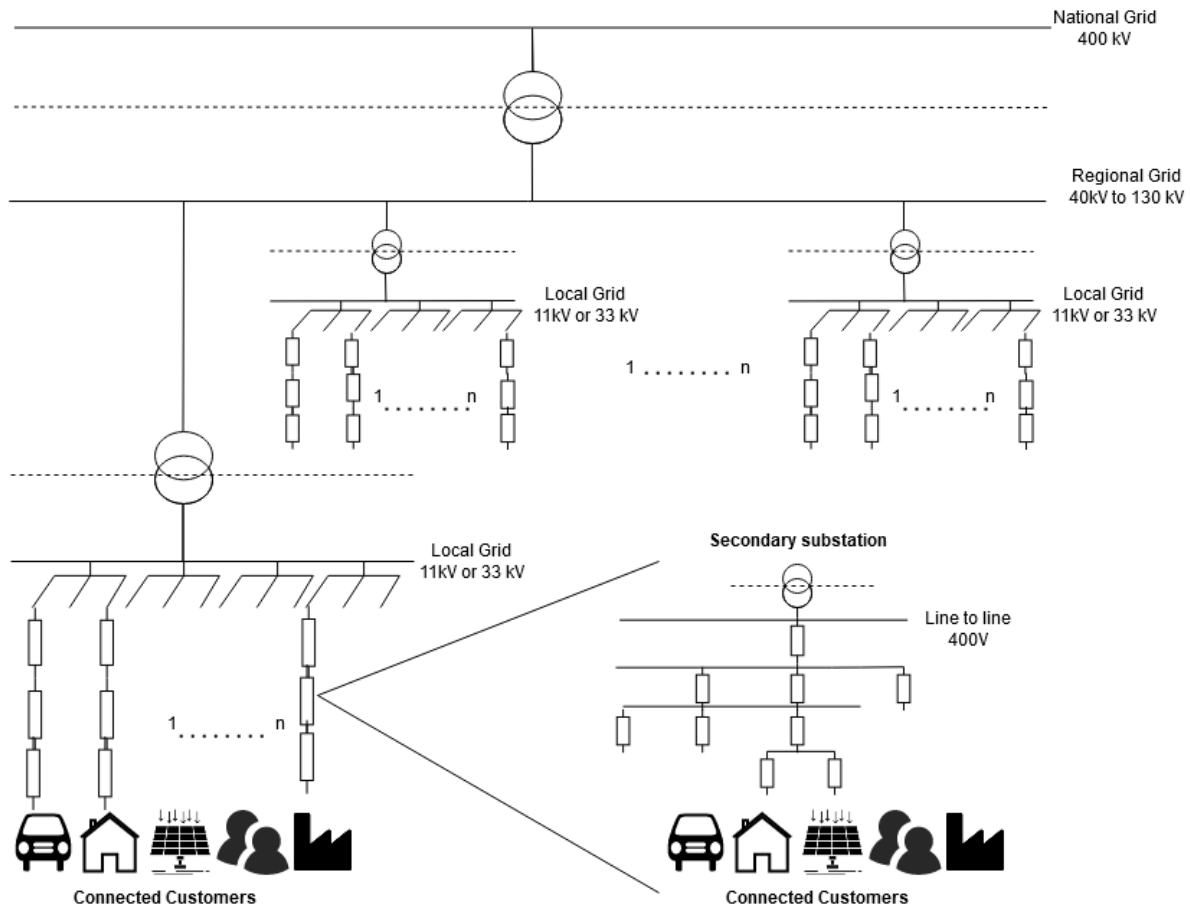
9

Figure 2: Power System Hieracrchy

2.2 Power unit

Power may be defined in different ways, namely active, reactive, apparent and complex power. The one measured at the secondary substations, and probably the one most people know of and think of when they think of power, is active power. This is the power that does actual work. Reactive power can be seen as the energy the magnetic field or electrostatic field has within a circuit and does not contribute to the actual work. It appears as soon as there are inductive and/or capacitive elements in the circuit. [7]. This power can be used to control the voltage levels (Reactive Power Control) across a transmission system [8]. Since both active and reactive power exists in the network it is important to know that there is a difference and to also know that only active power is used here.

Apparent power is the product of the amplitude of voltage and current, and is seen as the total power in an AC circuit. Power factor is the ratio between active and apparent power, and it indicates the level of utilisation of electrical power. See Figure 3 for how power factor is used and relations between active and apparent power [8]. Finally, complex power is the sum of active and reactive power and is a complex number.[7]
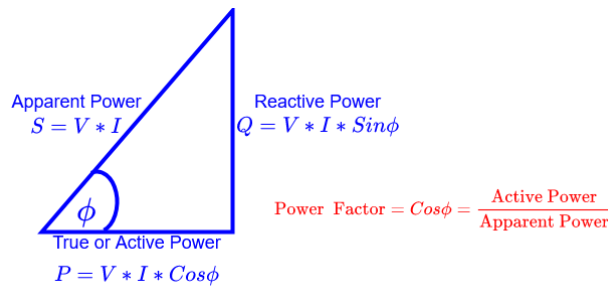
Figure 3: Power Factor [9]

In the visualisations the power factor is used to show the part of the capacity that is only active power to create a more realistic relation between load and capacity.

2.3   Solar module information

The solar module used in the model for solar power is the Sharp NUS0E3E. A snippet of the data sheet is seen in Figure 4 which shows the efficiency and the maximum power, among other things.

ELECTRO-OPTICAL CHARACTERISTICS

Parameters	Symbol	Min.	Typ.	Unit	Conditions
Open circuit voltage	V_{oc}	-	30.0	V	Standard test conditions (STC)
Maximum power voltage	V_{pm}	-	23.7	V	
Short circuit current	I_{sc}	-	8.37	A	Irradiance: 1,000W/m²
Maximum power current	I_{pm}	-	7.60	A	
Maximum power	P_m	171.0	180.0	W	AM 1.5
Encapsulated solar cell efficiency	η_c	-	15.7	%	Module Tempeature:
Module efficiency	η_m	-	13.7	%	25 °c

Figure 4: A snippet from the Sharp NUS0E3E solar module data sheet [10]

To note is that the values seen in data sheets for solar modules are found under so called "Standard Test Conditions". These are:

- Irradiance = 1000 $\mathrm{W\,m^{-2}}$

- Standard light spectrum = AM 1.5

- Temperature of the module = 25 °C

Where AM 1.5 is consider to be an average value of a full year of how far the light has travelled in comparison to a vertical path. It's also referred to as a light spectrum. [11, p. 25-26] Using STC for the data sheets allows for a good enough comparison between different solar modules, since in reality the values for irradiance, light spectrum and temperature will be different depending on the location of the solar module.

The full data sheet of the module can be found here [10].

The efficiency of a solar cell fundamentally depends on the semiconductor material and the energy which the sun provides. Physics put an upper limit on the efficiency which has to do with the fact that every semiconductor has a bandgap which is the amount of energy that needs to be absorbed to create a current of electrons. This means that not all wavelengths will carry enough energy to move an electron and so there is a physical limit on the energy coming from the sun [11, p. 93].

Standard test condition

When looking at the data sheets of solar modules, one will see different units such as maximal power output. This maximal power output varies depending on, not only the module itself, but also the circumstances and environment the module is placed in. However, the data found in the data sheet is done under the *Standard Test Condition*. In this way every solar module can be compared since they are using the same conditions as references. The conditions are [11, p. 15]:

- Irradiance = 1000 W m$^-$2

- Standard light spectrum = AM 1.5

- Temperature of the module = 25 °C

In the data sheets you will find values that are done under the STC. Refer to figure **??** for an example. This is from the data sheet of the solar module that is used in the model for the solar data later used in the thesis.

There is also a temperature dependency that governs the efficiency. This is found in the data sheet of the solar module and is a constant that tells how the efficiency changes per degree from the STC module temperature, and is given as a negative number. The highest average monthly temperature in Lund in 2018 was 23.0 °C in July, and the lowest average monthly average temperature was -1.4°C in February [12]. The temperature coefficient for power for the Sharp NUS0E3E is -0.485% / °C [10]. The efficiency in the data sheet is shown under standard test conditions, and as seen in Figure 4 the module efficiency is 13.7% at module temperature 25 °C. It is clear that the efficiency of a solar panel located in Lund takes on different values depending on what season it is.

In figure 5 one can see that silicon isn't the best, but also far from the worst, material in terms of efficiency and it's the most common material used. This is due to availability of the resource and the cost to create [11, p. 132].
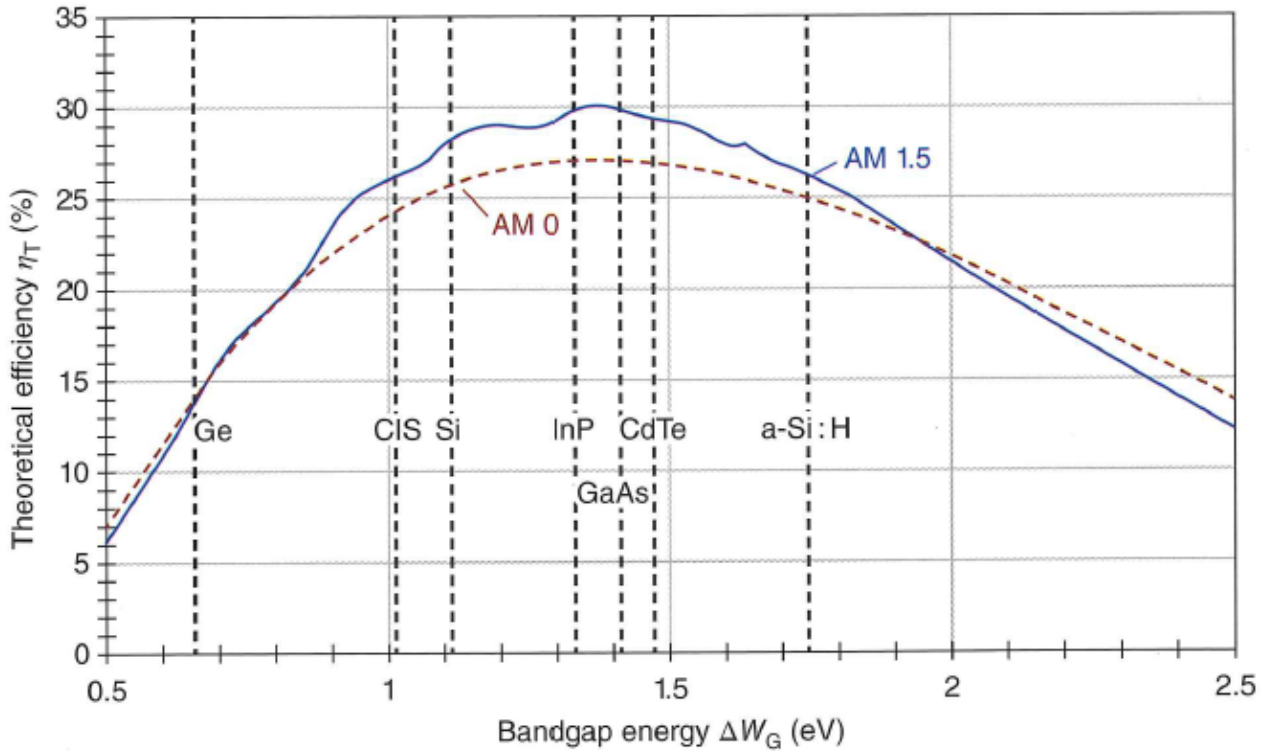
Figure 5: Theoretical efficiencies for different semiconductors [11, p. 95]

Where AM 0 is the spectrum outside of the Earth's atmosphere and AM 1.5 is the standard test condition spectrum.

What to take away from figure 5 is that the efficiency of silicon doesn't go above 28% at AM 1.5 [11, p. 95]. While it is interesting to dig further into the reasons as of why, it is not within the scope of this thesis and will not be discussed to any greater detail than this.

2.4 Photovoltaic systems and network capacity requirements

While the focus of this project is analysing the network loading in terms of hourly power consumption, the dimensioning of the network should take into account other factors such as the strength of the network and the ability to maintain a good power quality. With solar power in mind this is even more apparent. This subchapter gives a brief explanation of why strengthening the network is important to prepare for future solar power scenario and how it is usually done.

2.4.1 Power quality

The solar plants supply the local and regional power systems, this has the advantage of reducing the need for customers with solar PV to buy electricity. However it could be challenging for distribution companies to maintain good quality electricity for their customers when the number of small scale photo-voltaic systems increases. The Swedish energy regulator has defined a number of requirements to determine the quality of electric power[13]:

- Voltage variations

- Voltage sags

- Voltage swells

- Transients

- Flicker

- Unbalance

- Harmonics

- Frequency

These requirements describe power distribution unaffected by disruptions that arise from planned or unplanned events in the network. Those disruptions can be caused by connections in the network, rapid connection and disconnections by electrical loads, lightning, high frequency switching devices, weak network and time-varying generation by renewable energy sources [14].

2.4.2 Photovoltaic systems and strength of the network

The strength of the network is fundamental to maintain good quality electricity in a network with many of photovoltaic systems. When connecting solar power plants it's important to make sure they wont interfere with the operation of the network by introducing any disruptions or reduced quality of power as described above. The most common problems that can occur with a higher penetration of private power generation is voltage and frequency fluctuation, harmonics, power flow problems and power losses [15]. The quality of electricity depends on both the strength of the network and the connected devices.

The strength of a network describes how well it is prepared to handle any disruptions in the network. For a low voltage network it depends on the size of the transformers, cross-sectional area of the distribution lines and the corresponding properties of the distribution system right above in the network topology [16]. A strong network is characterised by a large transformer and large cross section area of the distribution lines which means it has low impedance. One way to define the strength of a network is the short circuit ratio between short circuit apparent power S_{SC} and the installed capacity for the generation power plant s_n [15]. For a three phase short circuit the apparent power S_{SC} is defined by:

$$S_{SC} = 1.1 \cdot U \cdot I_{SC} \cdot \sqrt{3} = \frac{U^2}{Z_{SC}} \tag{1}$$

The strength of the network is then defined by:

$$SCR = \frac{S_{SC}}{s_n} = \frac{U^2}{Z_{SC} \cdot s_n} \tag{2}$$

Where U is the voltage, I_{SC} is the short circuit current and Z_{SC} the short circuit impedance. The short circuit ratio decides the stability of the grid and a value under 10 is considered a weak power grid while a value over 20 is considered a strong power grid [15]. Which means the network's strength is in inverse proportional to the impedance of the transformer and distribution lines and a lower impedance is desired. Higher impedance of the transformer however, helps reduce the the fault current and thus can't be reduced however to increase grid strength [17].

Since this tool only look at the active power part and the maximum active power transfer in a lossless transmission line is is half the size of the short circuit apparent power [18] Equation 2 can be rewritten as:

$$SCR = \frac{2P_L}{s_n} \tag{3}$$

to determine the ratio between active power transfer and installed capacity for the generation power plant.

Another way to investigate the network's strength in a low voltage network is to check the voltage variation that appears when a connected customer rapidly connects and disconnects the load or micro-production plants [2]:

$$\Delta U = \frac{R \cdot P + X \cdot Q}{U} \cdot 100\% \tag{4}$$

Where Δ U is the voltage variation, U is the voltage before the connection and disconnection of the plants, R an X is the resistant respective reactant part of the network's impedance (Z), P and Q is active respective reactive power. Lower voltage variations for the number of connected micro-production means stronger network. The transformer rating decides the transformer series impedance. Assuming 145/11 kV 800kVA and a 145/11 kV 1600kVA rating transformers with both having $X_{eq} = 0.1$ p.u, the 1600 kVA rating should have half the X_{eq} on the 11kV side (in Ohm) and thus the voltage variation is down to about half according to Equation 4.

2.5 Solar energy and specific taxation in Sweden

For those who produce renewable energy with photovoltaics (but also wind and hydro), certain tax rules exist along with a couple of qualifications [19]. There are different rules that apply depending on if it's installed on a property that is part of a business, or a private home. If you install solar panels on a property that has both business and privately owned housing there's regulations for that too. Further, the rules also change depending on the purpose of the installation.

When using solar panels you can either feed the grid or use the energy yourself, or a combination of both. It's common to use the energy when the production doesn't exceed the consumption, and feed the grid with the energy that is left over when production is greater than consumption. As someone who feeds the grid with excess electricity when the production is greater than

consumption, you classify as a "micro-producer".

For the purpose of this thesis it's not necessary to go into detail about how you pay the taxes for your solar installation, it's enough to know that there are certain rules for declaring income through solar energy. The relevant part is the regulations governing tax reductions.

The first two conditions are:

- The production facility must have the same connection point to the grid as the property does, and also share the same main fuse

- There can never be more than 100 ampere going through the fuse at the connection point.

Once these two conditions are met the rules for tax reductions are then as follows:

- One can only get tax reductions up to the same amount of kilowatthours that are consumed. So, if the annual consumption is 20000kWh one will not get tax reductions on the produced electricity that exceeds 20000kWh

- One is eligible for tax reductions up to no more than 30000kWh

The reduction amounts to 60 öre (0.058 Euro) per kilowatthour, which gives a maximum of 18000 SEK (1762 Euro) per year.

The main difference between business and privately owned solar installation is when the subscription is shared. For privately owned installation some additional benefits may exist.

For businesses, assuming that everyone is connected to the same connection point, then everyone in the subscription can inform the network operator that you are producing electricity. However, the same rule about 30000kWh still exists, regardless of how many people are in the subscription or how many connection points that they connect together to. [20]

For privately owned installations you still need to be connected to the same connection point, but here the total amount of electricity fed into the grid is split equal between the people in the subscription. As well as for business, the tax reductions does not apply to anything produced above 30000kWh regardless of how many are sharing the subscription. Another difference is that as a private owner of an installation, one will also get allowance for feeding to the grid. This is paid by the network operator to you as a produce electricity. And lastly, you do not need to pay any energy tax on the electricity you produce if your solar energy installation has a peak power of up to 255kW, which normally is the case. [19]

3   Qlik Sense app development

In this chapter the different methods to handle measurement data and develop the analysing tool is presented. The consumption data were given from historical measurements stored in Kraftringen's database. As for the case with solar energy, data from a solar plant from 2008 is used to create a production profile. The analysing tool was mainly developed inside the Qlik Sense analytical platform.

3.1   Specification requirements

The analysing tool is developed inside Qlik Sense platform and uses standard features including data handling, data visualisation, data search and scripting [21]. Our design approach of the analysing tool has the ambition of presenting enough charts and data for analysis but still having a clean and easy to use interface. Qlik Sense provides adequate amount of features to make it possible.

3.1.1   Functional

The main function of the tool is visualising the total energy usage from the customers, supplied by a certain secondary substation, during different time of the day or day of the year so that the peaks can easily be identified. The visualisation must present the capacity of secondary substations to analyse whether they satisfy the need of the connected customers as well as how well they're prepared for the future scenario of more solar energy in the network.

The following functions should be included in the tool:

- Different kind of charts showing the relations between total energy usage and the capacity of the selected secondary substations. Bar graphs, line graphs and heat-maps are most suited for these kind of analysis.

- The energy usage data should be presented in such a way that allows the user to analyse it on a time basis: for example which time of the day or day of the month/year is the load at a peak.

- Secondary substations should be able to be sorted by ID, most and least strained or number of customers.

- Data from an individual secondary substation could be presented in a table by selecting it.

- A map that shows where the secondary substations are located geographically and the ability to select them on the map.

- Consider a scenario in which more solar power production in the network, it should be analysed by presenting them on top of the power consumption graphs.

- It should be possible to import more data to the app.

3.1.2 User interface

The tool utilises Qlik Sense analytic platform with dashboard views of data and relationships between data. The main idea is to present as many key figures and analysis as possible while maintaining a clear and easy to use interface. The data and charts should be presented in such a way that as many departments from Kraftringen as possible can utilise the analysis for planning and operating their network. At a minimum the interface should satisfy the following requirements:

- The Qlik Sense sheets are named according to their functionalities and purposes. User should know what to expect and where to find the analysis they are interested in in the app by looking at the overview.

- The graphs and tables are titled and captioned clearly and descriptive. Graph legend should be displayed in most cases.

- All measurements must display units in SI-unit. Any kind of conversion must be clarified in the figures.

- Search box is accessible for data relevant for the analysis.

- User can select and deselect data presented on graphs and tables for deeper analysis.

- Data and figures in each sheet are kept in a reasonable quantity, enough for a proper analysis but not making the screen too crowded.

3.2 Software

3.2.1 Qlik Sense

As mentioned earlier the main software used in the project was Qlik Sense. One of the reasons was the license that Kraftringen were being able to provide and there's great expertise amongst their employees to give us consultation if needed. Qlik Sense is already their main data analytic platform and the prototype would integrate into the company's current framework easily. Qlik Sense includes many tools for data visualisation and data processing in form of charts and scripts. It is possible to combine and analyse data in many graphical ways with a wide selection of graphs and tables. Furthermore there are many ways to filter, sort and search for data using standard features and scripts.

One important feature is the ability to import data sheets from other platform for example Microsoft Excel. One way to do so is through the Qlik Sense's script-editor in Figure 6:
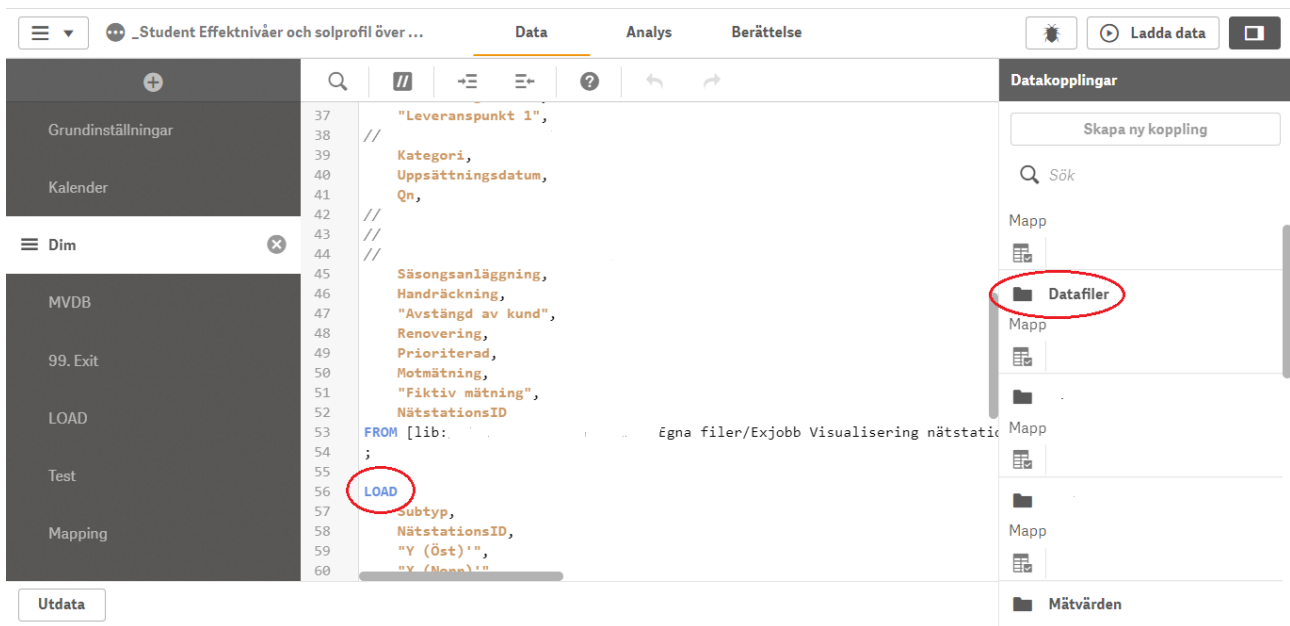
Figure 6: Qlik Sense's scrip-editor

External data sheets can be imported directly by navigating to the "Datafiler" directory then import it from the file system. Using the "Load" command one can choose which data field from the data sheet gets imported.

