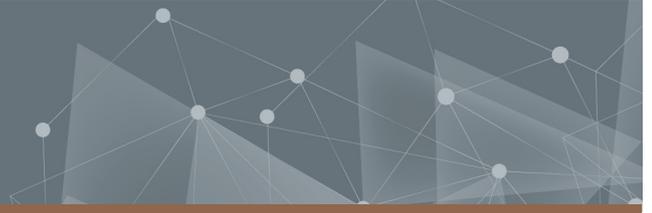




CHALMERS
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Price elasticity of district heating

Master's thesis in Sustainable energy systems

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DEPARTMENT OF SPACE, EARTH AND ENVIRONMENT

CHALMERS UNIVERSITY OF TECHNOLOGY
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MASTER'S THESIS 2023

Price Elasticity of District Heating

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Department of Space, Earth and Environment
Division of Energy Technology
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Abstract

Although district heating is a well established industry in Sweden it still faces challenges. One of these is their way of charging customers for supplied heat. These price models are often complicated to understand for both customers and company employees as well as sensitive for weather making it hard to predict income. The price itself could also affect the energy use which is relatively unexplored in DH. Therefor an analysis of how price elasticity can be used to predict energy use was done. It was done by doing a literature study which was followed by an interview study and creating three models, modelling the energy of two networks, in order to see if using price elasticity when setting prices is a good approach. The thesis also examines the what kind of building that is consuming the heat and the effect that has on the price elasticity. Lastly the thesis also investigates the correlation between district heating use and electricity prices in order to see if users of district heating increases their use of district heating instead of using other heating options.

The literature study concludes that the price elasticity of demand for district heating is inelastic, meaning that the changes in demand are rather small compared to the price changes.

The interview study concludes that district heating companies do think of price elasticity when setting prices but would be interested to use it in the future to better predicts revenues.

The studied models for elasticity show that the use of price elasticity in setting DH prices is somewhat unnecessary as the elasticity in literature as well as historically in the networks are rather low. The results also indicates that the use of individual metering for households in multi family buildings makes a difference on the elasticity in some capacity however it still remains rather inelastic.

Lastly there is low correlation between electricity prices and district heating use for most of the year.

Keywords: District Heating, price elasticity, energy use.

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Hugo Sandolf, Gothenburg, May 2023

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1

Introduction

The main goal of district heating (DH) is to distribute heat through a city or a town as efficiently as possible. In order to make this possible an underground network of insulated pipes is installed. These pipes deliver heat generated at a thermal plant to different kinds of buildings such as industry, commercial as well as residential buildings. An advantage of district heating, compared to every building heating itself, is the possibility to utilize waste heat from local industries which would otherwise be lost[1]. Due to its efficiency and possibility to utilize this waste heat DH is often looked at as playing an important role in the de-carbonation of the EU energy system[2]. If the DH is also utilizing bio fuels instead of fossil fuels such as natural gas this effect will be even greater.

In the European Union (EU) half of the final energy consumption stems from heating and cooling[3]. Currently around 13% of this heat is provided through DH[2]. In Sweden DH is more established than in the rest of the EU and has a larger share of heating at around 55% as of the year 2014[4]. Despite the fact that DH is a well established industry in Sweden with around 500 different networks[4], the DH industry is facing significant challenges. One of these challenges is the way DH companies are charging customers for their services. The price models used by these companies are troublesome in several ways: They are sensitive to weather making it hard for companies to predict revenue, they are not incentivising building owners to increase the energy efficiency of the building enough and they are hard for customers to understand as well as hard for DH employees to analyze, develop and change.[5]

The price and production costs of DH is highly depending on weather and the prices are often split into the four seasons of winter, spring, summer and autumn[5]. For each of these seasons there is a set price for the energy purchased (kr/kWh). Another part of the DH price is the heating power delivered. This is often calculated by taking the average load during the day by dividing the energy supplied by the amount of hours (kWh/h)[5]. However, the price models can vary substantially between different DH companies which also creates confusion for customers in case of change of DH provider[5].

In order to understand the value of a product companies can use price elasticity[6]. Price elasticity is a measurement on how many percent the requested quantity changes in respond to an increase in price. This can be used by DH companies to understand how their customers react to price changes and ease the prediction of income and operations. Price elasticity would be of great importance in the case

of DH companies wanting their customers to lower their energy use. They could then raise the price to a level that would result in the sought after reduction in energy use. There are however not many examples in literature or in industry of price elasticity being used in the district heating sector.

1.1 Aim

The aim of this thesis is to provide Utilifeed and the DH industry with an understanding of how price elasticity of district heating can be implemented in Utilifeed's platform and how DH companies in general can study and use price elasticity. The objective is to be able to present a method for using price elasticity when analyzing new price levels and/or price models for district heating.

1.2 Limitations

The price elasticity estimates will be found in literature and their effects examined. The thesis is only normalized for weather and does not take other factors such as inflation into account.

The thesis does not aim to provide Utilifeed with a product but rather a method of how they can start to try implementing elasticity in their work.

1.3 Research questions

The goal is to evaluate how price elasticity can be used in the setting of prices and price models of DH. The main research question is: "How will the energy use in a district heating network change when the price of district heating changes?" Other questions that is looked to be answered are: "How does DH companies use price elasticity today?", "How would DH companies like to use price elasticity in the future?" and "How can Utilifeed use this knowledge in their work?"

2

Theory

2.1 District heating in Sweden

The Swedish district heating sector consists of around 500 networks of varying sizes[4]. The total final energy use of this sector was as of 2020 around 47 TWh out of 355 TWh final energy use in Sweden[7]. The distribution of which is shown in Figure 2.1.