The data sheets can then be used for analysis in the analytic editor in Figure 7. This is where our visualisations were created. This is a powerful tool with many options for graphical presentation and data processing. On the left of the figure one can choose which type of graphs or which data field can be presented in the middle. It is a simple drag and drop function and one can easily start creating graphs or any of the analytical tools Qlik Sense can offer. The toolbar on the right is where one can choose what data or data associations can be presented with the graphs and other tools. It also includes other options such as data sorting, data processing, chart editing and more.
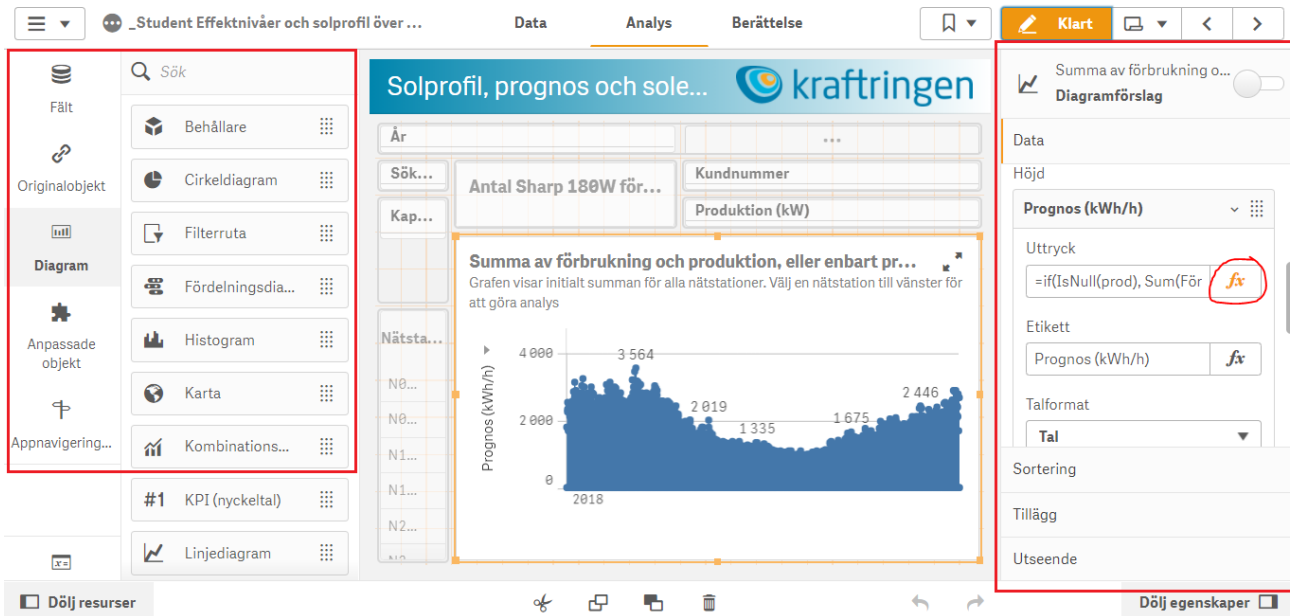
Figure 7: Qlik Sense's analytic editor

Beside the basic editing options developers can apply more in depth functions by opening the expression editor marked with "fx" in Figure 7. Here one can use Qlik Sense scripting language to create more complex analysis of the data and data associations. Figure 8 shows the expression editor window and a script to do some calculations for the solar production profile. The result can then be used in this case for graphical plots.
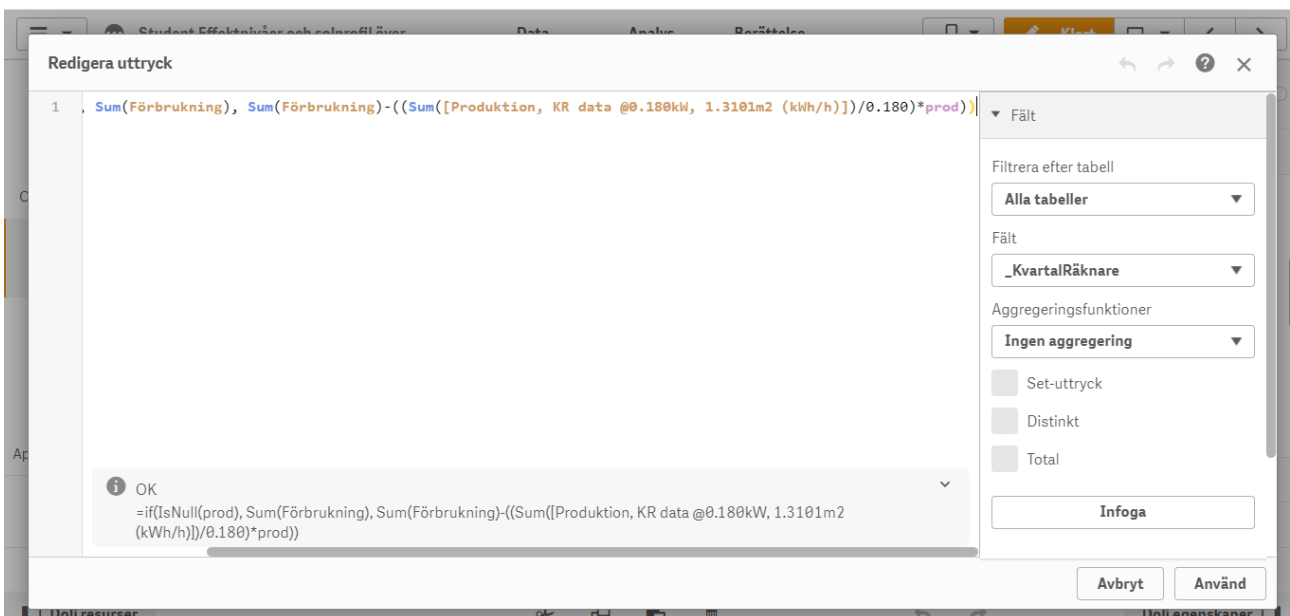

Figure 8: Qlik Sense's expression editor

These features and tools are just one part of the Qlik Sense platform but provided enough functionality for our needs and were mainly used for the creation of our analytical tool. The

current web-based Qlik Sense client doesn't allow simultaneous editing of the app. To get around it one needs partial administrative privilege from the webmaster at Kraftringen. With this privilege, the developers can give and take ownership of the app when needed as well as making copies. This is currently the most optimal way of co-developing a Qlik Sense app.

3.2.2 Microsoft Excel

Microsoft Excel is a useful tool for this project. While Qlik Sense has many options for data processing and was used as the primary tool for that purpose, Excel provides a great option for gathering data and importing them into Qlik Sense. In this particular project, this is a necessary step since connecting the app directly to the measurement database isn't possible yet and the data used come from an existing app alongside other complementary data sheets. The data can be pre-sorted and pre-filtered before importing into Qlik Sense as shown in Figure 9, or more specifically it can be used as a reference tool to find values that are false or wrong in any sense and then take action in Qlik Sense to correct it. As mentioned before, Excel was also used heavily in preprocessing the data for the solar profile.
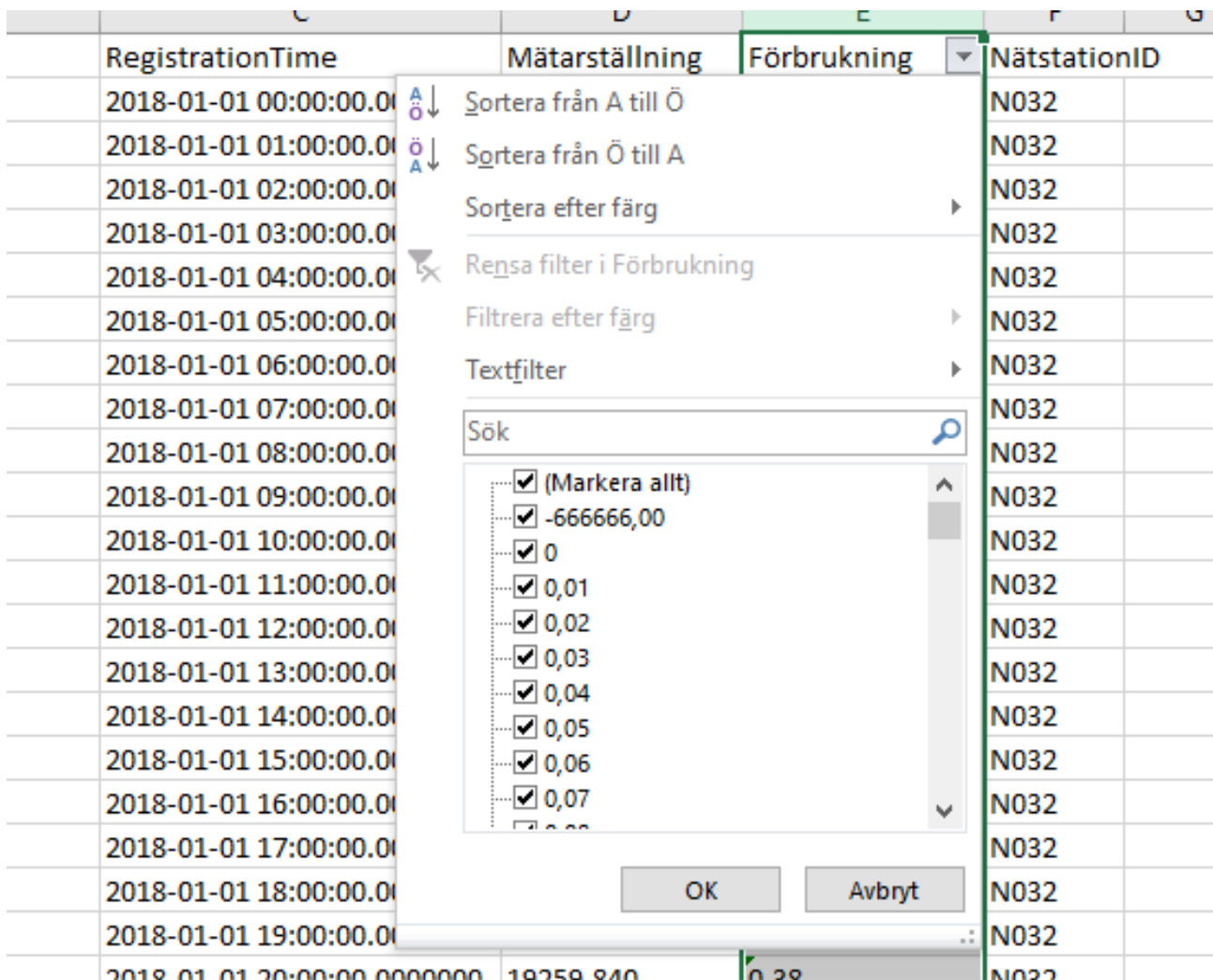

Figure 9: Data filtering with Excel

The data sheets can then be easily imported into Qlik Sense with option to select relevant data fields or columns in the Excel sheets as shown in Figure 10 (the customers' IDs in the figure are manually edited out using external software to protect their identity). This procedure allows continuous development of the existing Qlik Sense app for more or different types of data.
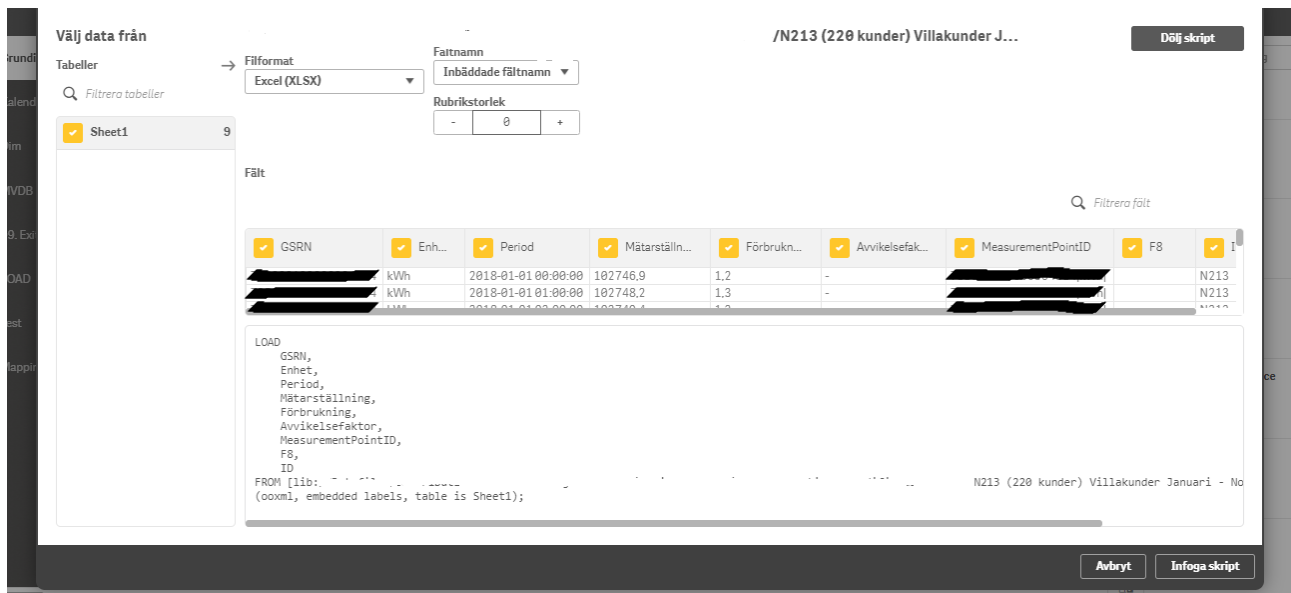

Figure 10: Importing Excel sheets into Qlik Sense

3.3   The data

The measurement data are raw energy data taken from electricity meter that has been digitised and stored in the database. Energy usage from customers in Kraftringen's network is the primary data needed to reach the goal, however other data from the secondary substations such as ID number, capacity and geographical location are also essential. Some of this data is protected by law and may not always be presented in great details in this report. There were ambitions to use data from all secondary substations belonging to Kraftringen's network for the analysis and development of the analysing tool. Unfortunately due to technical shortcomings that prevent fluid development, only data from a handful of secondary substations were used. The solar data was given to us by Kraftringen as well, in the form an excel file used to create production models.

The data used in the development can be grouped by the following:

- Energy usage data from every customer in the selected secondary substations and the timestamps of the gathered measurements. The data is from the year 2018 excluding December.

- Data associated with the selected secondary substations such as ID number, capacity, geographical location and more.

- Solar power production profile.

3.3.1 Handling of the load data

The energy usage data are raw data and thus needs to be filtered before the analysis. The most interesting outliers are the zeros and unusually large negative energy usage. For the zero energy usage, through pre-analysis, the conclusion is drawn that most of them are reasonable according the timestamps because people could be turning off central switch when they go to work or the properties are not utilised during certain time of the year. Too large and negative numbers are removed as well as false the day of the month, noticeably if the month February has 30 or 31 days. The range is fixed between -5000kWh and 5000kWh, as agreed upon from consulting with our supervisor that it is large enough to include all consumption and (expected) solar power generation data while still filters out most of the unreasonable values. The lower limit was set as both 0 and -5000 to test if the solar power prognosis was affected but the results remain unchanged. Unusual large and negative energy consumption appears because how it is interpreted from reading the electricity meters. The electricity meter updates its counter continuously and the hourly power consumption is deducted from the difference between two readings. If the counter resets or the electricity meter gets replaced there will be abnormal "consumption". See Table 1 for example. The 100 kWh difference between "Reading 1" and "Reading 2" from the counter is assumed (correctly) to be the energy consumed in that period. At "Reading 3" the counter is reset to zero and we have incorrect negative consumption data.

	Counter	Consumption
Reading 1	1000 kWh	
Reading 2	1100 kWh	100 kWh
Reading 3	0 kWh	-1100 kWh

Table 1: Example how energy consumption reads from counter

These numbers can be filtered using Qlik Sense scripting language. For example:

```
1  LOAD
2      .
3      .
4      .
5  //  GSRN,
6      Mätserie,
7      Avvikelsefaktor,
8      Avvikelsestatus,
9      StatusFörbrukning,
10     Förbrukning
11 FROM [lib://../Mätvärden_2018*.qvd]
12
13 (qvd)
14
15 Where Exists(MeteringPointID)
16 and
```

```
17  ([Förbrukning]>-5000) and ([Förbrukning]<5000)
18  ;
```

Listing 1: Scripting to filter out values outside the range 0-5000 kWh

Line 17 in the code is the one doing the filtering. This is done when loading data files/sheets into Qlik Sense and energy consumption outside of the -5000 to 5000 kWh range is filtered out.

3.3.2   Handling the solar power data

The production model is made up in an excel sheet and is based on the Sharp NUS0E3E module. It has the options to enter the direction the model faces and also it's angle. According to the model, the optimised values are when the module is facing south with the module in a 45°angle right between laying down and standing straight up. The option to enter how much peak power the installation shall have is also available, which in this case were set to 180W to mimic one Sharp NUS0E3E panel. The hourly production, for a whole year, is then generated as a list. This list is the input for the Qlik Sense solar profile. To be able to scale the installation a reference value based on the original hourly values from the 180W installation is needed. This was calculated by taking every hourly value and dividing it by 180W, thus creating the correct scale factor for each hour.

$$ScaleFactor = P_{hourly}/P_{installed} \tag{5}$$

The actual calculation is made directly in Qlik Sense. So for example, if the user selects 10 kW as the installed power then Qlik Sense will use the list, and for every hourly value it will divide it by 0.18 kW and multiply with 10 kW.

The design approach for the solar profile is that first there is a bar graph showing worst case scenarios, then a line graph showing the full year or specific time depending on the user, a map of Lund with all secondary substations in it that changes colour depending on the production level and how close they are to reach their critical power limit and two charts for finding and analysing individual customers' power loading and how much solar power they can produce before hitting the tax reduction eligibility limit. Overall, the option to select a specific consumer is also implemented to make case-to-case studies if needed. The bar graph shows, as stated, the critical cases for the secondary substations, with the secondary substations on the x-axis and the load/generation on the y-axis along with reference lines showing the capacity of each secondary substation. The two critical cases' were accomplished by using min and max values, respectively, of the load and subtracting the generation for each of the two cases. The aggregation is done over the whole time period that is chosen (2018 by default) and for all secondary substations. The line graph was created to show a selection of time intervals to give the user the power to choose between the whole year, quarter, week, month, day or hour. The time period was created so that the user can choose what the graph will show. This can be

used to go into great detail to see the profile for just a few hours on a specific day, or even just one hour. There is also an option to only show the power generated from the solar energy.

4 Results

The Qlik Sense app in its current state has eight main sheets divided into analysis of the transformer loading in term of hourly consumption and solar power scenarios as well as other features such as information about the stations and their geographical location on the map. As seen in Figure 11 these are:

- Analysis of the highest loading compared to the secondary substations' capacity.

- The overall loading for the secondary stations in a year.

- Table with relevant information about the secondary substations in the study.

- A map showing the stations' geographical location and colour code for the highest loading compared to the capacity.

- Analysis of worst case scenario with solar power compared to the secondary substations' capacity.

- Analysis and prognosis of the future solar power production's impact on the network with the tax reduction calculation feature.

- A map showing the stations' geographical location and colour code for the highest solar production compared to the capacity.

- Duration curve.
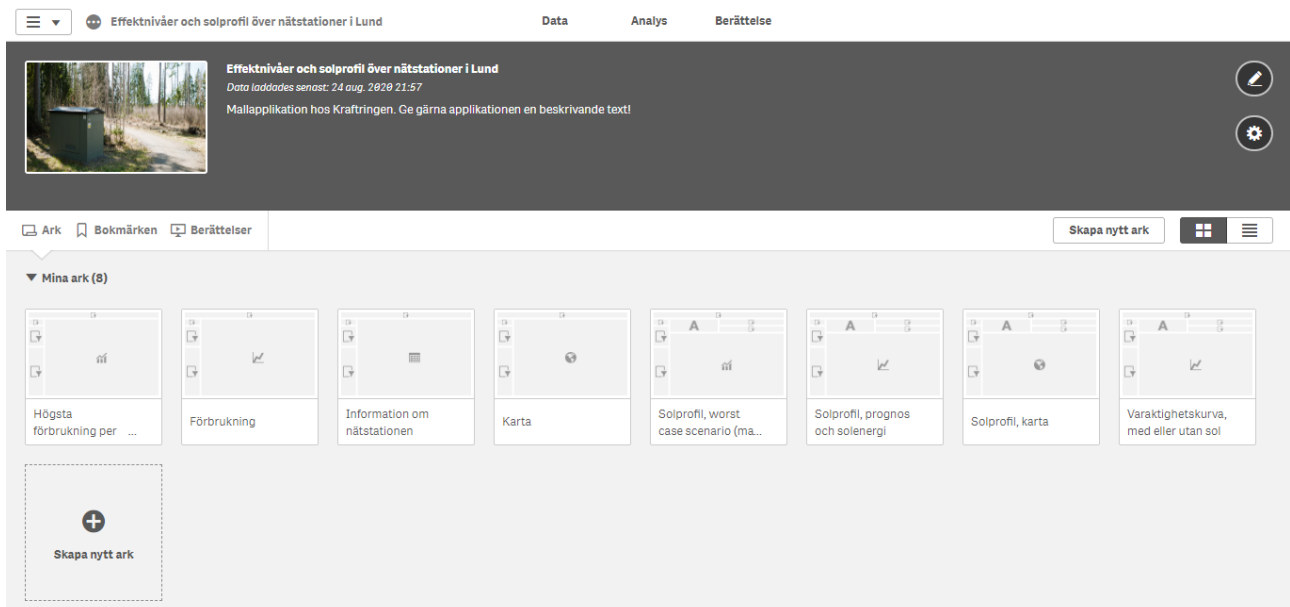
Figure 11: Overview of the analysis tool

The overview of the Qlik Sense app for the visualisation and the case study of network loading in Lund will be presented here. The different scenarios with solar power in the network will also be shown.

4.1 Load profile

The Qlik Sense sheet in Figure 12 below shows the graph for the highest hourly consumption in each secondary substation in the study. They are shown as the blue bar graphs in the figure. There are time selection tabs so the user can select to view the hourly consumption in certain months, weeks, days or quarter of a year (See Appendix A for more instruction). If no tab is selected the highest hourly consumption of the entire year is shown as default. The yellow and red line graphs represent the capacity of the secondary substations as rated capacity and capacity with power factor $cos\phi = 0.9$ respectively. Note that the power factor is different for different transformers and varying depending on how much active power is drawn at the time. The value is just an approximation.
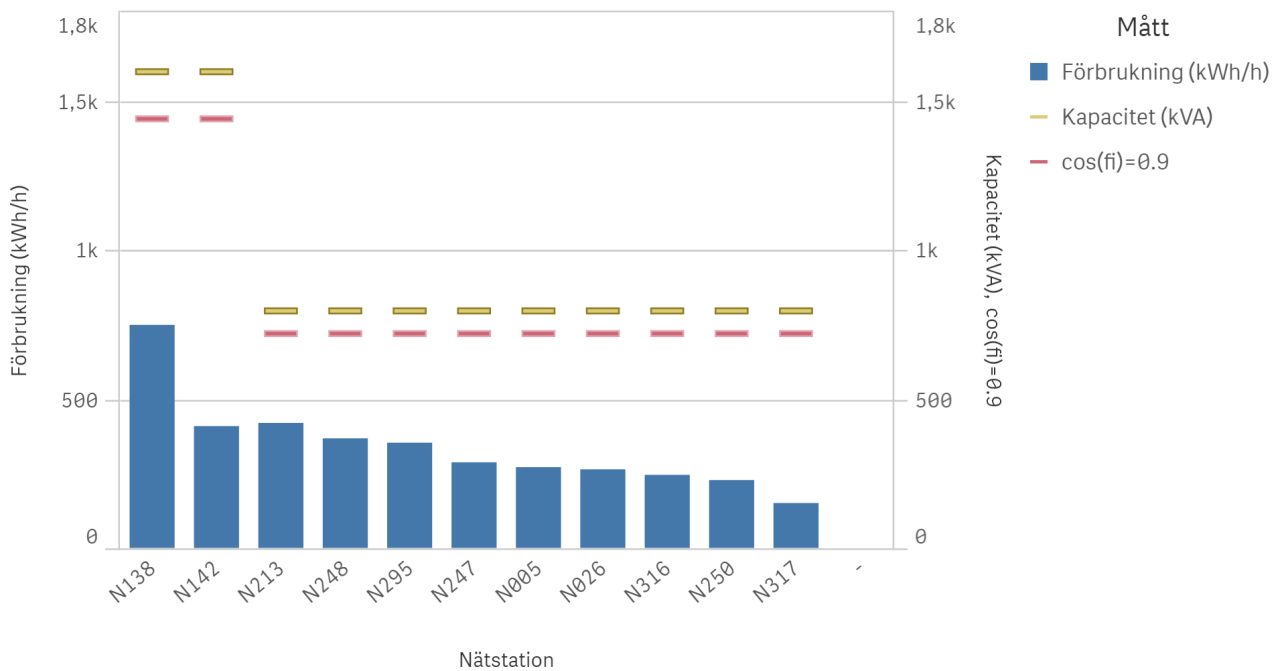
Figure 12: Highest hourly values of the transformer loading in a year for all of the secondary substations

The sheet in Figure 13 shows the overall loading of station N138 for a certain time interval. Here the user can view not only the highest but detailed hourly consumption in a time interval. For better analysis time selection and substation filtering function should be utilised. By selecting desired options the user can view for example how the hourly consumption looks like in a day for one secondary substation. If all stations are selected the graph shows the sum of all of the loading.
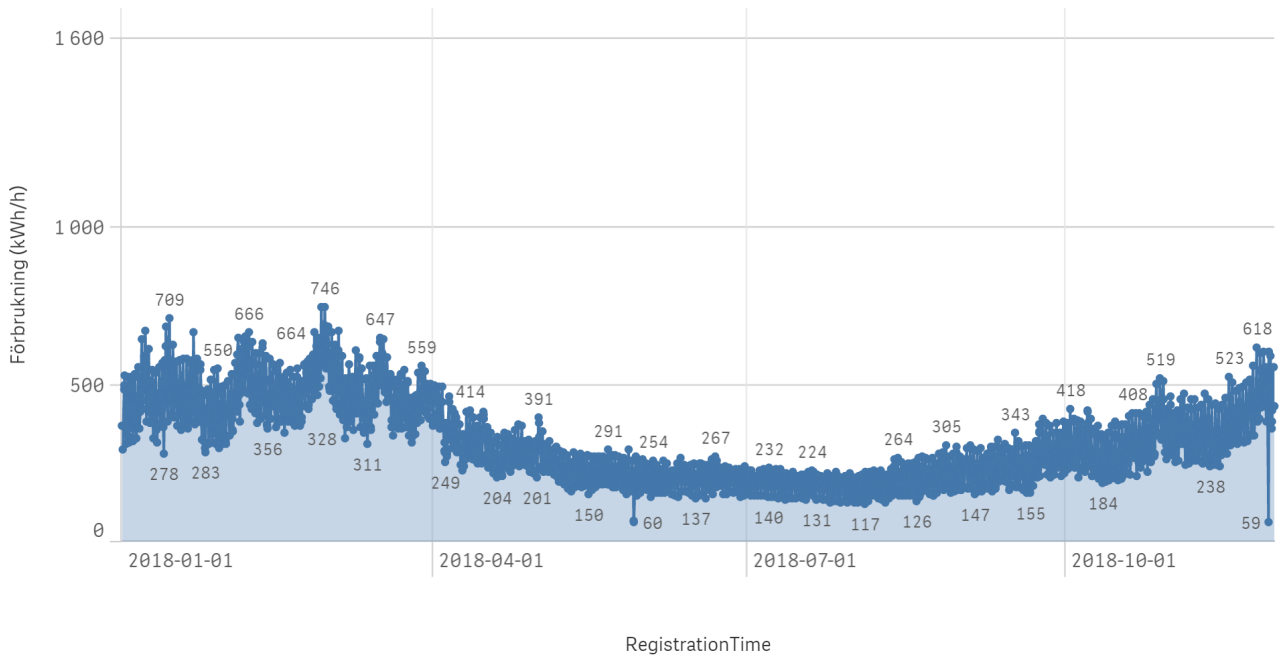
Figure 13: Overall consumption for station N138

Another useful feature in the tool is the ability to view the load duration curve of the network. This graph is similar to the one in Figure 13 but the power demand is shown in descending order of magnitude instead of chronologically. The highest power demand is plotted at the left and decreasing towards the right. This shows the overall capacity utilisation over a time period with the area below the curve representing electrical energy. Information about the average demand in specific time period can be obtained by:

$$\text{Average demand} = \frac{\text{Electrical Energy consumed in given time period}}{\text{hours in time period}} \tag{6}$$

Figure 14 shows the annual load duration curve for a secondary substation in Lund. The lower graph shows the full duration curve and the selected part labelled "Scroll function" is shown enlarged in the graph above.
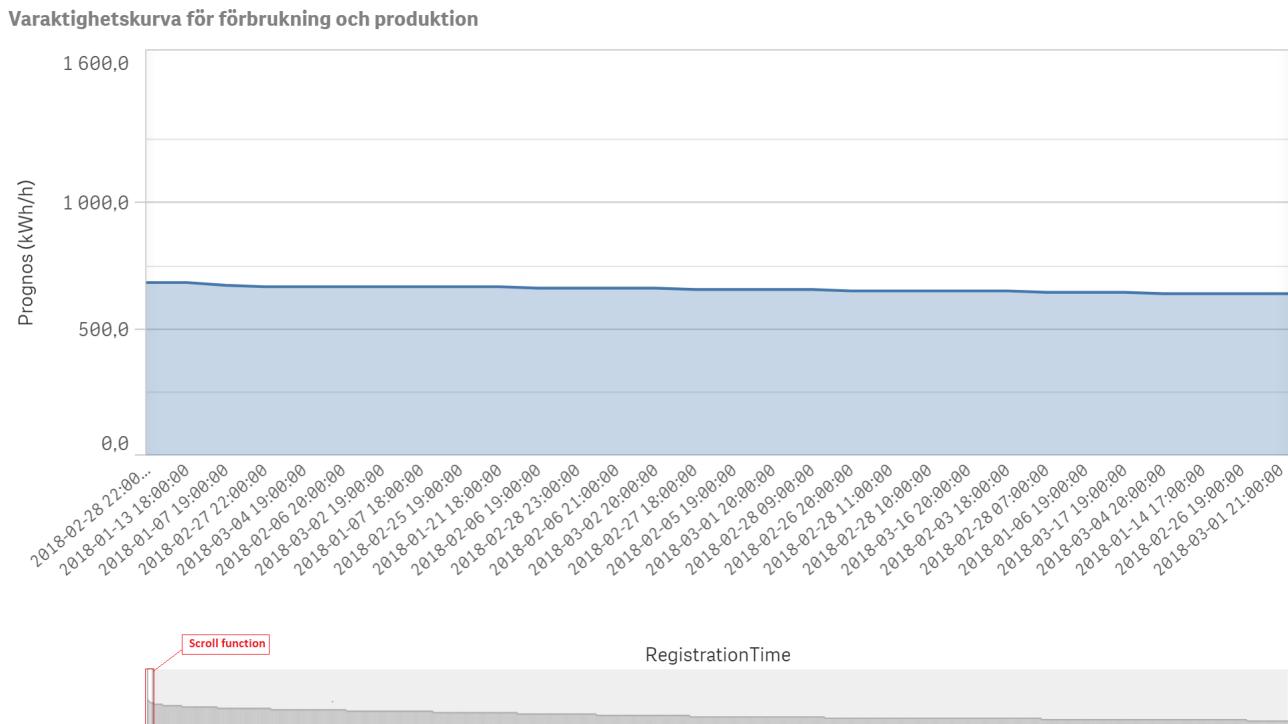
Figure 14: Annual load duration curve for station N138.

4.1.1 Highest transformer loading graphs some secondary substations

This subsection presents the visualisation of the transformer's loading for some of the secondary substations in the study. The graphs show the day with the highest hourly value of the loading which is a more detailed result of what was shown in Figure 12. The max value on the y-axis represents the station's transformer capacity. For complete results for all stations see Appendix C.

What can be said about these graphs is they're quite similar in form and the dates the peak loading occur are almost always during the coldest days of the year between January-Febuary month, in the evening. Station N138 in Figure 15 has the highest peak transformer loading but still under 50% of its capacity. Station N317 in Figure 16 has the lowest peak transformer loading and not even surpass a quarter of its capacity. Station N21 in Figure 17 is actually the one with highest loading in comparison to its capacity, the only in the study with a peak over 50% of the transformer's capacity. Station N295 in Figure 18 is the only station for which the highest loading occurs in the autumn instead of winter which is unusual. Looking at the span of a year however shows that station N295 has the same load pattern as other stations, suggesting the peak is an exception rather than the norm.

Figure 15: Hourly values of the transformer loading for the day with highest loading, station N138
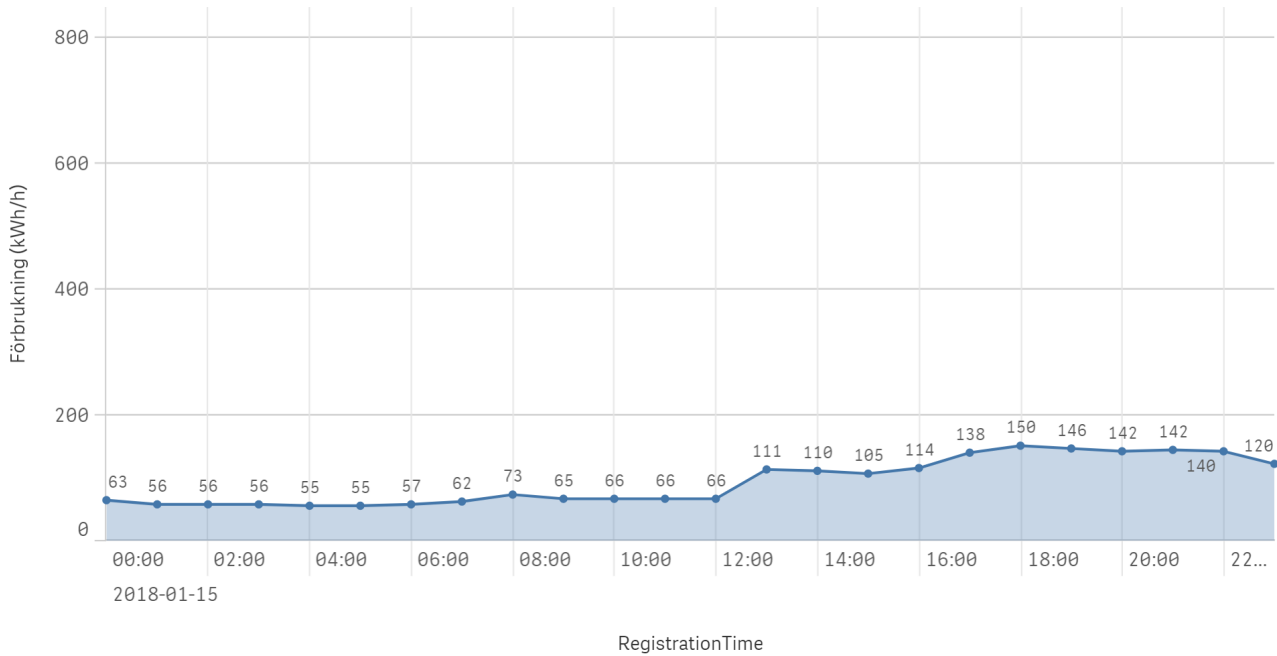
Figure 16: Hourly values of the transformer loading for the day with highest loading, station N317

Figure 17: Hourly values of the transformer loading for the day with highest loading, station N213
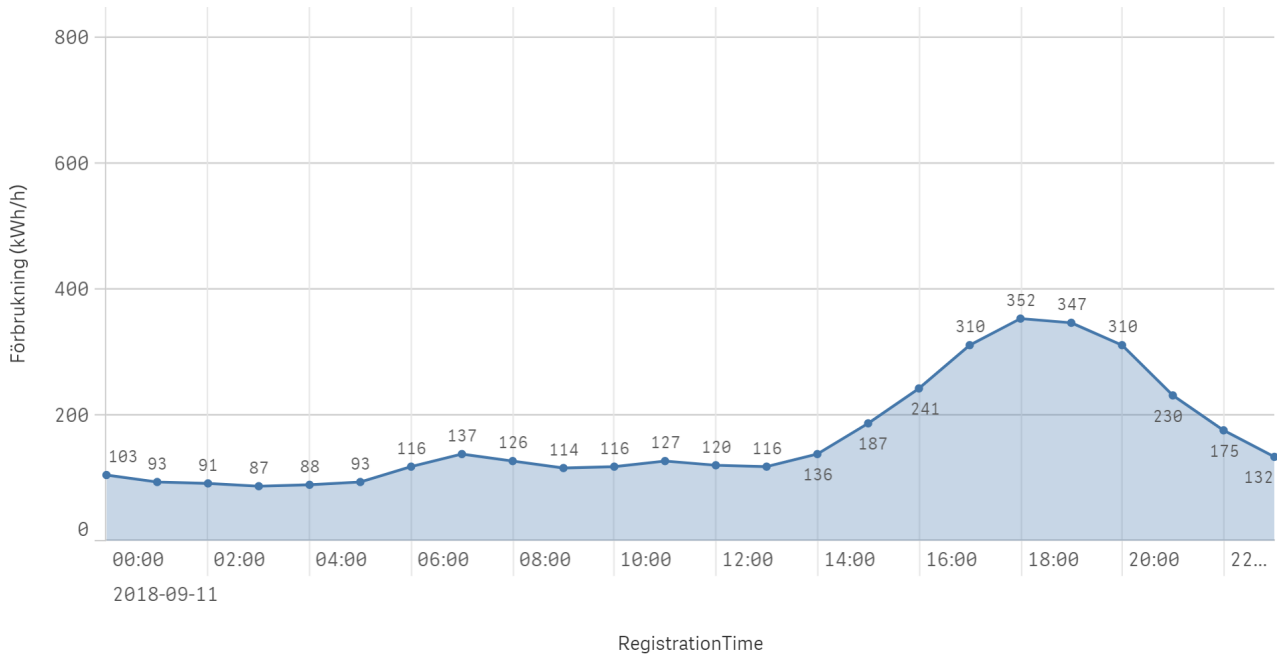
Figure 18: Hourly values of the transformer loading for the day with highest loading, station N295

4.2 Information about the secondary substations

The sheet in Figure 19 shows tables with some information about the secondary substations in Lund. Time selection and substation filter function can be used here in the same manner as for the other sheets. Also the tables can be sorted by name or values, in ascending or descending order.

Allmän information om nätstation

Nätomr...	Stationsnamn	Nätstatio...	Summa förbrk per tidsenhet (kWh/h)	Medelförbr. per kund per timme (kWh/h)	Antal kunder	Högsta timvärde (kWh/h)	Kapacitet (kVA)
Totalvärden			**11 519 612**	**1,0**	**1458**	**746**	
LUN	Thulehemsv.	N138	2 470 173	1,1	273	746	1600
LUN	Skyttelinjen	N295	1 254 427	0,7	229	352	800
LUN	Trossvägen	N213	1 443 953	0,8	220	419	800
LUN	Griffelvägen	N142	1 310 053	0,8	217	408	1600
LUN	Råbylund V.	N316	767 474	0,8	119	245	800
LUN	Annehemsvägen	N026	827 260	1,2	88	263	800
LUN	Hills väg	N248	981 696	1,5	83	367	800
LUN	Råbylund Ö.	N317	408 602	0,7	72	150	800
LUN	Tornavägen	N005	803 237	1,6	62	271	800
LUN	Tornaplatsen	N247	794 447	1,8	56	287	800
LUN	Seved Ribbings väg	N250	458 289	1,5	39	227	800

Figure 19: Information about the secondary substations

The sheet in Figure 20 shows where the secondary substations are geographically located. The colour coding acts as an indicator of how close the maximum hourly loading is approaching the substations capacity. The more orange/red it shows on the graph the higher the transformer loading in absolute hourly value. This can be useful for network operator to have an overview of the power consumption in certain area.
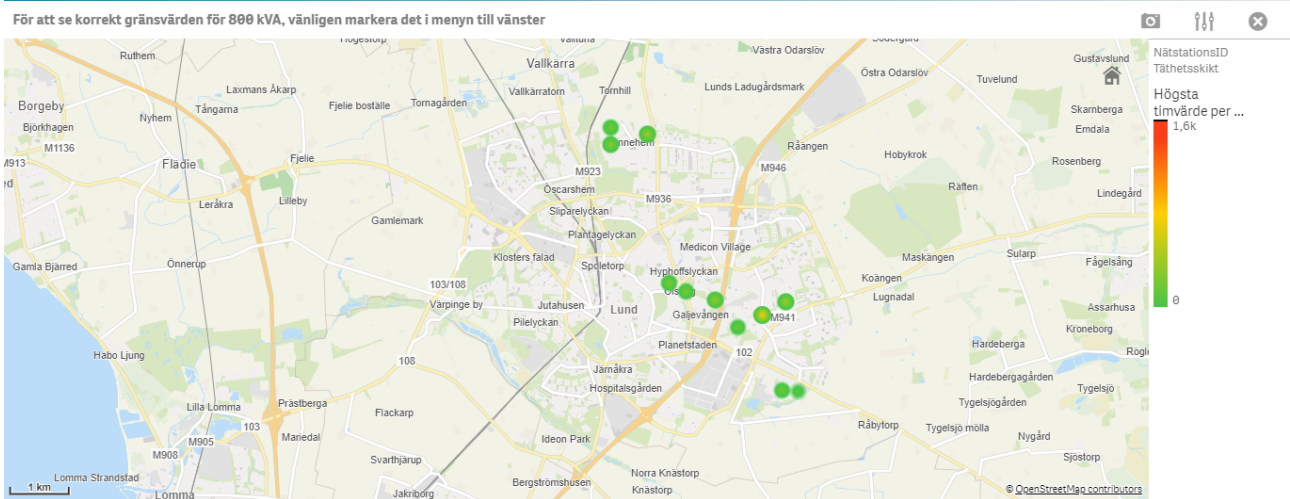
Figure 20: Geographical locations of secondary substations in Lund

4.3 Solar profile

The results will be centred around the same graphs as for no solar energy shown in section 4.1 and 4.2 and then modified to reflect the addition of solar power as well as feature to find tax reduction limits when producing solar power.

4.3.1 Critical cases

At the transformer when no solar power is being produced, the critical cases are when the load is at its highest peak. When solar power is being produced a critical case is when the consumption is low and the production is high. The lowest peak is when the power has shifted direction so that power goes from the consumer to the grid instead of vice versa. This occurs when the solar power production is greater than the consumption.

The highest peak is when the load at the consumers are the highest, which is the same as shown in Figure 12. That graph, and the one seen in Figure 21 is without any solar power production.


Figure 21: Lowest transformer loading

In Figure 21 it is apparent that most secondary substations have a point throughout the year 2018 where the consumption is zero, not all though. When adding a large solar power installation, for example 500 kW peak power arbitrarily chosen, with the capacity limit of 800 kVA and 1600 kVA in mind to show the effect of large generation, the consumer-to-grid case changes quite a bit, as in Figure 22, while the grid-to-consumer case looks almost the same. This may seem strange, but is explained in the analysis section 5.2.

These graphs give a good overview and a quick way see if anything is close to reaching the capacity limit.

(a) Maximum load per secondary substation with a solar power installation with 500 kW peak power
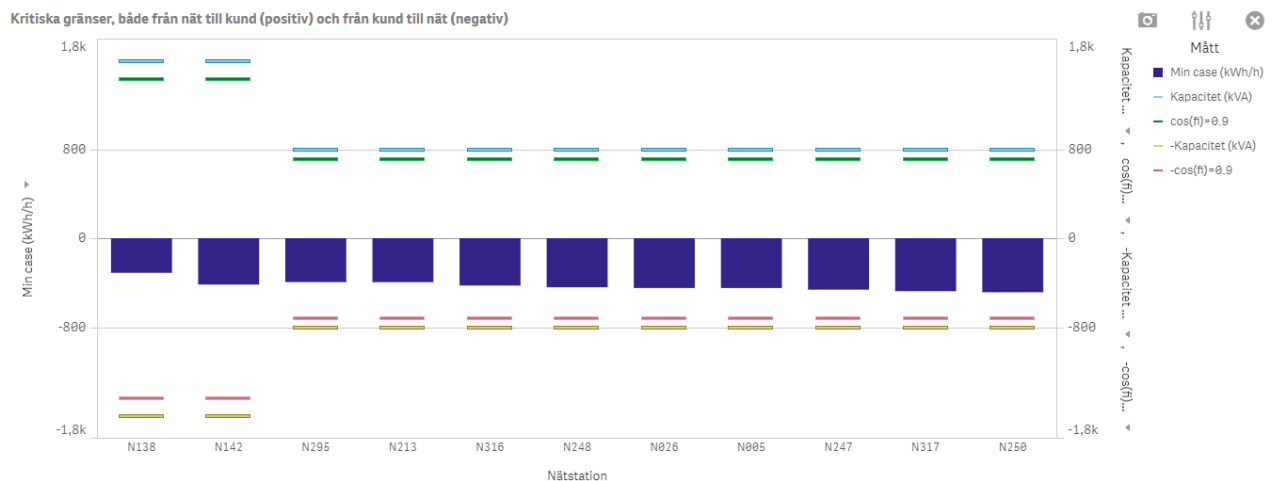
(b) Minimum load per secondary substation with a solar power installation with 500 kW peak power

Figure 22: A 500 kW Solar power installation at critical cases (a) maximum load and (b) minimum load

What is seen is the same as without production, except that it finds the hour on the year where the critical cases, minimum/maximum values, are calculated through subtraction of the production for when a solar power installation with 500 kW peak power is added each secondary substation.

### 4.3.2 Overall consumption updated with solar energy production options

The next feature similar to the one seen in Figure 13, except now it has an option to enter production. In this graph, one can go in great detail to look at hourly transformer loading and how the production affects it. It also has a feature to show only the solar energy production. Below, in Figure 23, the secondary substation N213 is displayed in different ways. Besides looking at the whole year, one can go into look at a certain quarter, month, week, day and hour. This can be used to make predictions as well as reference scenarios for decision making.
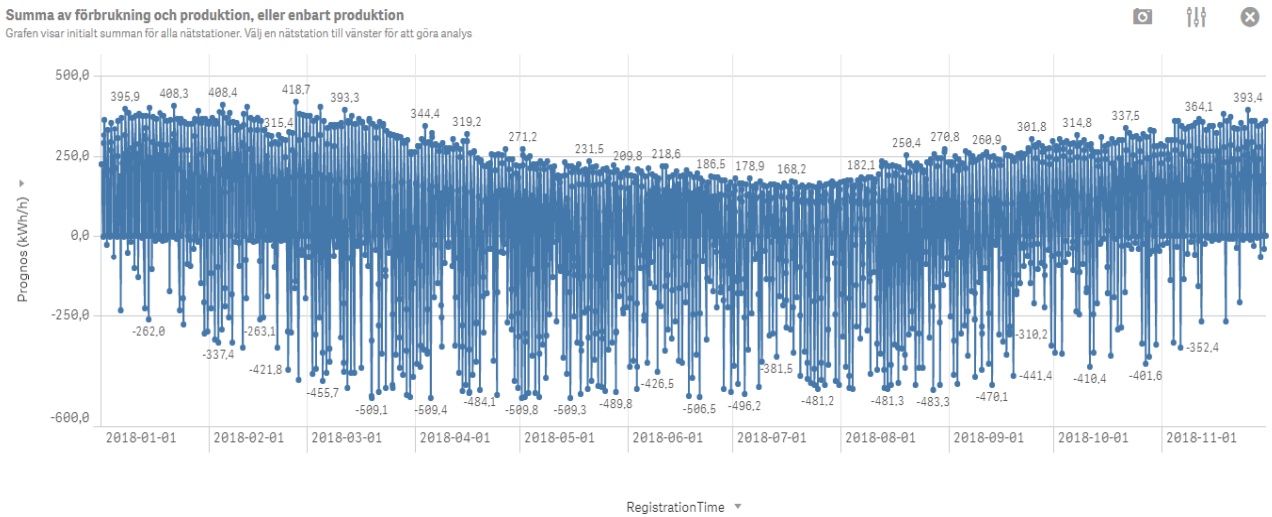
(a) Load profile with a solar power installation with 500 kW peak power connected to each secondary substation
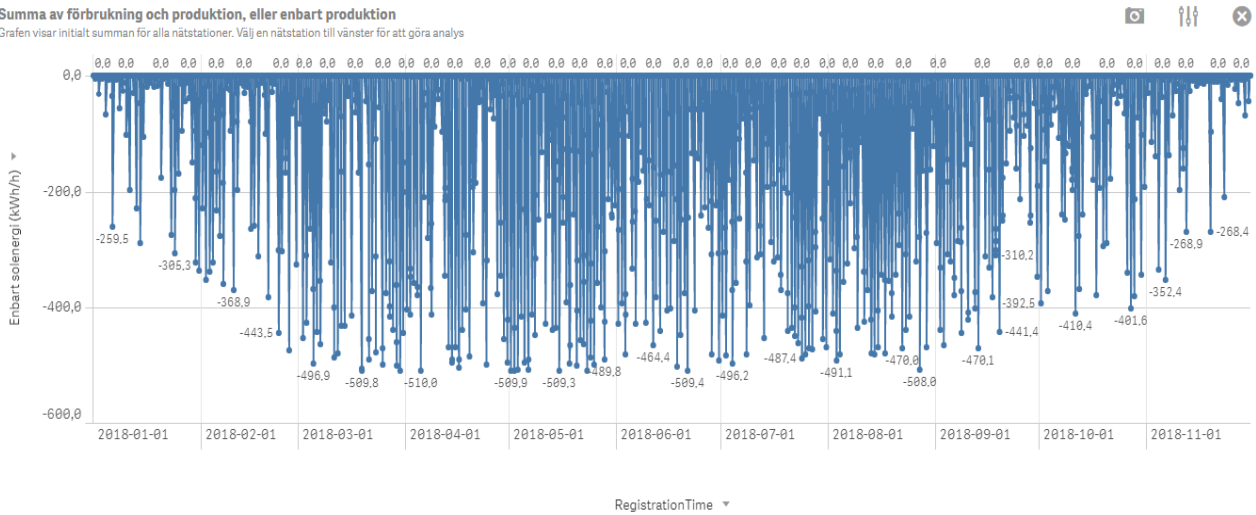

(b) The solar energy production only
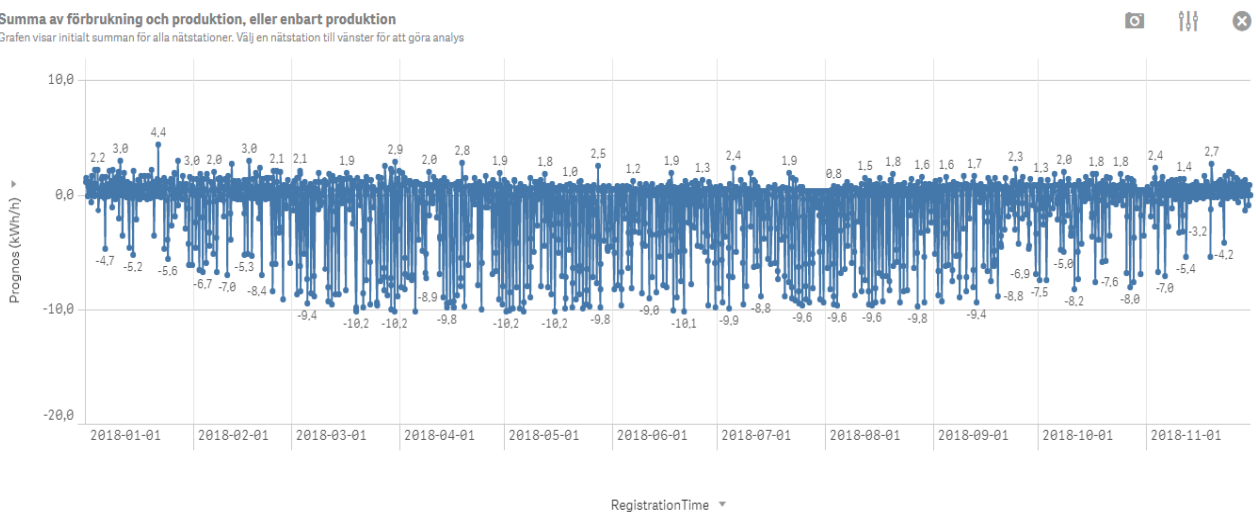
(c) One of the customers connected to the secondary substation and how it's load profile looks like with a solar power installation with 10 kW peak power

Figure 23: Secondary substation N213 and three different views using the same graph

4.3.3 Map view with solar energy production implemented

As well as without solar, a map functionality was created. An updated version of Figure 20 with solar power subtracted from the load is shown in Figure 24. There is a slight difference in functionality as well. The map did not handle negative values, which occur once enough solar power is subtracted from the load, and to get around this the absolute value of the solar power subtracted from the load was used. Using the absolute value will result the same value as using a negative scale, but simply displayed as positives values. What is seen here is firstly the map with no selections made at all, and almost all secondary substations are invisible due to having no load or production. This is the same thing as seen in Figure 21 just in a different way. Secondly, to show how this map works differently than the other, selecting the 800 kVA secondary substations and adding a solar power installation with 800 kW peak power, to each secondary substation, the critical transformer loading is reached. This is indicated by the circle being more and more red and also having a black spot to further indicate that the capacity limit is reached.
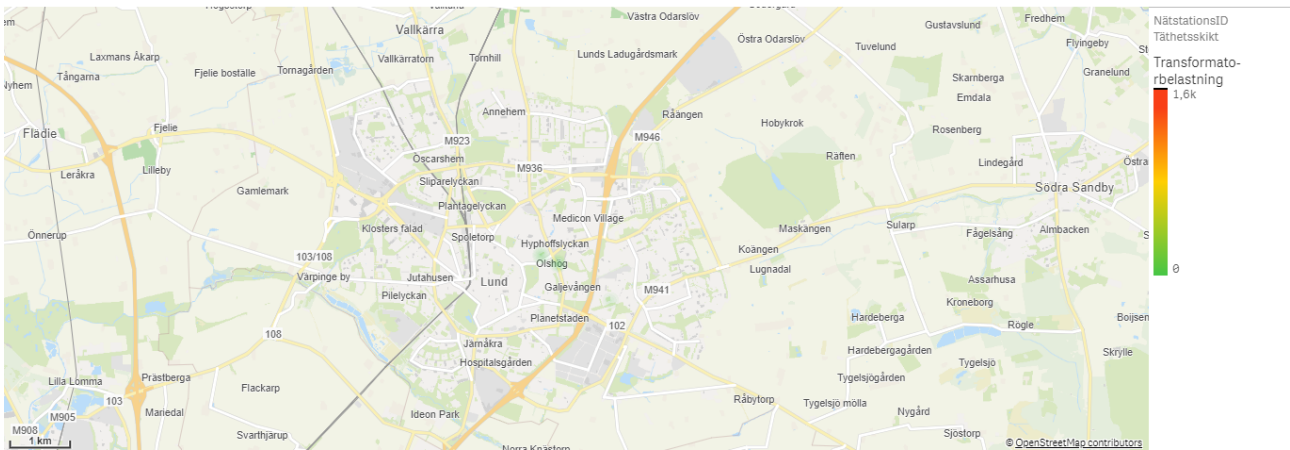
(a) Map view for the solar profile with no solar power added at the case where the loading is at it's minimum
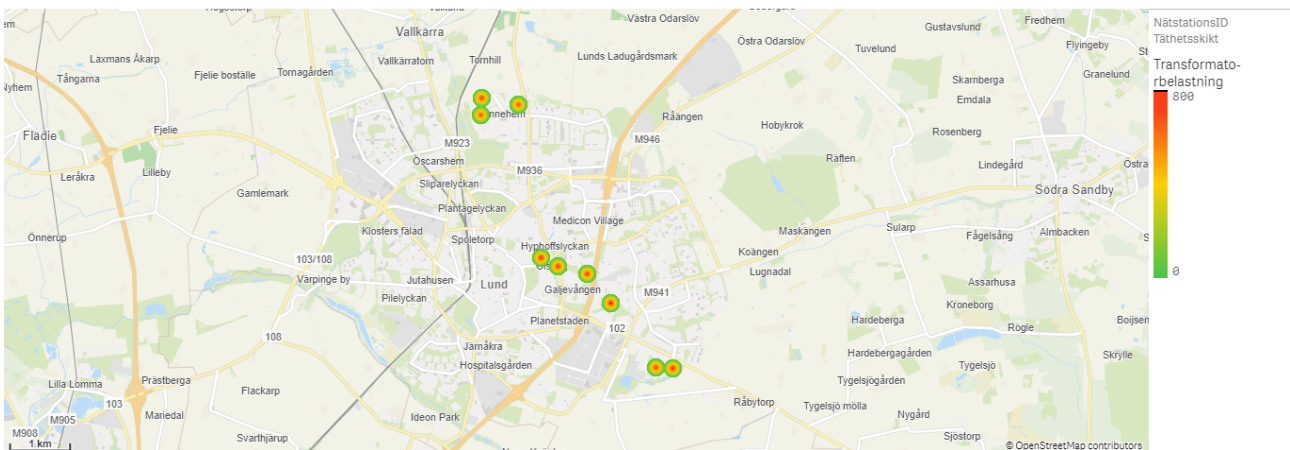
(b) Map view when the capacity limit has been reached

Figure 24: Map view of the secondary substation solar scenario. (a) Is minimum transformer load and (b) critical case with 800 kW production

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4.3.4 Using the visualisation tool to find the limit for tax reduction eligibility

Since the Swedish regulations make it possible for owners of solar energy installations to get tax reductions it is relevant to have a feature to calculate the largest PV installation that can be installed. This is done by dividing each customers individual annual consumption with the amount of sun hours that year. The amount of sun hours is calculated by summarising all hourly values for the solar power and divide that by the power of the panel, as follows:

$$t_{SunHours} = \frac{1}{P_{module}} \sum_{n=1}^{8016} P_{n,hourly} = \frac{1}{0.180kW} \cdot 183.7kWh = 1020h \tag{7}$$

In the summation symbol the upper limit is 8016, which is not the correct amount of hours for a full year. But, the data does not include December which is why the number is lower than for a full year and is correct for the year of 2018 excluding December. This value is then used to calculate the total amount solar power as mentioned above with the following equation:

$$P_{InstallationLimit} = \frac{P_{annual}}{t_{SunHours}} \tag{8}$$

In section 2.7 it was stated that a customer can't produce more energy than what it's consuming in order to be eligible for tax reduction. In an attempt to create relatable scenarios, average annual values for the electricity consumption for a house and an apartment as references when analysing the tax reduction limits was found. The average annual electricity consumption in Sweden for a house is around 25000kWh and around 2500kWh for an apartment [22]. With the visualisation tool this can then be found for a certain secondary substation to create a realistic scenario when finding the limit for tax reduction eligibility. There is also the limit of 30000 kWh per year, and in order to take this in to account every customer that has a consumption equal or greater than 30000 kWh per year has its value set to exactly 30000 kWh per year. Equation 7 from above is then applied to the 30000 kWh to find the solar power installation limit. In Figure 25 the feature to show all customers is displayed. With this feature it's easy to navigate the above two cases. With the equation above for $P_{InstallationLimit}$, the limit for tax eligibility for the house and the apartment case becomes:

- $P_{HouseLimit} = \frac{25000kWh}{1020h} = 25.08kW$

- $P_{ApartmentLimit} = \frac{2500kWh}{1020h} = 2.5kW$

There is also the limit of 100 A going through the fuse. A fuse of 100 A is unusually large in the context of households, more common are 32 A or 64 A. This means that a household might not be able to push the solar power production to it's limit, because the fuse limit is reached before. Using the follow relation $P = I * \sqrt{3} * V_{LL}$ the total maximum power for the fuse to not go off is found. For the fuses this respectively is:

- 32 A fuse: 22 kW

- 64 A fuse: 44 kW

- 100 A fuse: 69 kW

Using the tool to find reference scenario for an apartment and a house

In Figure 25 a feature showing all the customers and their individual annual power consumption is shown. This is used to locate the correct values for the references. It is not shown which secondary substation is chosen for this, but it's the N005 one. There is no specific reason for choosing this one since it's done arbitrarily to simply find the two reference values for a house and an apartment.
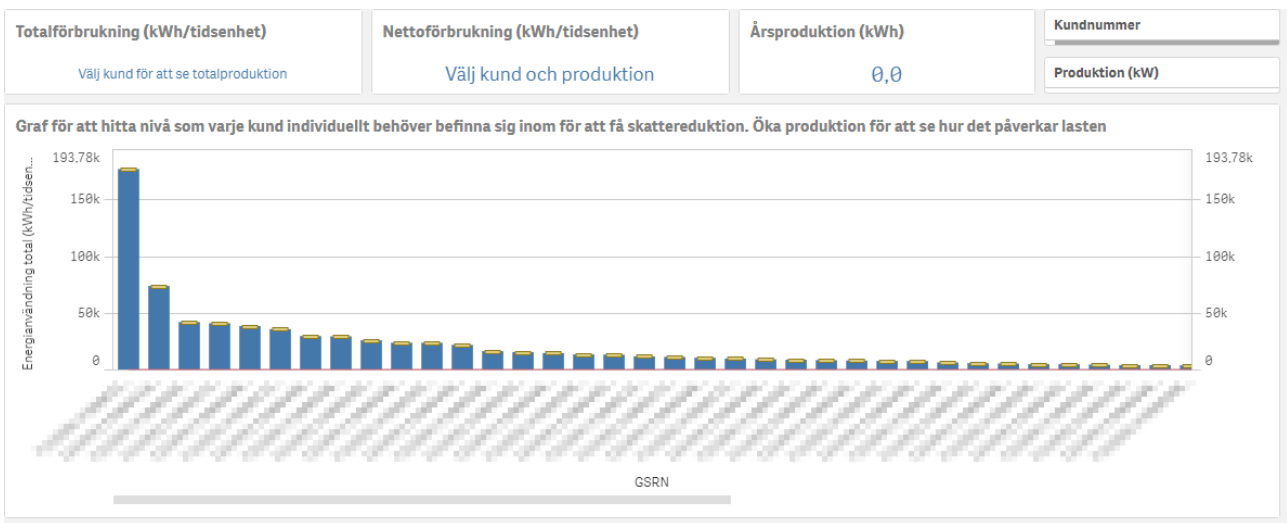
Figure 25: The feature that displays the customers on the x-axis and the load on the y-axis. Due to secrecy the customer ID has been blurred out.

The "Totalförbrukning (kWh/tidsenhet)" is the total consumption for the specific time period, the "Nettoförbrukning (kWh/tidsenhet)" is the resulting power when solar power production is added, "Årsproduktion sol (kWh)" is the annual production from solar energy and finally the "Produktionsnivå för skatteavdrag (kW)" is the maximum capacity of the solar power installation for being eligible for tax reductions. A secondary y-axis has been added where the graph can be used to instantly show, for each customer, how much solar power can be installed before reaching the limit. This is shown in the figure below.
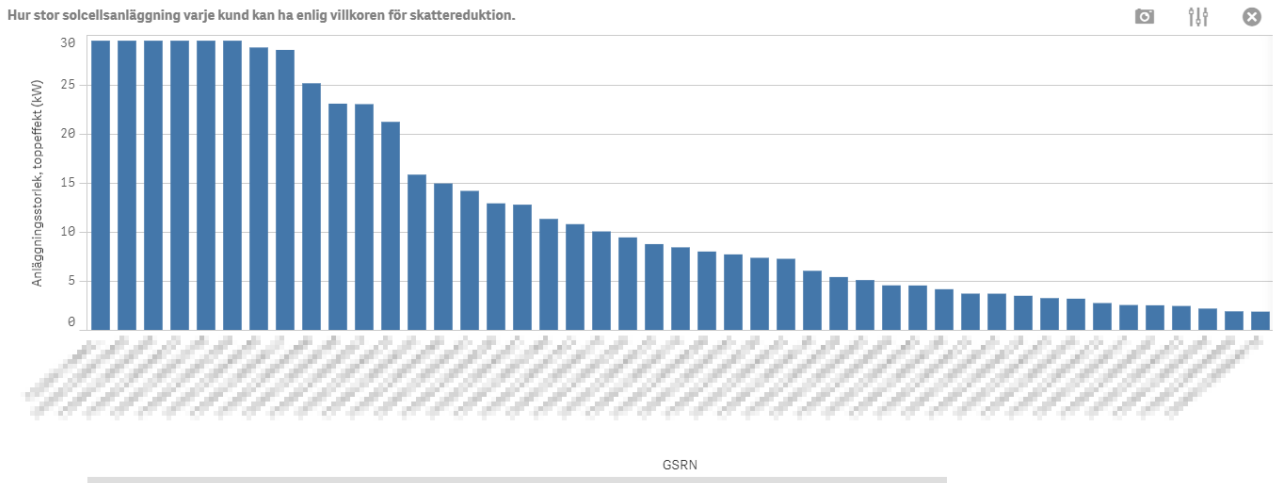
Figure 26: A bar graph displaying the largest solar power installation and still be eligible for tax reductions. Due to secrecy the customer ID has been blurred out.

Continuing to work with the feature from Figure 25, the two consumption values mentioned above have been found by looking at the graph. This can be interpreted as an apartment and a house, respectively, and are shown in Figure 27a and 27b.

(a)
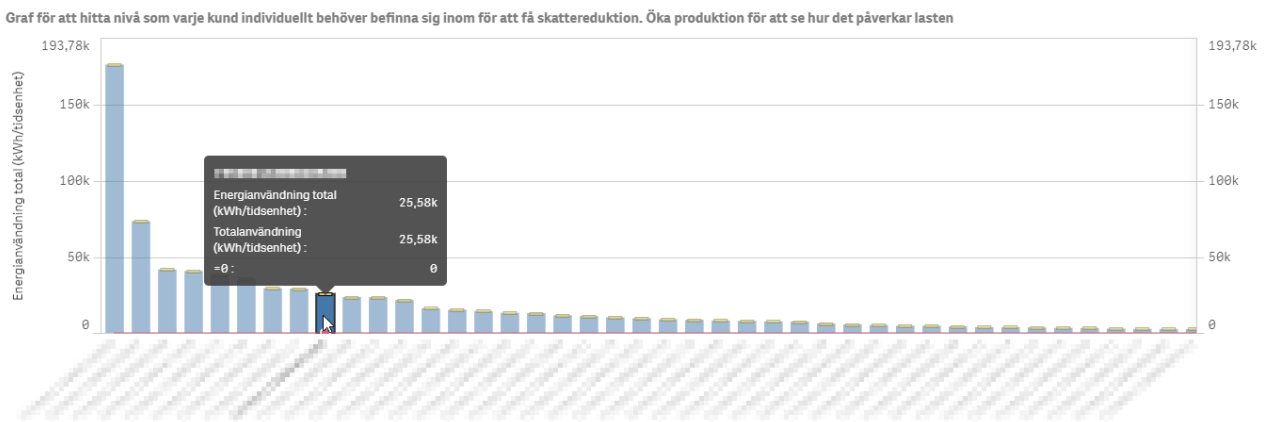
(b)

Figure 27: Annual loading for each customer connected to the N005 Secondary Substation where (a) is seen as an apartment and (b) as a house

The tax reduction eligibility limit for each of the house and apartment case is found by simply selecting each case one at a time and looking at the number that appears in the "Produktionsnivå för skatteavdrag (kW)". The calculation is made automatically. The "Nettoförbrukning (kWh/tidsenhet)" shows that the difference between consumed and produced power is zero, just like it should be.

In case of production equal to the annual average of an apartment
To begin, the load profile without solar power production is shown and then the case when the limit has been found.
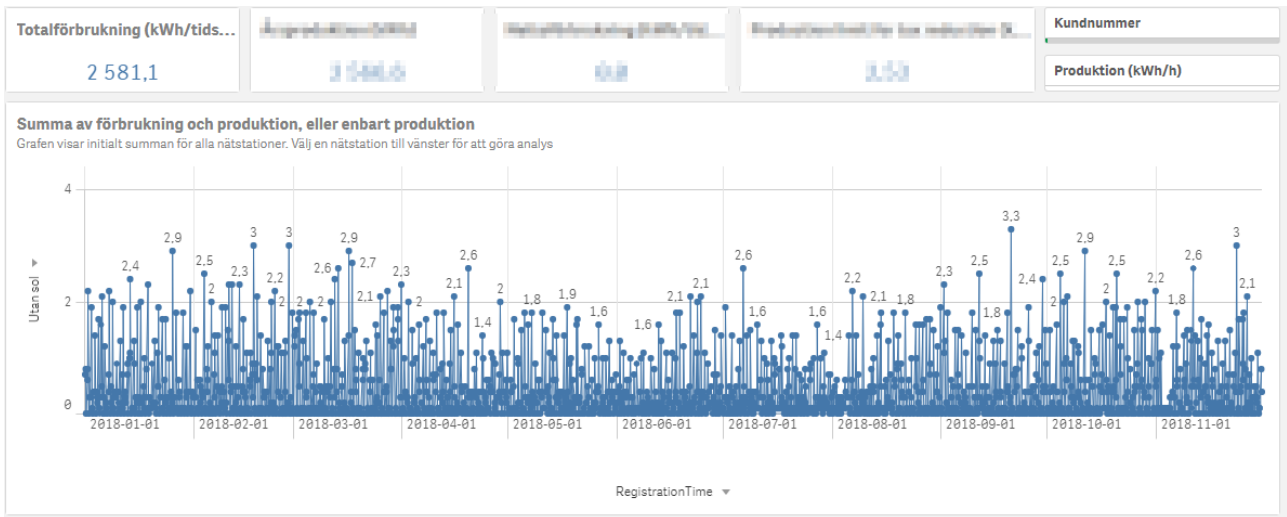
Figure 28: Load profile for the customer with around 2500 kWh annual consumption, representing an apartment

Here in Figure 28 the annual consumption is 2553.4 kWh, and in the next figure the limit has been reached by increasing production level.
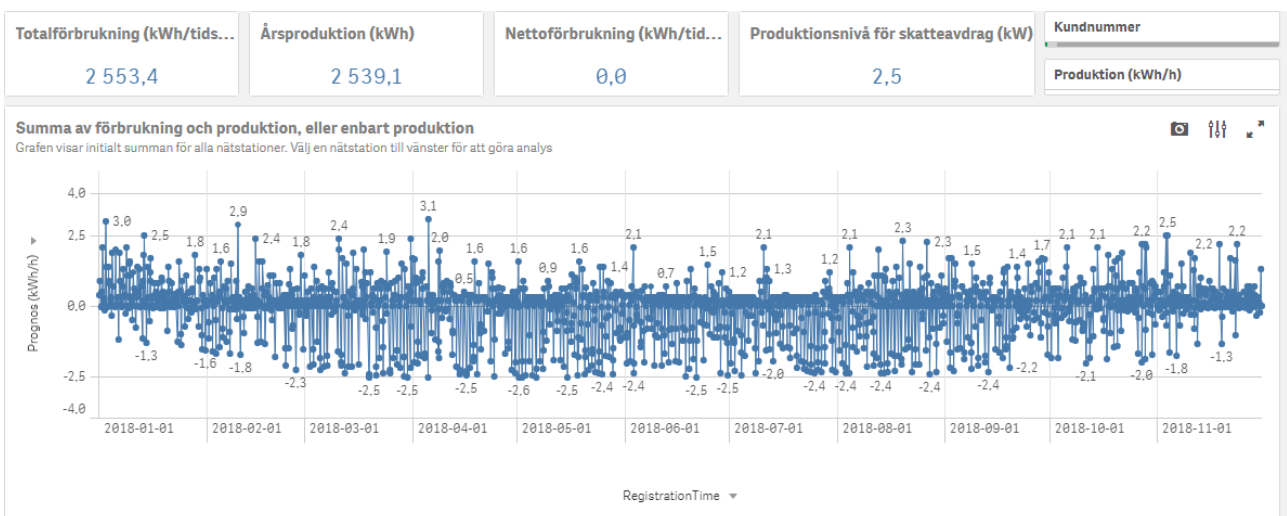

Figure 29: Production level limit for tax reduction eligibility for the apartment case

The top production level is found to be 2.5 kW which in the apartment case is equal to 2566.6 kWh annually being generated back to the grid. Anything above 2.5 kW will result in producing more than consumed and will not contribute to tax reductions.

In case of production equal to the annual average of a house
Like before the case without production will be presented first and then again with solar power production.
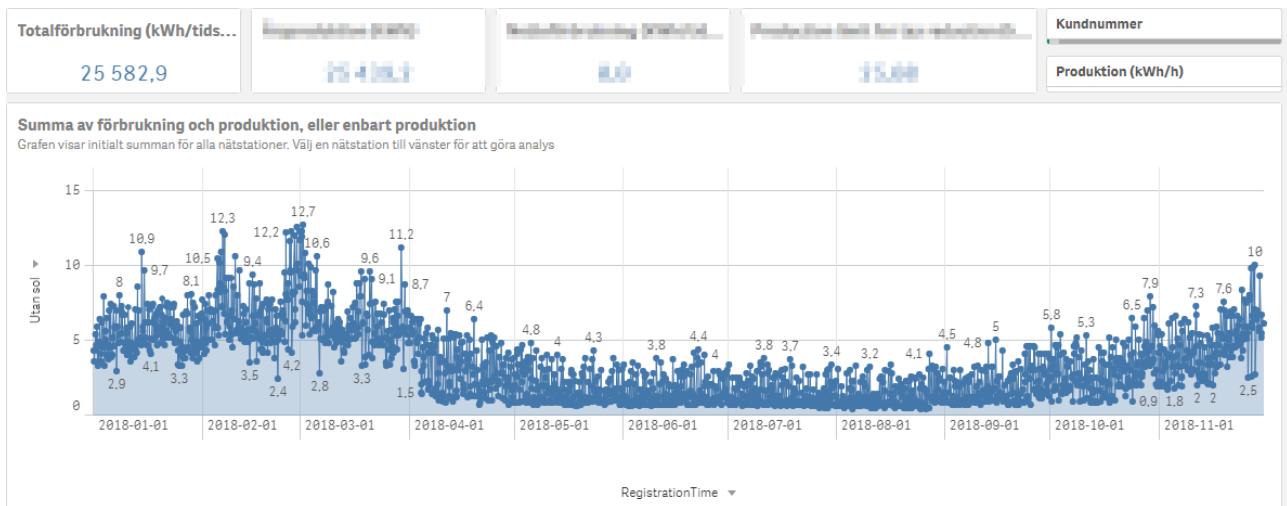
Figure 30: Load profile for the costumer with around 25000 kWh annual consumption, imitating a house

The annual average load is a lot higher in this case, in the picture above it shows that it is at 25582.9 kWh. Next, the limit for a house for tax eligibility is shown.
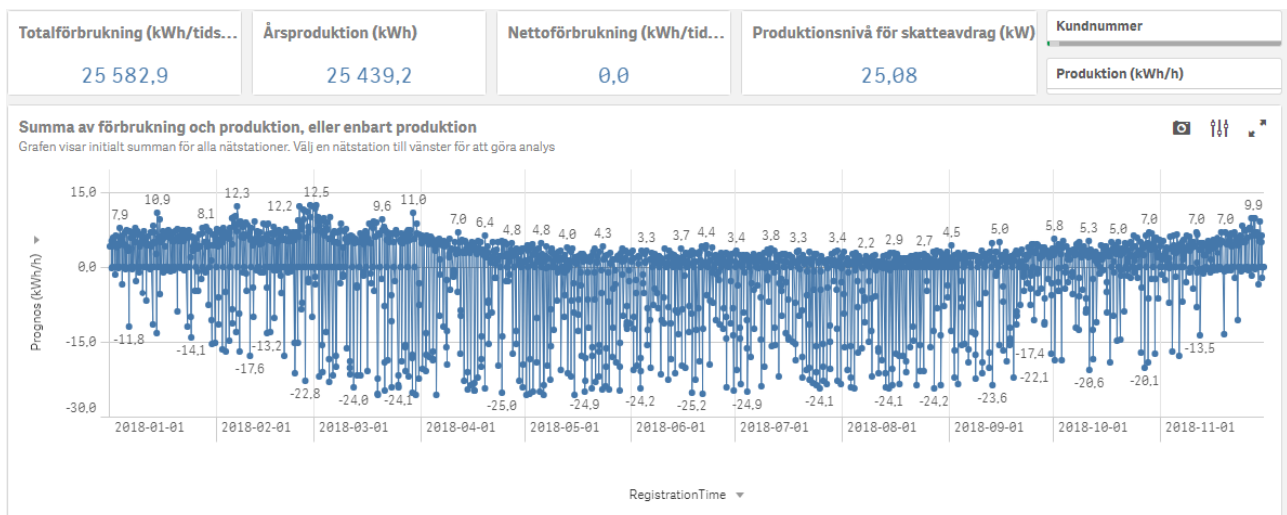

Figure 31: Production level limit for tax reduction eligibility for the house case

In Figure 31 the annual consumption is 25439.2 kWh and a production limit of 25.08 kW solar power.

A short summery of the two cases and the limit for tax reduction:

- **Apartment**: annual average load is 2500 kWh and can install up to 2.5 kW

- **House**: annual average load is 25000 kWh and can install up to 25 kW

- **Fuses**: 32 A fuse -> 22 kW, 64 A fuse -> 44 kW, 100 A fuse -> 69 kW

As can be seen, the apartment case works for every fuse whereas the house case works with every fuse but the 32 A one.

Another aspect to keep in mind is that the assumption that only houses and apartments are connected to the secondary substations is not fully realistic, there might be apartment complexes described purely as one customer and there might also be industries connected to it. But for the purpose of demonstrating the power of the tool, it is assumed that only houses and apartments are connected.

The table below is demonstrating the difference between transformer capacity and the size of the solar power installation in peak power if the customers fulfil the conditions for tax reduction eligibility and no more.

Secondary Substation	Number of customers	Tax reduction limit (kW)	Capacity (kVA)	Capacity - Tax reduction limit (kW)
N138	273	1679	1600	-79
N295	229	1211	800	-411
N213	220	1353	800	-553
N142	217	1271	1600	329
N316	119	652	800	148
N026	88	774	800	26
N248	83	960	800	-160
N317	72	362	800	438
N005	62	567	800	233
N247	56	748	800	52
N250	39	449	800	351

Table 2: Number of customers, solar power installation peak power for tax reduction eligibility, capacity and the difference between the capacity and solar power installation peak power

Let's take a look at the secondary substation with the most customers, the N138. It has the highest limit at 1679 kW peak solar power installed. This is however above it's capacity at 1600 kVA, resulting in that the transformer rating needs to be increased so that all customers can be able to have their largest solar power installation whilst being eligible for tax reductions. Of all the secondary substations, 7 of them can handle if every customer pushes the solar power production to the limit in regards to tax reductions, whereas 4 of them can not and 3 of those 4 have a customer count higher than 200. In the analysis section of the thesis, some of the secondary substations that would need a transformer with higher ratings are looked into. The secondary substation that has the highest margin is the N317 with just about half of the capacity reached, having room for another 438 kW before the transformer ratings would need to increase.
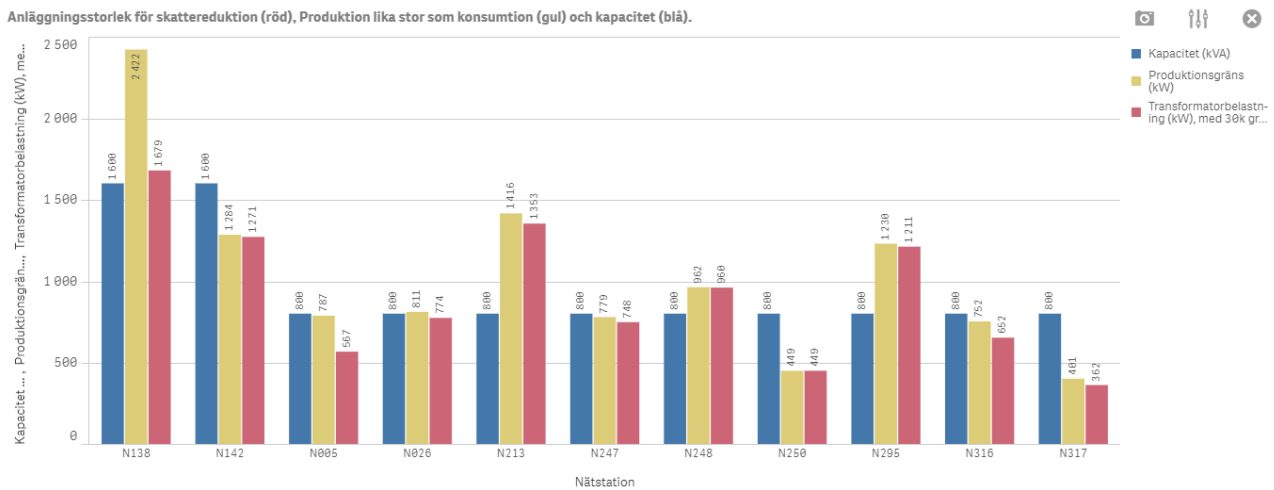
Figure 32: Capacity (blue), solar power installation if production is equal to consumption (yellow) and solar power installation if all customers with consumption greater or equal to 30000 kWh is set to 30000 kWh. The y-axis is in kW and the x-axis is the secondary substation

Figure 32 demonstrates what happens if the customers either produce as much solar power as the corresponding energy consumption, or if they have a consumption larger than 30000 kWh then the consumption is set to a fixed value of exactly 30000 kWh. In this way the condition stating that no tax reductions are valid on produced solar energy above 30000 kWh is taken into account.

4.4 Working with Qlik

The Qlik Sense platform is the central part of the project. The vast amount of features and easy to use interface made it an overall positive experience learning and using it to develop our app. That being said, there were some limitations with Qlik Sense that explain why some of our goals took a different direction than how they were thought initially.

There was an ambition from our side to continue the developing of an already existing app with all digitised data from every secondary substations belonging to Kraftringen. It is an extensive collection of measurement data with many useful features and the app is used by workers at Kraftringen on a daily basis. Since the Qlik Sense client used is web-based and the amount of data can lead to memory related issues on the server, keeping a fluid workflow during the development proved to be a challenge. Most noticeably is the loading time while opening and editing the app. The solution is creating a copy of the app and removing much of the data from it, leaving data from a handful of secondary substations as a proof of concept. Memory related issues also prevent two persons working on the same app simultaneously which make co-developing not as fluid as desired.

Duration curve is a great tool to analyse the loading of a network and there was an attempt from our side to recreate it from the load curve (see Figure 14). However due to the limitation

in scaling of the graph and how Qlik Sense handles the timestamps on the x-axis, the end result isn't as useful as expected.

These problems described while not completely changed the objective of the project, it raised the question whether web-based Qlik Sense and the current server capacity is suitable for this kind of development. It may form the basis for improvements in Qlik Sense, especially when it comes to the ability to handle large amount of data and larger projects with many people involved.

5   Analysis

5.1   Network loading

As seen in Figure 12 for the year 2018 every secondary substation in Kraftringen's network in Lund had the peak hourly consumption below its capacity, most of them with a good margin. Station N138 had the highest peak hourly values at 746.44 kWh/h compared to its transformer's capacity of 1600 kVA, see Figure 33. The peak was recorded in February 28th at 19:00. The station with lowest peak hourly values was station N317 at 150.2 kWh/h compared to the transformer's capacity of 800 kVA, see Figure 34. The peak was recorded in January 15th at 18:00. The results were expected since the distribution networks in Sweden are generally over-dimensioned and the consumption is often at the peak during the colder days of the year.

Totalförbrukning för nätstation(er) för specifikt tidsintervall
Grafen visar initialt summan för alla nätstationer. Välj en nätstation till vänster för att göra analys
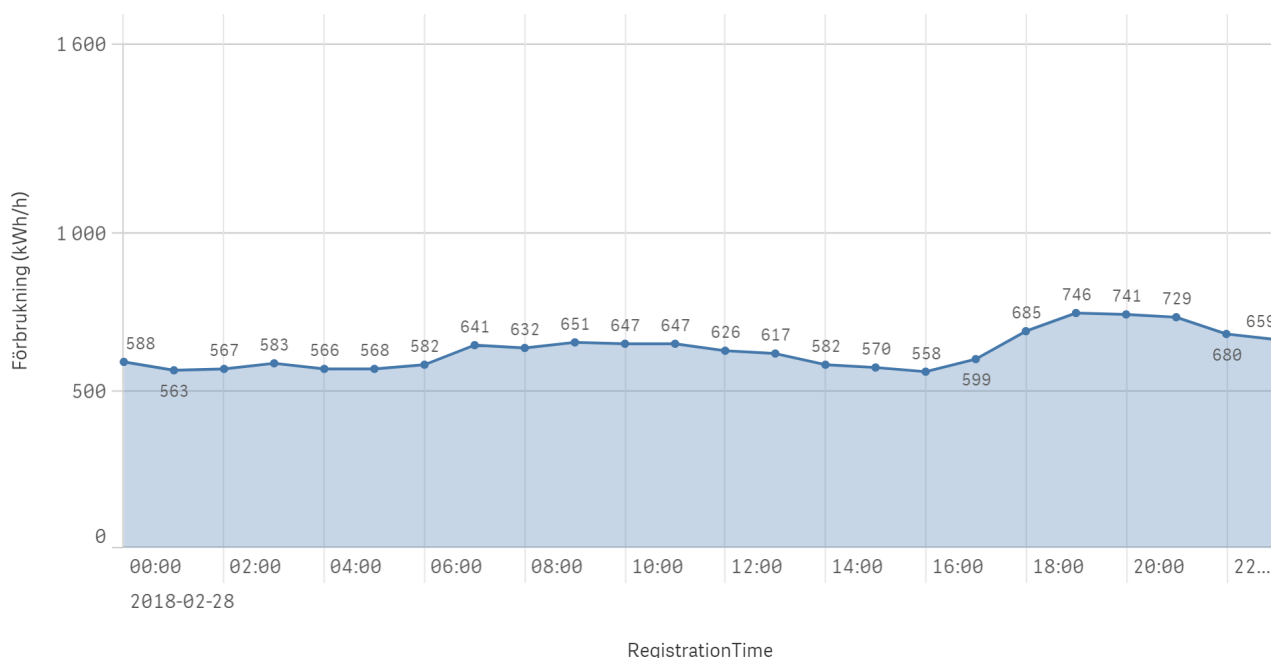
Figure 33: Hourly values of the transformer loading for the day with highest loading, station N138
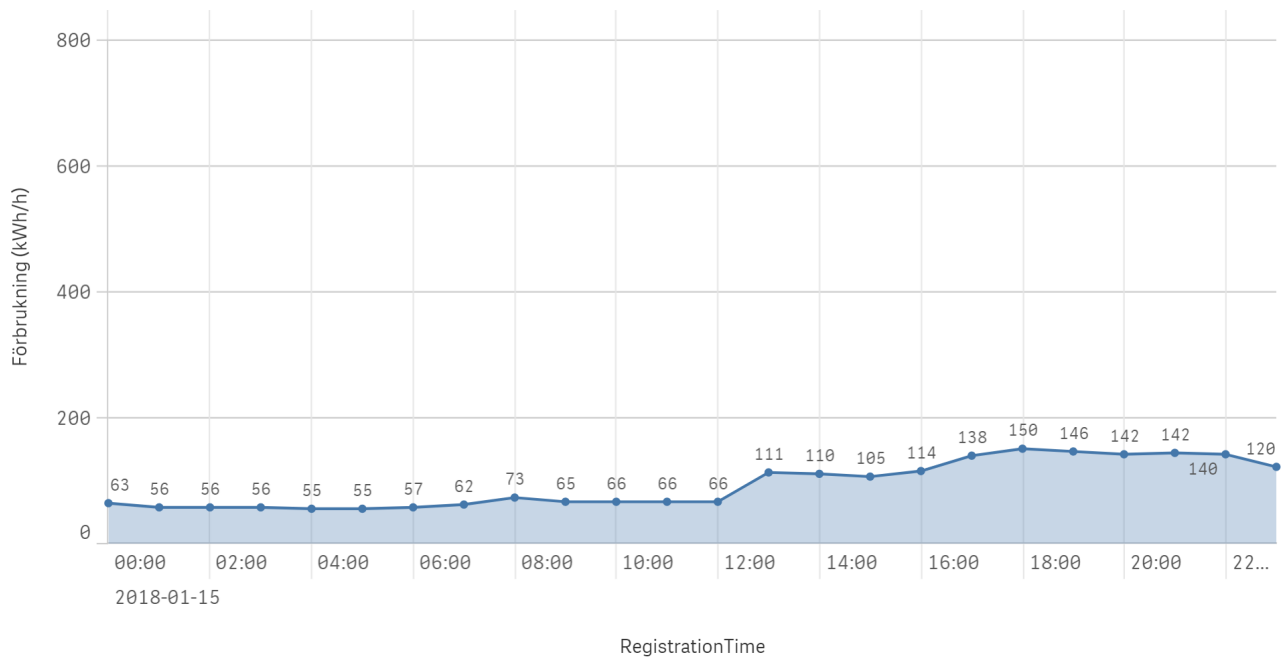
Figure 34: Hourly values of the transformer loading for the day with highest loading, station N317

The majority of the secondary substation in the study use transformers with the capacity of 800 kVA. The capacity margin is considerably smaller than the stations with 1600 kVA transformers. While station N138 has the highest hourly values, N213 has the highest loading with peak hourly values over 50% of the station's capacity of 800 kVA. Station N142 has lower loading and a capacity of 1600 kVA in Figure 35. Transformers with lower capacity are often preferred due to lower investment cost and no-load losses. Transformer's capacity doesn't seem to be the major cause of disruption in the network either as it's roughly estimated to account for 10% of the power quality problems according to [23].
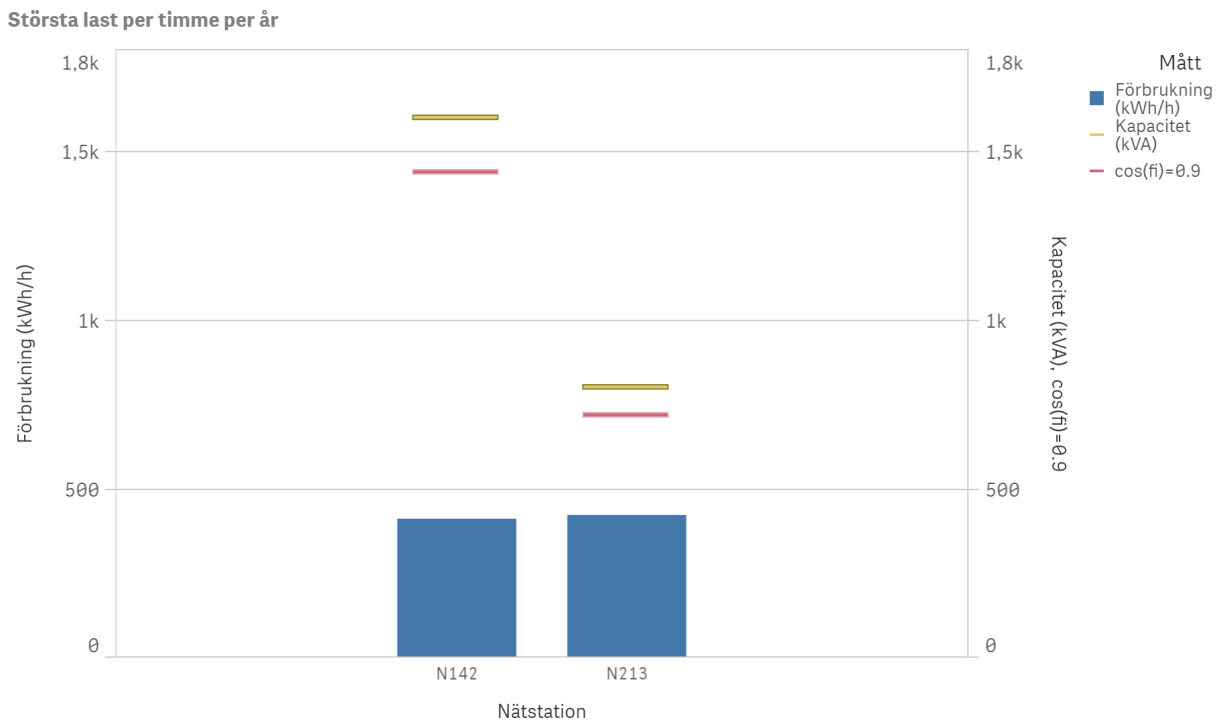
Figure 35: Highest hourly values of the transformer loading for station N142 vs N213

5.2 Solar energy scenario

The first thing to take a look at is the fact that when a solar power installation with 500 kW peak poweris added, the maximum load worst case scenario in Figure 22a doesn't seem to decrease by a significant margin compared to the case without solar power production, see Figure 12. By investigating this using the in-depth graph showing the entire year and narrowing down the peak and then taking a look at the solar energy production on that peak, one will see it's zero, or close to zero. This is shown in the figures below.
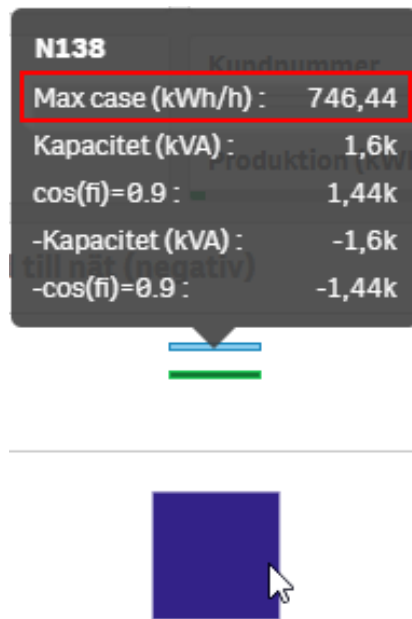
Figure 36: Highest hourly load at secondary substation N138 from Figure 12, the highest hourly value graph squared in red.

From the picture above one will see that the "Max case", the highest hourly value of the year, for N138 is around 746 kWh/h. To find when on the year this is, the N138 secondary substation is selected and next, the overall consumption feature is used to locate the 746 kWh/h peak. Once that is done and the value is selected, the exact time stamp of when that is also selected, as seen in Figure 37 below. This happens to be 2018-02-28 at 7pm.
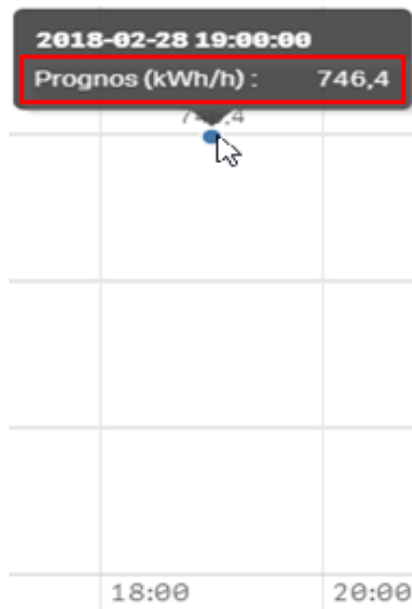

Figure 37: Highest hourly load at secondary substation N138 from Figure 13, but zoomed in on the specific hour for the highest consumption. The power is here also squared in red

And thirdly, the solar power feature as seen in Figure 23b is turned on to see how much

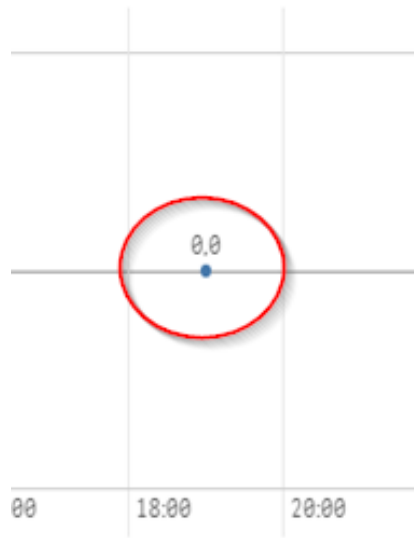generation occurs at the specific hour selected in the previous step.

Figure 38: Solar power production at the hour of highest load. Note that the solar power is zero, as circled in red

And as expected there is no solar power at that time, which is why the highest hourly values do not differ with or without solar power. The case is the same for all the other secondary substations; it does not affect highest hourly value to a noticeable level.

The tax reduction eligibility is an interesting thing to look at, and combining the results from the two cases that were created with the Table 2 and Figure 32 some analysis can be made. The secondary substation that would need the biggest upgrade in terms of transformer rating is N213 since it presents the highest difference between capacity and solar power production at tax reduction limit, namely 553 kW. N213 has a capacity of 800 kVA meaning that the rating would need to increase by at least 70% to handle a solar power installation of a size of 1353 kW peak power.

Below the secondary substation N138 is analysed, with the customers on the x-axis and power consumption for the selected time period on the y-axis. The time period is by default the year of 2018 in our application. The secondary substation of choice is because this one has a customer connected to it that has a very large consumption, and it's interesting to see how the solar power installation size would change when tax reduction conditions are implemented.
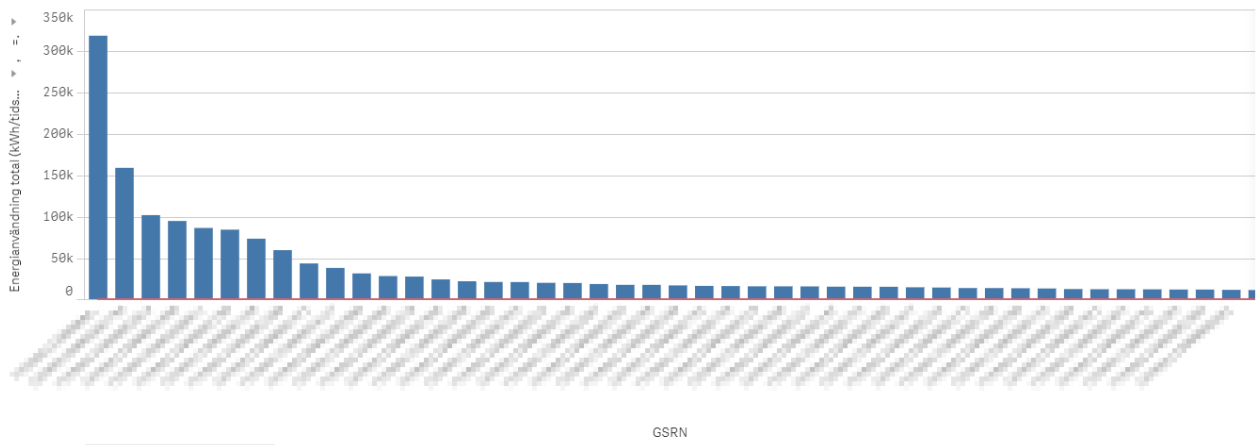
Figure 39: Secondary substation N138, customers on the x-axis and power consumption on the y-axis. Note that the entire x-axis is not showing and that there is a scrolling feature built in with Qlik Sense to navigate in the graph.

It seems that this secondary substation has a few customers with very high loading, which in turn means they can produce a larger amount of solar power before reaching the limit. At this secondary substation it is a small number of customers with very high load that pushes the transformer above its capacity. However, every secondary substation has customers like that, but still exceeds the capacity of the transformer. In Figure 32 the N138 secondary subsation demonstrates that when the conditions are in place the size of the solar power installation decreases from 2422 kW to 1679 kW. The transformer would still need to increase its rating, but not as much as without the condition of 30000 kWh production limit.

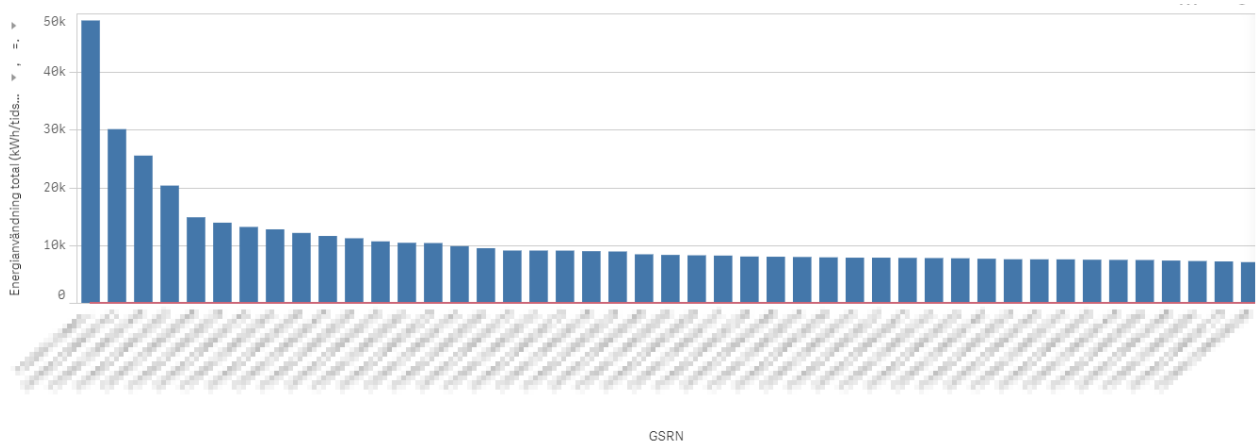Let's look at secondary substation N295 in the figure below.

Figure 40: Power profile for each customer at secondary substation N295

The customer with the highest load at this secondary substation has a load of around 50000 kWh for 2018, compared to N138 where the highest load was around 320000 kWh for the same year. But the N295 would still need to increase the transformer rating if every customer

connected to it installed solar power to the limit. From Figure 32 it says that the N295 has a capacity of 800 and that when the 30000 kWh production limit is implemented it barely makes a difference. The difference between the solar power installation peak power and the capacity is around 420 kW when the condition is in place, that's half the size of the transformer capacity and it would therefore need to be increased by at least 53% in order to just handle it. To be noted is that there is then no safety margin, so a more realistic case would be that the rating would need to increase even more.

6 Conclusion and future development

6.1 Conclusion

Network dimensioning is an important part of planning and operating a distribution network. In practice, hourly consumption data gathered from electricity meters are the most valuable measurement data from the distribution companies point of view. Not only that they are used for billing they also provide a great insight of how well the network operates, which part of the network needs improving and the consumption habits of the customers. Qlik Sense is a useful analysing tool with many analytical and graphical options to present these kind of data in a meaningful way. Analysing historical consumption data and future load scenario is a central process in dimensioning the network, especially with the growth of interest in private solar production in mind.

Using the Qlik Sense analytical platform, the project has successfully created an analysing tool to visualise historical network loading data for several secondary substations in Lund in the span of a year. There are options to analyse the hourly consumption data over an entire year, month or day. This fulfils the initial goal of presenting the hourly consumption data graphically and in detail from which the network's capacity to handle the load can be analysed. Furthermore there is also an option to present the loading with respect to a future scenario with solar power production and the loading graphs will be adjusted for it. The tool is a proof of concept and may improve with more features, however we can think of its application for planning and operating of a distribution network. Importing other type of data from other measurement system to the tool is also possible, but requires some adjustment in the code and with the limits in speed and handling of data it is not recommended in the current version of the tool.

The results from analysing sample consumption data from the secondary substations in the year 2018 shows that Kraftringen's network is more than capable of handling the load, with no peak hourly consumption exceeding 50% of the capacity of any station's transformer. This result is expected since the distribution network in Sweden is traditionally over-dimensioned to ensure stability and power quality.

At the critical cases, a solar power production of 800kW puts the majority of secondary substations in the study to the capacity limit, the 1600 kVA ones however are safe, which is reasonable due to no load at that point. By studying the results from the tax reduction eligibility it turns out that only 6 of the 11 secondary substations would be safe if every customer connected to the installed solar power to the limit. If all customers that can produce more than 30000 kW chooses not to, because one can only get tax reduction for the produced solar energy up to 30000 kWh, it shows that only a few of the transformers would be able to handle it. Worst off is secondary substation N213 needing to increase the transformer rating about 70%, and best off is secondary substation N317 with more than half the capacity available, based

on that the conditions are met and that the produced solar energy doesn't exceed 30000 kWh annually.

6.2 Future development

The project reached the initial goals, however, this is a proof of concept that has a lot of potential and can be improved with further development. Qlik Sense offers many possibilities to give this tool a wider range of application that people with greater Qlik Sense knowledge than us can make use of. Here are some areas that the project can be expanded upon:

- One of the early goals of the project was to visualise the hourly consumption data in a graph similar to the one in in Figure 41. Optimally, there should have been a three dimensional surface graph that showed both an overview of the consumption in a year and detailed consumption in a day on the same graph. Unfortunately this is not possible to accomplish with the version of Qlik Sense we had (there might be extensions for it, those are out of our reach however). Using the surface graph will provide the user with additional information that might be useful. It also increases the level of overview one can achieve.
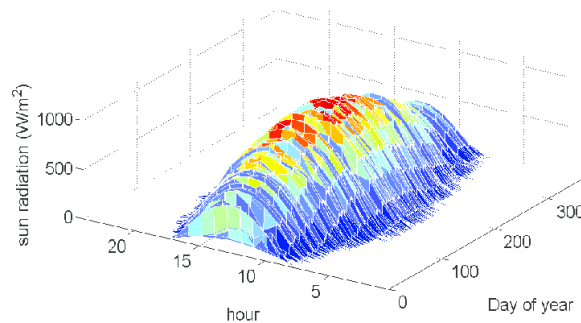

Figure 41: Illustration with measurement data from solar IR radiation. [24]

- The sample data used in the analysis were taken from eleven secondary substations in Lund for the year 2018. While it is adequate for proof of concept, to dimension a network usually takes longer planning, and more data should be analysed. Initially there was consumption data for all secondary substations belonging to Kraftringen but this made the application almost unusable due to extreme waiting times that caused time out errors or simply took too long for it to be useful. If stability can be improved when using the amount of data that all secondary substations bring it would create a better overview. A possibility could be that Qlik Sense is not the right tool to use for this amount of data, but this has to be looked into since this is not something we can say for certain.

- There has been discussions on what impacts the photovoltaic systems have on the network beside the loading. One important topic is the network's ability to maintain good power quality with a varying generation of renewable energy sources. To investigate

the network's strength in a low voltage network a good method is to check the voltage variation when the customers rapidly connect and disconnect the load or micro-production plants. Since there's no data on voltage and current available from the current installed electricity meters this is out of the scope of this project. However with the future installations of new electricity meters such data could be available and utilised by this tool. There's also work done before by Bergh & Estenlund to calculate voltage from effects measurements and the network's impedance [25]. Voltage and current measurement also enables the detection of leakage of sorts and then further investigate the source of this.

- The implementation of electrical vehicles in private homes can make the tool more wholesome, providing both information about consumption, solar energy and the charging of electrical vehicles. An inspiration of this can be found in [26].

- When it comes to solar energy and solar cells and creating a realistic theoretical prediction, one needs the temperature of the cell, the nominal operating cell temperature, ambient temperature and more. If one also were to include the temperature and meteorological difference each year have, it creates a non-trivial task to complete. However, there is a lot potential in making this type of calculations and visualisations, since it can be used for a variety of things. This calculation should absolutely be possible, and with a more in-depth and robust calculation of solar energy, one can create really good predictions based on any type of solar panel. And if make it so that the visualisation tool will have the option to select a large variety of solar panels and update the parameters used in the calculations automatically, this would give the company that dimensions the solar energy operation a lot of power. Say a consumer wants to install solar power on the roof. Based on previous years of power consumption data (which is measured and available), all data of the solar panel used and meteorological data from previous years, this will result in a profile for that one consumer which reflects the reality in great detail. The consumer will then know more about how solar energy will impact the yearly energy consumption. The more knowledge the consumer has about the impact the more trustworthy the company seems and the consumer would perhaps be more willing to install solar energy. Along with this, even better package solutions can be developed. The power of being able to tell in realistic scenarios how the energy consumption will look if they install solar energy seems as if it would bring much usefulness for both the company and the consumer.

- In combination with the aforementioned you could also add the option to chose between different solar panels and add the price for each. In this way the tool can be used to make great predictions and also calculate the cost, making it a complete solar panel tool.

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Appendix A - User manual

The Qlik Sense App is published only to Kraftringen's internal network that requires authorised accessed. This user manual is aimed at people who received entry privilege on the web based Qlik Sense client at `https://qliksense.kraftringen.se` and assumed basic knowledge in the Qlik Sense analytic platform. This document should be viewed with software that displays colour to be understood well.

A.1 The app

In the Qlik Sense Hub navigate to our app called "Effeknivåer och solprofil över nätstationer i Lund". Open the app to see an overview of the app divided to several sheets representing different features in Figure 42. There's an option to create new Qlik Sense sheet (Skapa nytt ark) to continue development of the app.
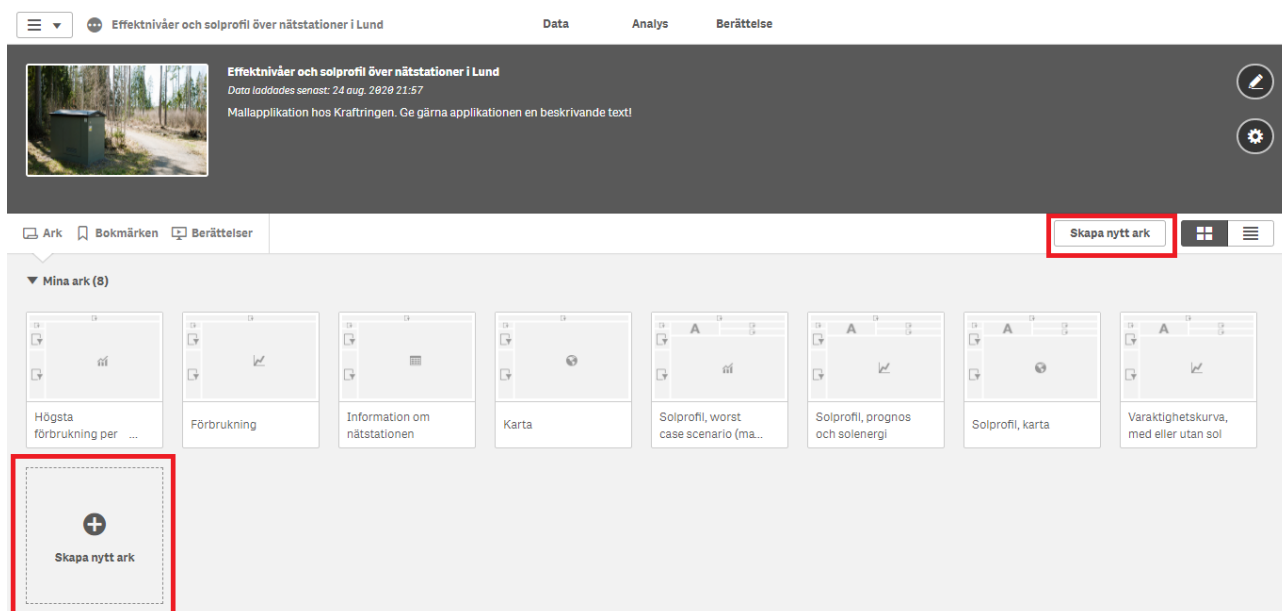
Figure 42: Overview of the Qlik Sense App

A.2 Basic functionality

Selecting one of the sheet open up its view with graphs, tables and analytic options. Each sheet has its unique features but some functions remain the same in all of them. This section goes through these by using one of the sheets as an example and should look the same for every other sheets.

Figure 43 shows how to select which time period the data will be displayed for. By clicking on the tabs marked with a red squared user can choose which year, month, week, date and time the consumption data will be taken from. A dialogue box will be open and user can either select the time from the drop down list or search for it in the search box. A green checkbox confirms selection. The graph should be changed accordingly.
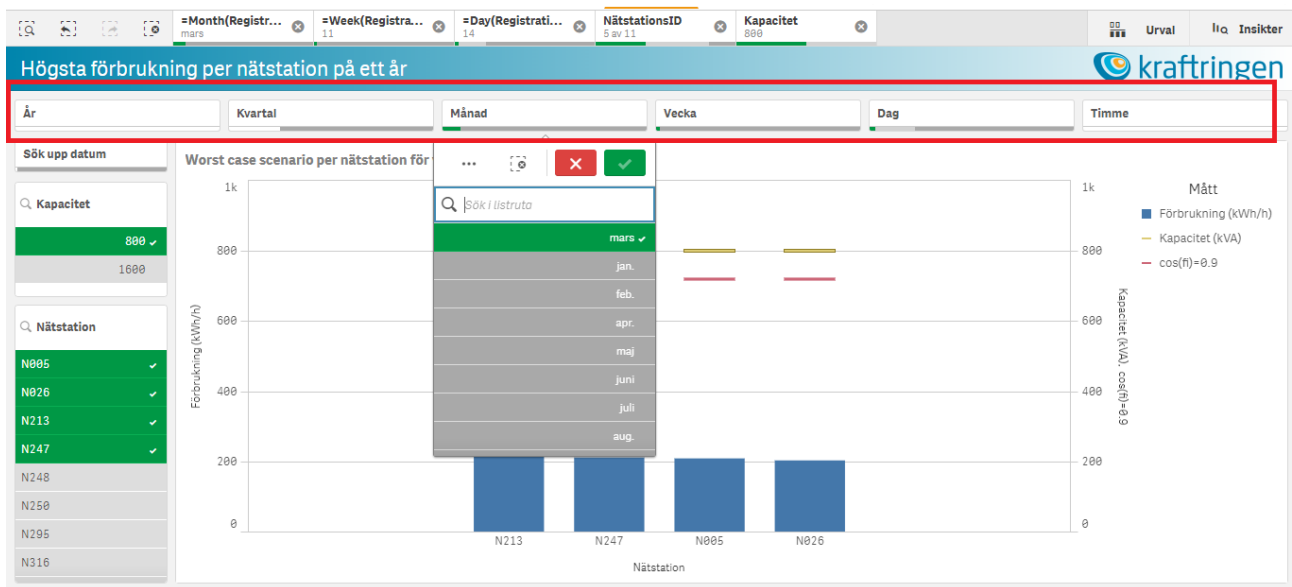
Figure 43: Time period selecting function

Figure 44 shows how to select which secondary substation the data will be displayed for. By clicking on the table to the left marked with a red squared user can choose station or group of station the consumption data will be taken from. The stations can be grouped either according to capacity or just arbitrary. A green checkbox confirms selection. The graph should be changed accordingly.
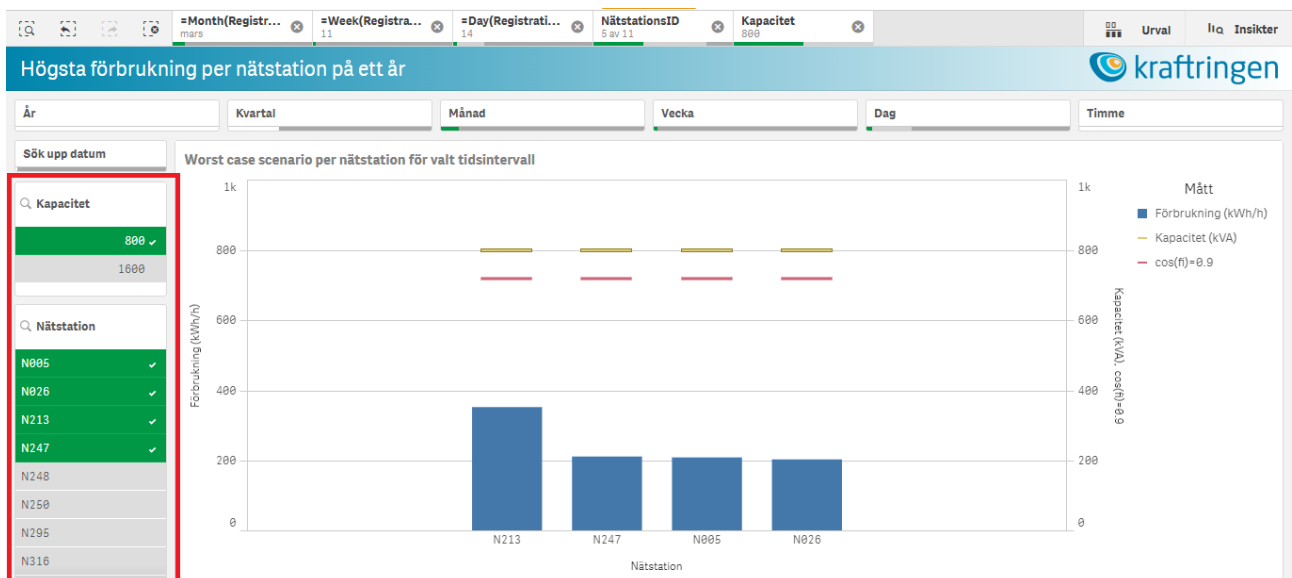

Figure 44: Secondary substation selecting function

Figure 45 show how to quickly select which date- or timestamp the data will be displayed for. By clicking on the tab to the left marked with a red squared user can search and select which time the consumption data will be taken from. A dialogue box will be open and user can either select the time from the drop down list or search for it in the search box. A green checkbox confirms selection. The graph should be changed accordingly.
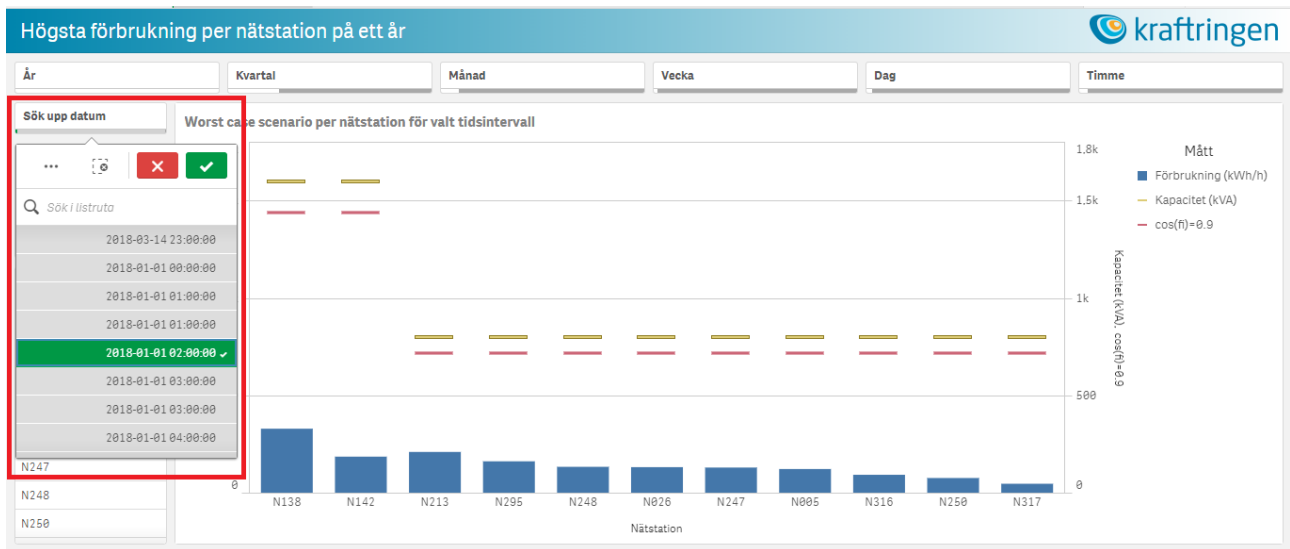
Figure 45: Time searching function

The selected timestamp, station and other will be saved and displayed as shown in Figure 46, marked with a red square on top. They will follow as preselected when user view other graphs or sheets. To clear them simply click on the cross button next to each on of them.
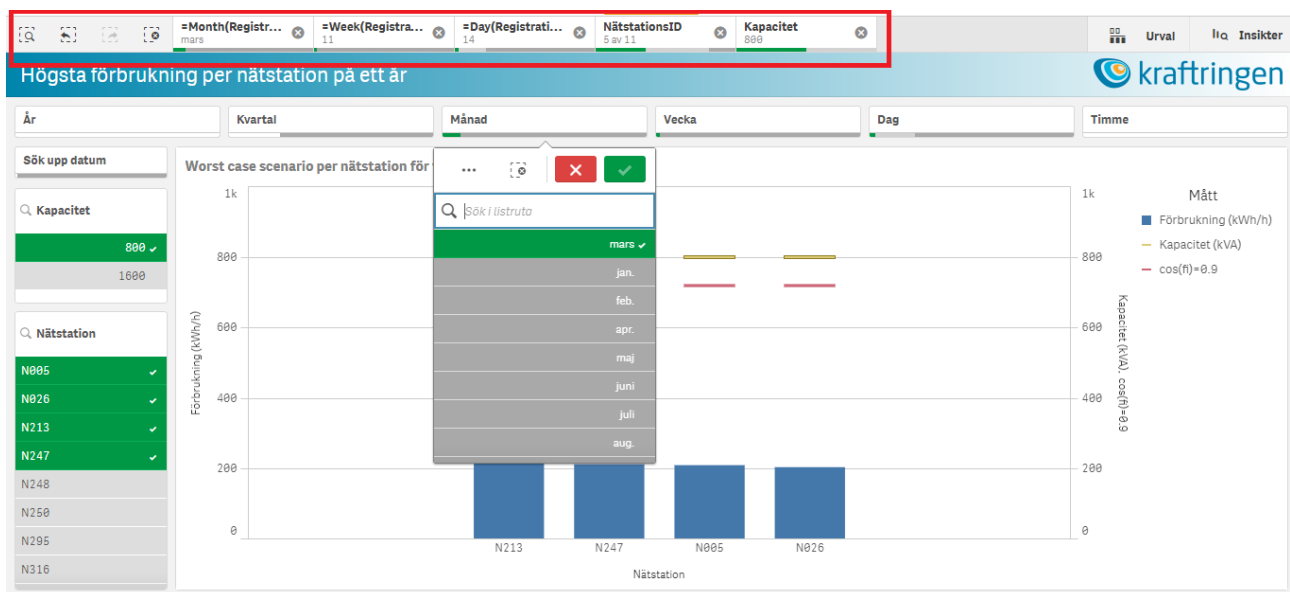
Figure 46: Deselecting function

A.3 Solar profile sheets

The Qlik Sense sheets for solar profile contains all the basic functions described above with a few added features. Figure 47 shows the tabs that allow user to select to view the scenarios with certain amount of solar power production and how it impacts the network. The production scenario can either refer to certain customer by selecting "Kundnummer" or just the sum of production in "Produktion (kW)" tab. A dialogue box will be open and user can either select

the customer/production from the drop down list or type in the dialogue box. A green checkbox confirms selection. The numbers of connected Sharp 180W model solar plants will be displayed and the graph should be changed accordingly.
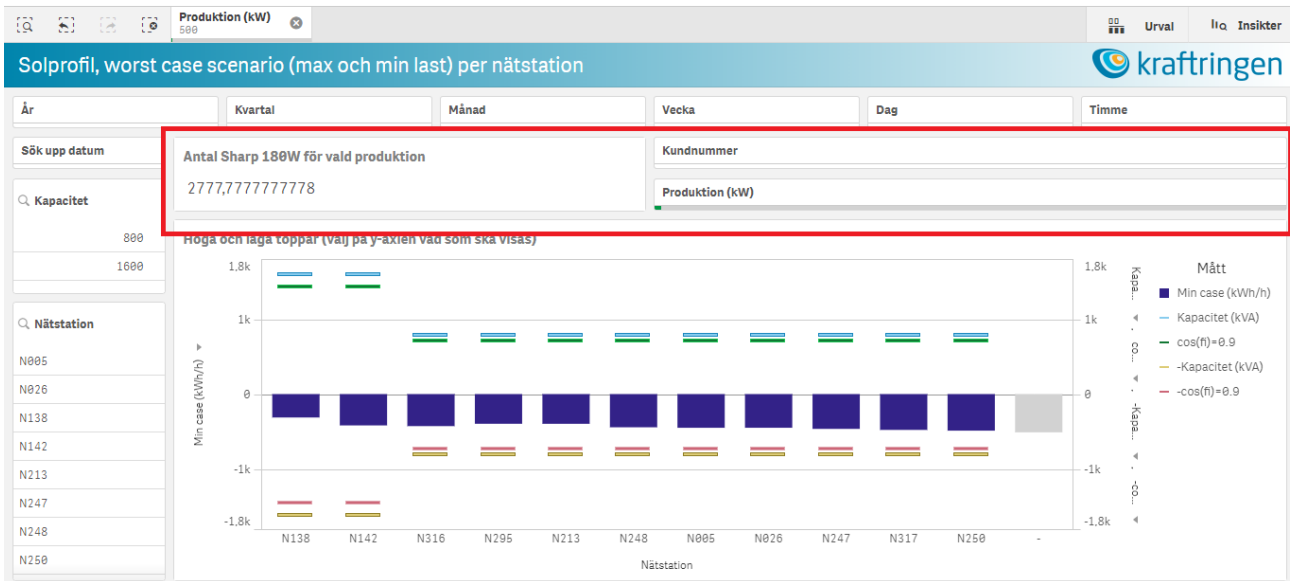
Figure 47: Solar profile exclusive functionality

Solar profile sheets contain more analysis option and it's helpful to be able to quickly change the view of the graphs for desired purpose. Figure 48 shows how to quickly change between max/min graphs for the worse case analysis. Figure 49 between the prognosis for the solar scenario's impact and the graph with only solar production. To change between the graphs simply click on the y-axis label and choose from the checkbox.
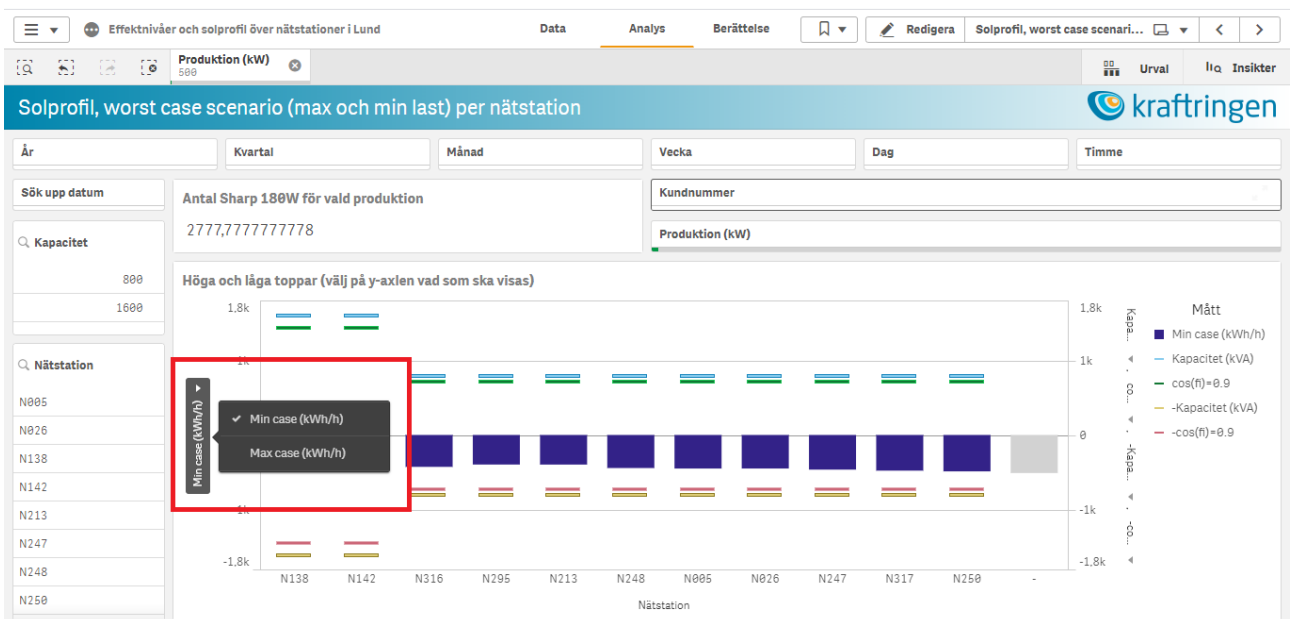
Figure 48: Min max graphs selection
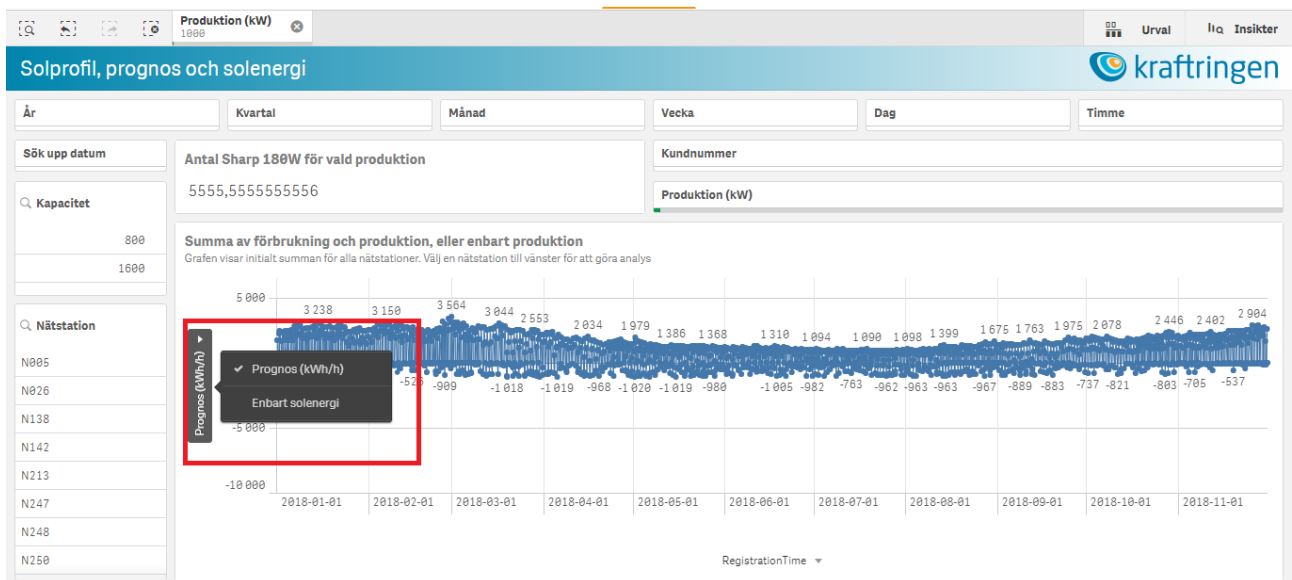
Figure 49: Prognosis and solar production only graphs

Appendix B - Code

References to Kraftringen's filesystem is edited out due to security reason.

B.1 Basic settings

```
1 SET ThousandSep=' ';
2 SET DecimalSep=',';
3 SET MoneyThousandSep=' ';
4 SET MoneyDecimalSep=',';
5 SET MoneyFormat='# ##0,00 kr;-# ##0,00 kr';
6 SET TimeFormat='hh:mm:ss';
7 SET DateFormat='YYYY-MM-DD';
8 SET TimestampFormat='YYYY-MM-DD hh:mm:ss[.fff]';
9 SET FirstWeekDay=0;
10 SET BrokenWeeks=0;
11 SET ReferenceDay=4;
12 SET FirstMonthOfYear=1;
13 SET CollationLocale='sv-SE';
14 SET CreateSearchIndexOnReload=1;
15 SET MonthNames='jan.;feb.;mars;apr.;maj;juni;juli;aug.;sep.;okt.;nov.;dec
    .';
16 SET LongMonthNames='januari;februari;mars;april;maj;juni;juli;augusti;
    september;oktober;november;december';
17 SET DayNames='mån;tis;ons;tors;fre;lör;sön';
18 SET LongDayNames='måndag;tisdag;onsdag;torsdag;fredag;lördag;söndag';
19
20 //ID och Titel och starttid
21 LET vL.DocumentName = DocumentName();
22 LET vL.DocumentTitle = DocumentTitle();
23 LET vL.DocumentTitleQVD = Replace(DocumentTitle(),' ','_');
24 LET vL.StartTime = Now();
25 Let vSenastOmladdad = Now(1);
26
27 //Fält prefixade med "%" döljs i gränssnittet.
28 SET HidePrefix='%' ;
```

B.2 Calendar

```
1 LOAD
2     %Key_Kalender,
3     Datum,
4     År,
5     ÅrKvartal,
6     ÅrMånad,
7     ÅrVecka,
8     VeckoÅr,
9     MånadsNummer,
```

```
10        Månad ,
11        Vecka ,
12        Dag ,
13        Veckodag ,
14        ÅrVecka2 ,
15        ÅrVecka3 ,
16        Kvartal ,
17        _VeckoRäknare ,
18        _ÅrVeckaRäknare ,
19        _ÅrVeckaRäknare_YYYYVWW ,
20        _MånadsRäknare ,
21        _ÅrMånadRäknare ,
22        _KvartalRäknare ,
23        _ÅrKvartalRäknare ,
24        _ÅrRäknare ,
25        _ÄrRödDag ,
26        _ÄrArbetsfriDag ,
27        _ÄrArbetsdag
28 FROM [lib://../T1_Kalender.qvd]
29 (qvd)
30 ;
```

B.3 Dim

```
1 Mätare:
2 LOAD
3        SERVICEIDENTIFIER as MeteringPointID ,
4        ID_MEASURAND ,
5        %Key_Mätare ,
6        ID_DELIVERY_POINT ,
7        Mätpunktsnamn ,
8        Nyttighet ,
9        Mätpunktstyp ,
10        Avräkningstyp ,
11        GSRN ,
12        Nätområde ,
13        Tjänstenummer ,
14        "Tjänst beskrivning" ,
15        Fastighetsbeteckning ,
16        Tjänsteställenummer ,
17        Säkring ,
18        "Abonnerad effekt" ,
19        Mikroproduktion ,
20        Produktion ,
21        Anslutningseffekt ,
22        "Leveranspunkt 1" ,
23        Kategori ,
24        Uppsättningsdatum ,
```

```
25      Qn,
26      Säsongsanläggning,
27      Handräckning,
28      "Avstängd av kund",
29      Renovering,
30      Prioriterad,
31      Motmätning,
32      "Fiktiv mätning",
33      NätstationsID
34 FROM [lib://../MVDB_Dim_Mätpunkter.qvd](qvd)
35 Where WildMatch([NätstationsID], 'N005','N316','N295','N250','N248','N247
       ','N213','N142','N138','N026', 'N317', 'N316')
36 ;
37
38 LOAD
39      Subtyp,
40      NätstationsID,
41      "Y (Öst)'",
42      "X (Norr)'",
43      "Sammanfogad (google format)"
44 FROM [lib://../Koordinater stationer.XLS]
45 (biff, embedded labels, table is Stationer$)
46 Where WildMatch([NätstationsID], 'N005','N316','N295','N250','N248','N247
       ','N213','N142','N138','N026', 'N317', 'N316')
47
48 ;
49
50 LOAD
51      Kapacitet,
52      NätstationsID,
53      Stationsnamn,
54      Subtyp
55 FROM [lib://../Nätstationer 11kV - kopia.xlsx]
56 (ooxml, embedded labels, table is Sheet0)
57 Where WildMatch([NätstationsID], 'N005','N316','N295','N250','N248','N247
       ','N213','N142','N138','N026', 'N317', 'N316') ;
58
59 LOAD
60      Kapacitet,
61      NätstationsID,
62      Stationsnamn,
63      Subtyp
64 FROM [lib://../Nätstationer 20kV - kopia.xlsx]
65 (ooxml, embedded labels, table is Sheet0)
66 Where WildMatch([NätstationsID], 'N005','N316','N295','N250','N248','N247
       ','N213','N142','N138','N026', 'N317', 'N316') ;
```

B.4 MVDB

```
 1 Värden:
 2 Load
 3 ␣␣Null() AS MeasurementPointID,
 4 ␣␣Null() AS MeteringPointID,
 5    Null() AS %Key,
 6 ␣␣Null() AS Mätarställning,
 7 ␣␣Null() AS Enhet,
 8 ␣␣Null() AS Status,
 9 ␣␣Null() AS RegistrationTime,
10 ␣␣Null() AS %Key_Kalender,
11 ␣␣Null() AS %key_MätserieDag,
12 ␣␣Null() AS %key_MätserieMånad,
13 // ␣Null() AS GSRN,
14 ␣␣Null() AS Mätserie,
15 ␣␣Null() AS Avvikelsefaktor,
16 ␣␣Null() AS Avvikelsestatus,
17 ␣␣Null() AS StatusFörbrukning,
18 ␣␣Null() AS Förbrukning
19 Autogenerate(0);
20
21 Concatenate(Värden)
22
23 LOAD
24    MeasurementPointID,
25    MeteringPointID␣␣␣AS %Key,
26    MeteringPointID,
27    MeterReading ␣␣␣␣␣AS Mätarställning,
28    Unit as Enhet,
29    RegistrationTime,
30    %Key_Kalender,
31    %key_MätserieDag,
32    %key_MätserieMånad,
33    Mätserie,
34    Avvikelsefaktor,
35    Avvikelsestatus,
36    StatusFörbrukning,
37    Förbrukning
38 FROM [lib:/../T1_MVDB_Mätvärden_2018*.qvd]
39
40 (qvd)
41
42 Where Exists(MeteringPointID)
43 and
44 ([Förbrukning]>=0) and ([Förbrukning]<5000)
45 ;
46
47 Soldata:
48 LOAD
```

```
49  ⎵  RegistrationTime,
50     "Lufttemperatur, malmö (grader celcius)",
51     "Global irradians (W/m2)",
52     "Cell temperature (grad celc)",
53     "Efficiency, Trina with cell temp",
54     "Efficiency, Sharp with cell temp",
55     "Produktion, KR data @0.180kW, 1.3101m2 (kWh/h)",
56     "Produktion, KR data @0.180kW, 1m2 (kWh/h)",
57     "Produktion, Sharp, Beräknad per panel (kWh/h)",
58     "Produktion, Sharp, beräknad per kvadratmeter",
59     "Produktion, KR data @0.315kW, 1.3101m2 (kWh/h)",
60     "Produktid, KR data @0.315kW, 1.6368 m2 (kWh/h)",
61     "Produktion, KR data @0.315kW, 1m2 (kWh/h)",
62     "Produktion, Trina, Beräknad per panel (kWh/h)",
63     "Produktion, Trina, per kvadratmeter"
64 FROM [lib://../Soldata.xlsx]
65 (ooxml, embedded labels, table is Soldata);
66
67 LOAD
68     "Antal paneler",
69     "Produktion (kW)",
70     Area
71 FROM [lib://../Soldata.xlsx]
72 (ooxml, embedded labels, table is Paneldata);
73
74 Paneldata:
75 LOAD
76     Solpanel,
77     "Area (m2)" as Panelarea,
78     "Temperature Coefficient, Pm",
79     NOCT,
80     "Maximum Power (kW)",
81     "Module Efficiency @25"
82 FROM [lib://../Soldata.xlsx]
83 (ooxml, embedded labels, table is Paneler);
```

B.5 99.Exit

```
1
2 //Sätt laddtid och avsluta.
3 LET vL.EndTime ⎵= Now();
4 LET vL.LoadTime = Time(vL.EndTime - vL.StartTime);
5
6
7 EXIT SCRIPT;
```

B.6 Load

```
1  // LOAD
2
3  Measurement:
4  Load  MeasurementPointID,
5        MeasurementNumber,
6             MeasurementSeriesType,
7             RegisterCode,
8             Measurement,
9             RegistrationTime,
10            Year,
11            Month,
12            Day,
13            Date,
14            Hour
15  ;
16
17  MeasurementPoint:
18  Load  MeasurementPointID,
19        Status,
20             Name,
21             BuildingType,
22             MainFuse,
23             MeterPanel,
24             Phase,
25             MeasuringSeriesType
26  ;
27
28  MeasurementValue:
29  Load  %PointTimeKey,
30        MeasurementPointID,
31        MeasurementSeriesType,
32        Quantity,
33        Unit,
34        Start,
35        End,
36        Status,
37        StatusReason,
38        RegistrationTime,
39        Year,
40        Month,
41        Day,
42        Date,
43        Hour,
44             Type,
45        Quantity
46  ;
```

B.6 Mapping

```
1
2 LOAD
3     ID_TRANSLATION,
4     ID_CULTURE,
5     ENTITY,
6     "ATTRIBUTE",
7     TRANSLATED
8 FROM [lib://../META_TRANSLATION.qvd]
9 (qvd);
10
11
12 map_utility:
13 Mapping LOAD
14     ATTRIBUTE,
15     TRANSLATED
16 FROM [lib:../META_TRANSLATION.qvd] (qvd)
17 WHERE
18 ⎵⎵ID_CULTURE = 'SV'
19     AND ENTITY = 'META_UTILITY'
20 ;
21
22 map_deduction:
23 Mapping LOAD
24     ATTRIBUTE,
25     TRANSLATED
26 FROM [lib://../META_TRANSLATION.qvd] (qvd)
27 WHERE
28 ⎵⎵ID_CULTURE = 'SV'
29     AND ENTITY = 'META_DEDUCTION_TYPE';
30
31
32 map_Period_Size:
33 Mapping LOAD
34     ATTRIBUTE,
35     TRANSLATED
36 FROM [lib://../TRANSLATION.qvd] (qvd)
37 WHERE
38 ⎵⎵ID_CULTURE = 'SV'
39     AND ENTITY = 'META_PERIOD_SIZE_ALL';
40
41 Map_ID_DEDUCTION_CODE:
42 Mapping LOAD
43 ⎵⎵ID_MEASURAND,
44 ⎵⎵ID_DEDUCTION_CODE
45 FROM [lib://../MEASURAND_DETAIL.qvd] (qvd)
46 ;
47
```

```
48 map_Tidsserier:
49 Mapping LOAD
50     Produktkod,
51     Tidsserier
52 FROM [lib://../Tidsserier_produktkoder_190619.xls]
53 (biff, embedded labels, table is Sheet1$);
54
55 map_status_text:
56 Mapping LOAD * Inline [
57 __Kod,__Text
58 __P,____Provad
59     N,____Nedtagen
60     U,____Uppsatt
61     S,____Skrotad
62     O,____Oprovad
63     M,____Saknas
64 ];
```

Appendix C - Peak transformer loading for all of the stations

Totalförbrukning för nätstation(er) för specifikt tidsintervall
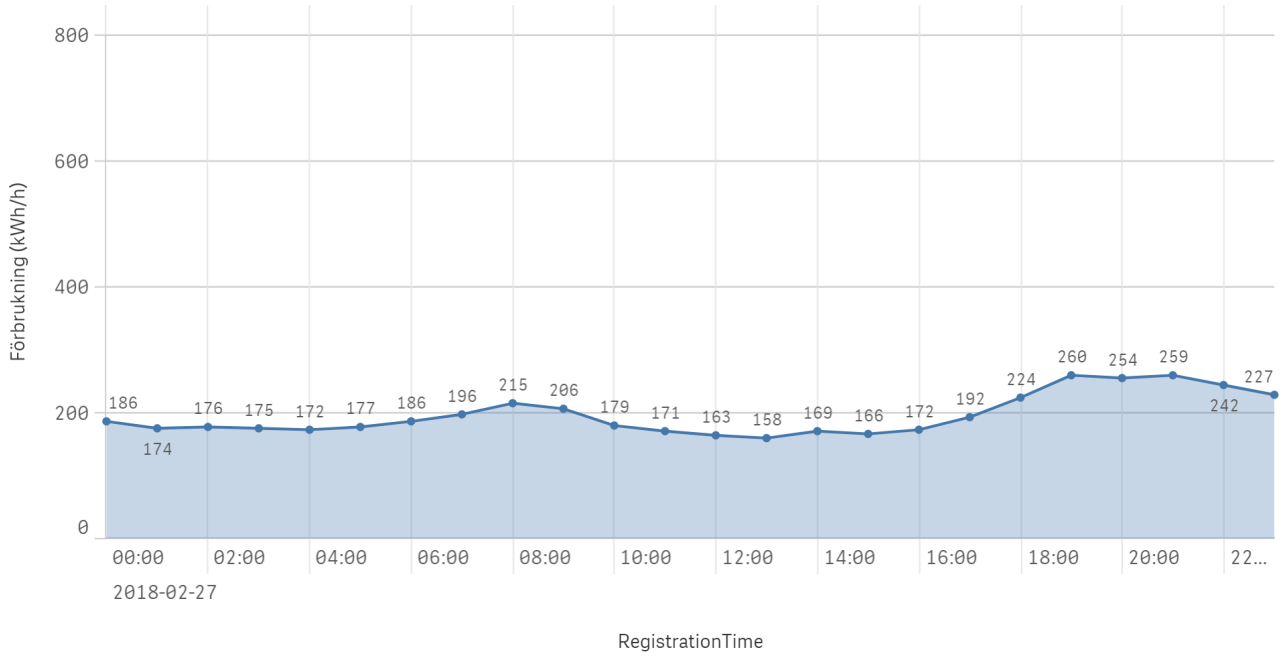Grafen visar initialt summan för alla nätstationer. Välj en nätstation till vänster för att göra analys
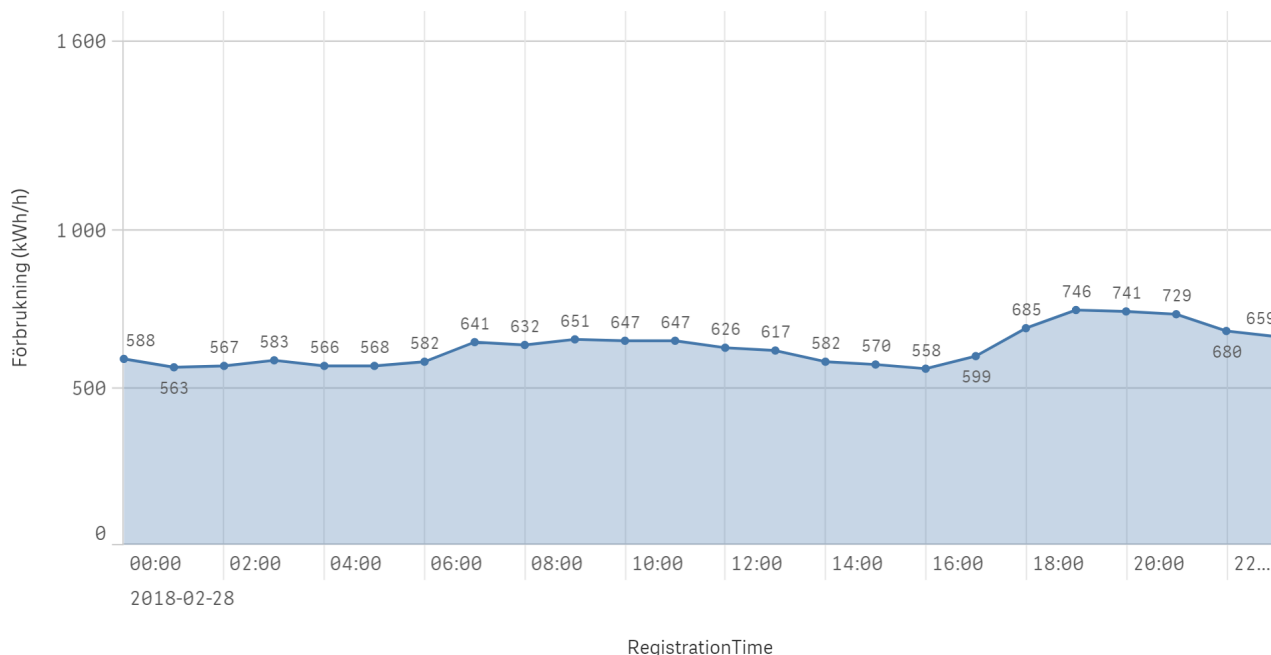
Figure 50: Hourly values of the transformer loading for the day with highest loading, station N138

Totalförbrukning för nätstation(er) för specifikt tidsintervall
Grafen visar initialt summan för alla nätstationer. Välj en nätstation till vänster för att göra analys
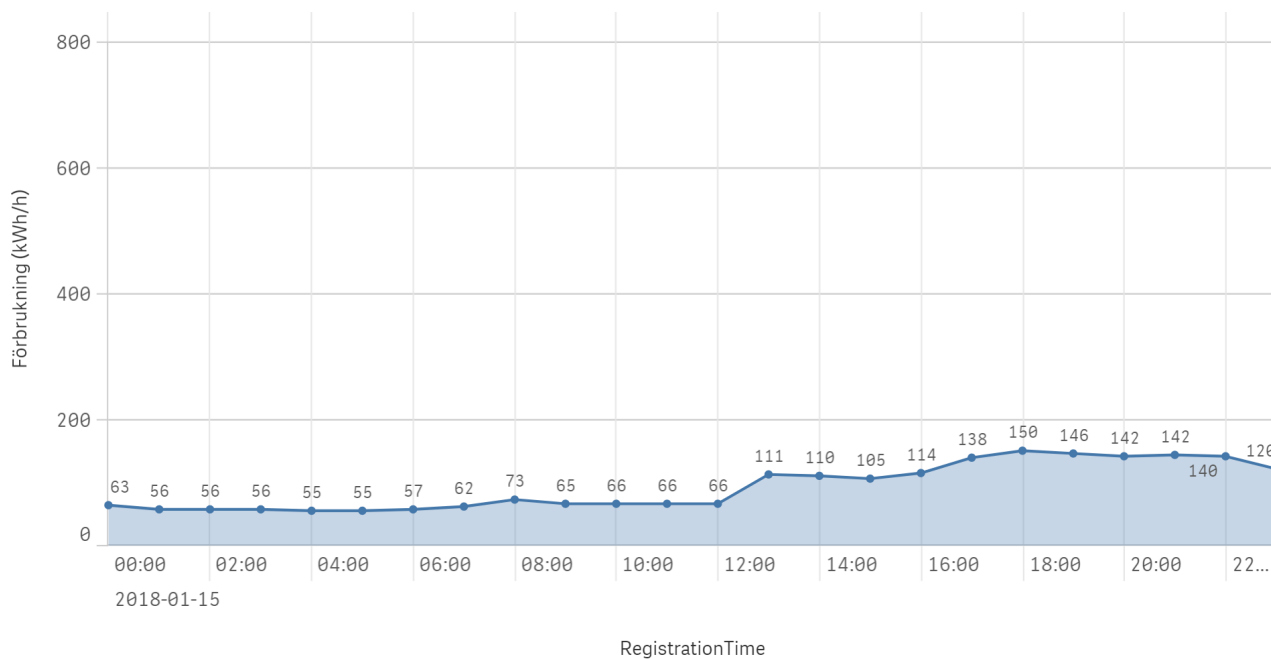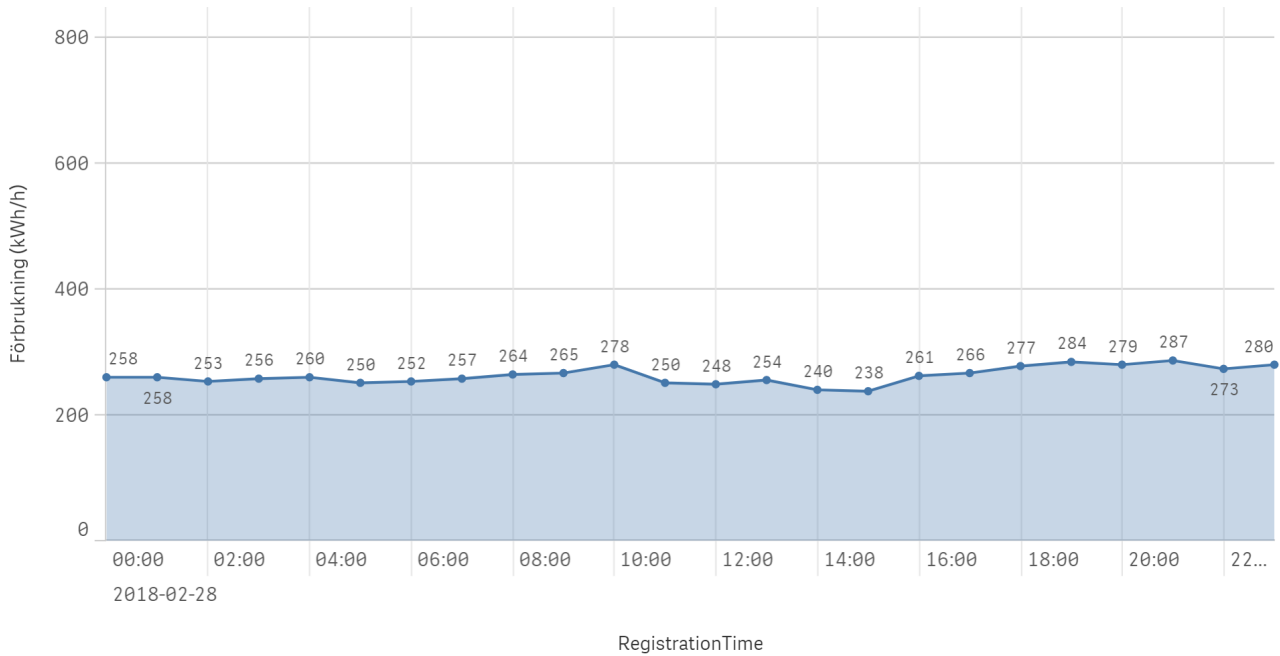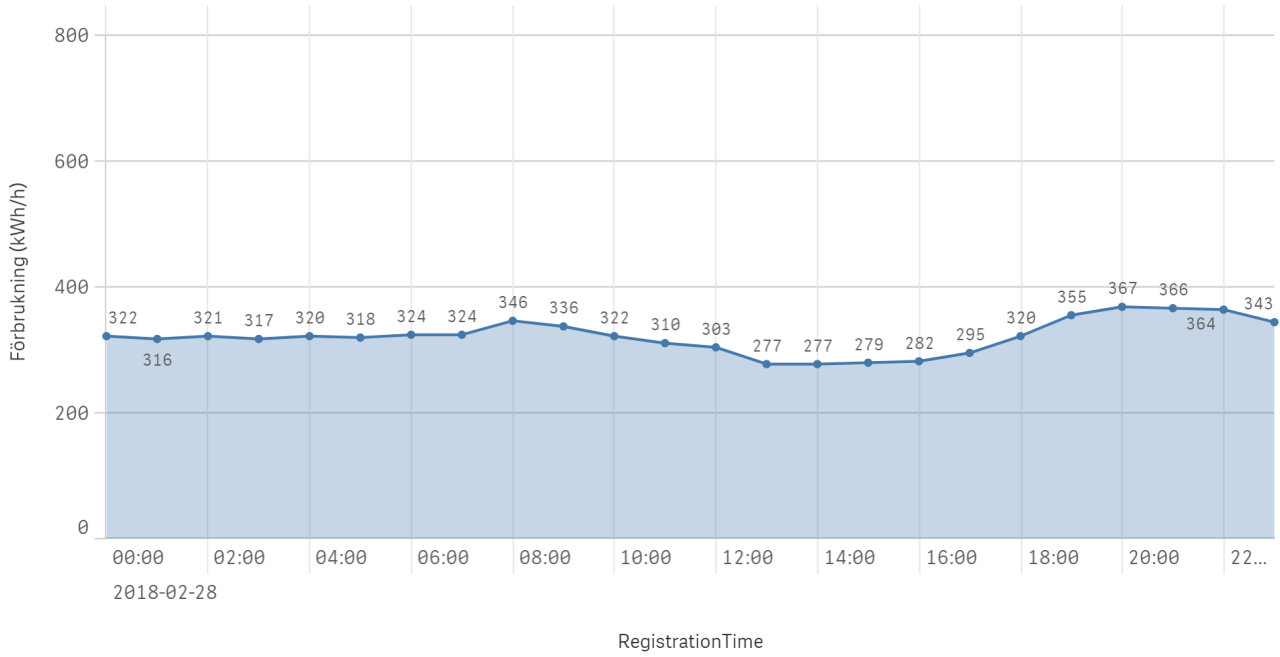
Figure 51: Hourly values of the transformer loading for the day with highest loading, station N317
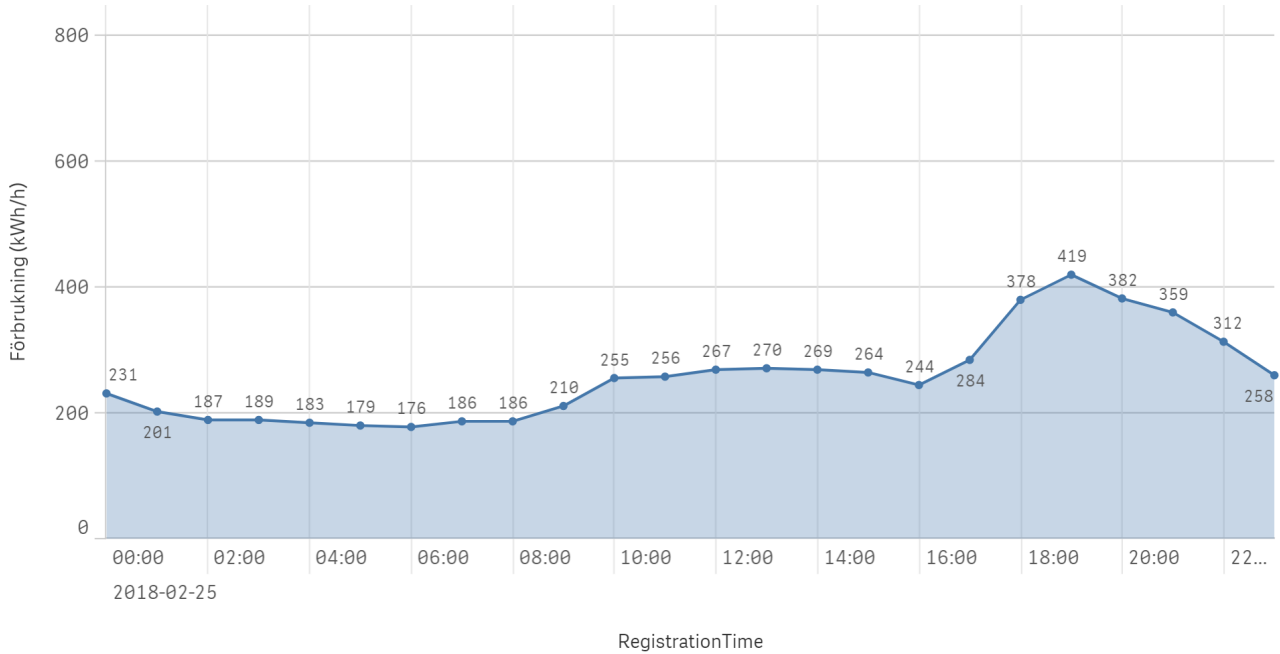
Figure 52: Hourly values of the transformer loading for the day with highest loading, station N213
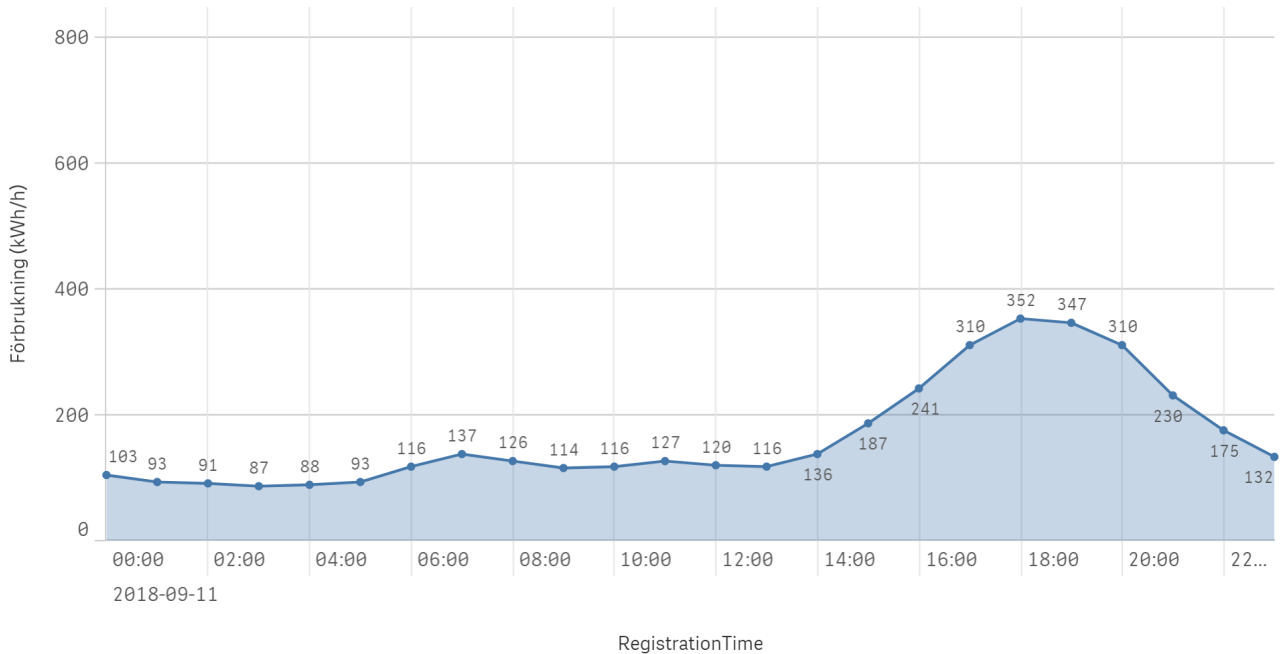
Figure 53: Hourly values of the transformer loading for the day with highest loading, station N295
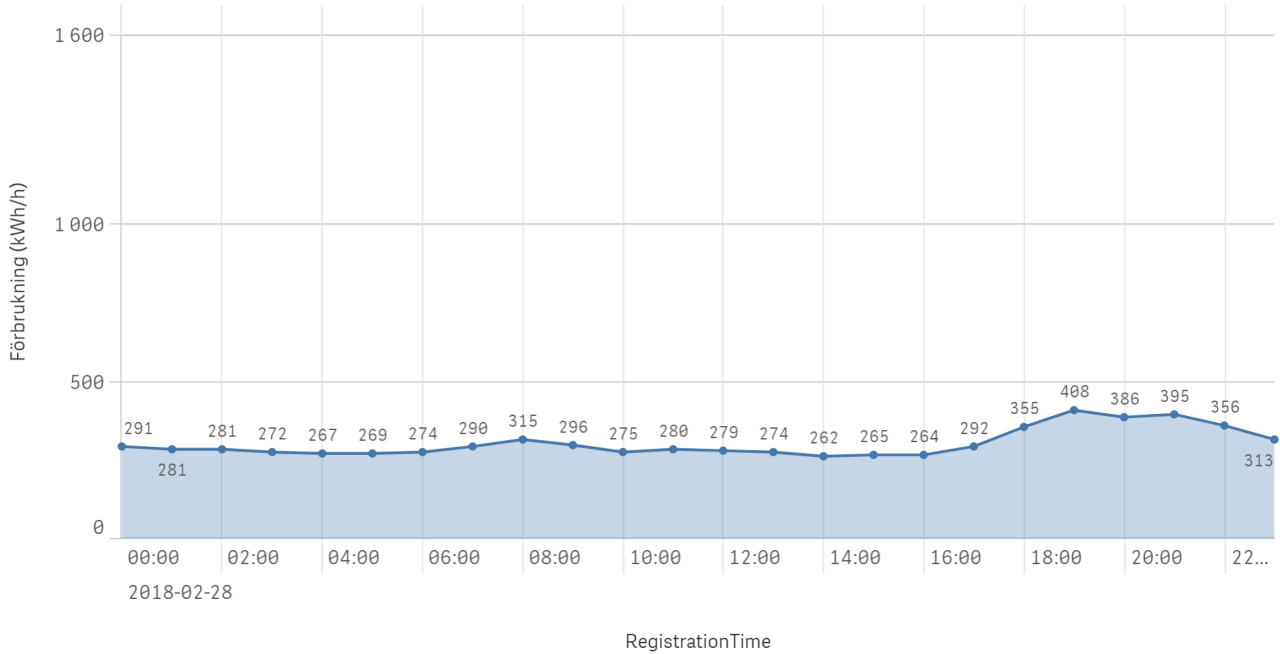
Figure 54: Hourly values of the transformer loading for the day with highest loading, station N142
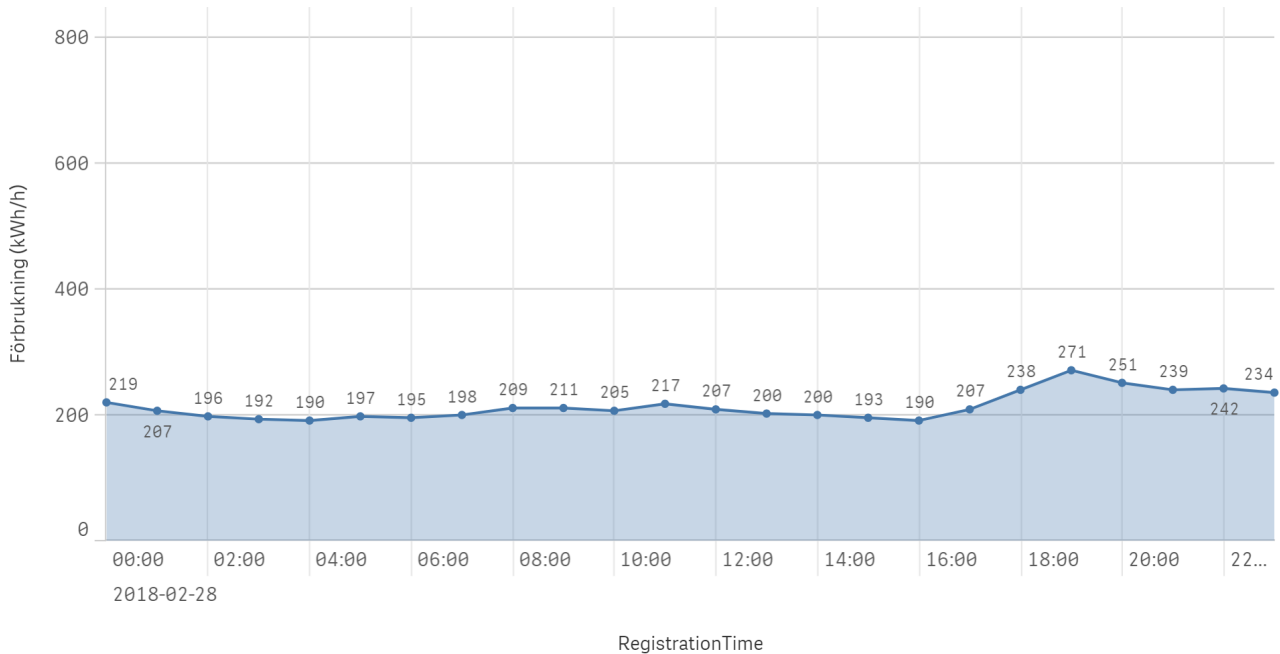
Figure 55: Hourly values of the transformer loading for the day with highest loading, station N005

Figure 56: Hourly values of the transformer loading for the day with highest loading, station N026

Figure 57: Hourly values of the transformer loading for the day with highest loading, station N247

Figure 58: Hourly values of the transformer loading for the day with highest loading, station N248
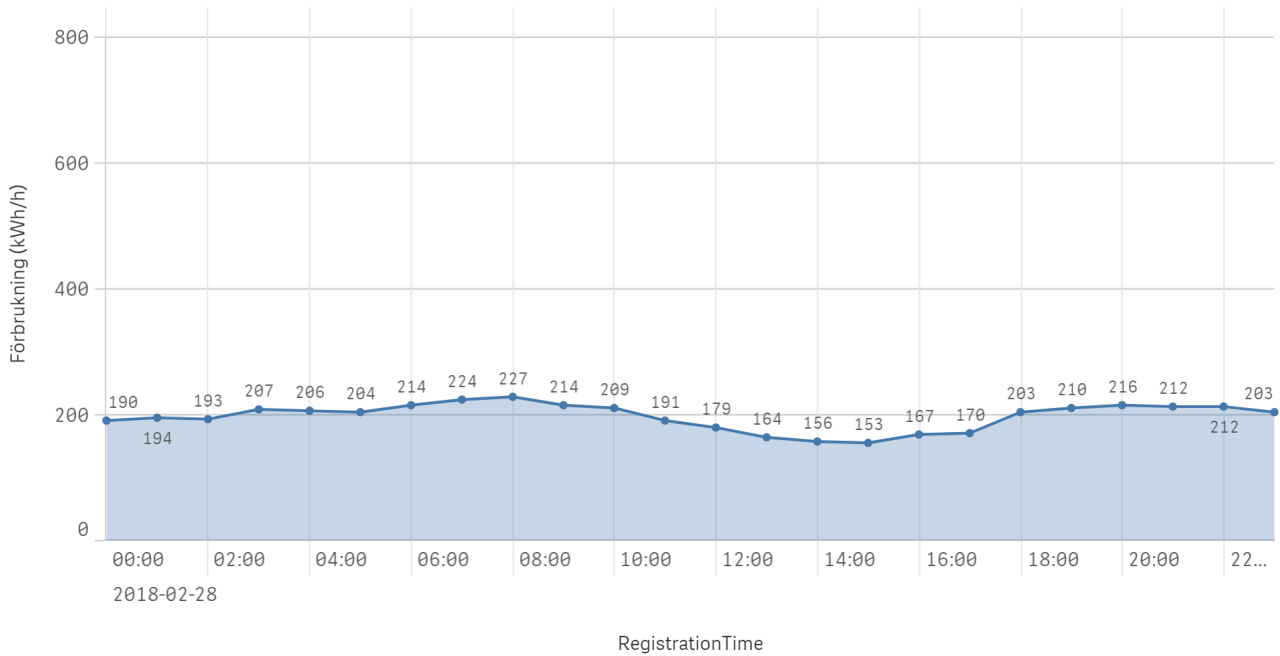

Figure 59: Hourly values of the transformer loading for the day with highest loading, station N250

Totalförbrukning för nätstation(er) för specifikt tidsintervall
Grafen visar initialt summan för alla nätstationer. Välj en nätstation till vänster för att göra analys
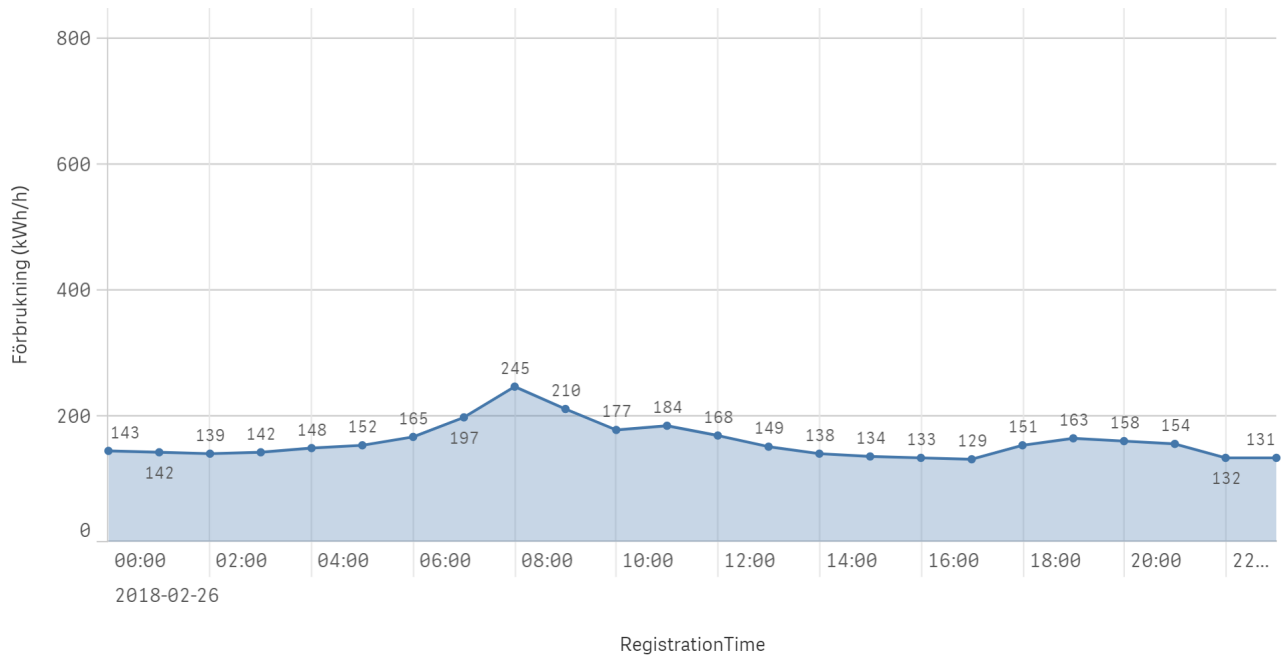
Figure 60: Hourly values of the transformer loading for the day with highest loading, station N316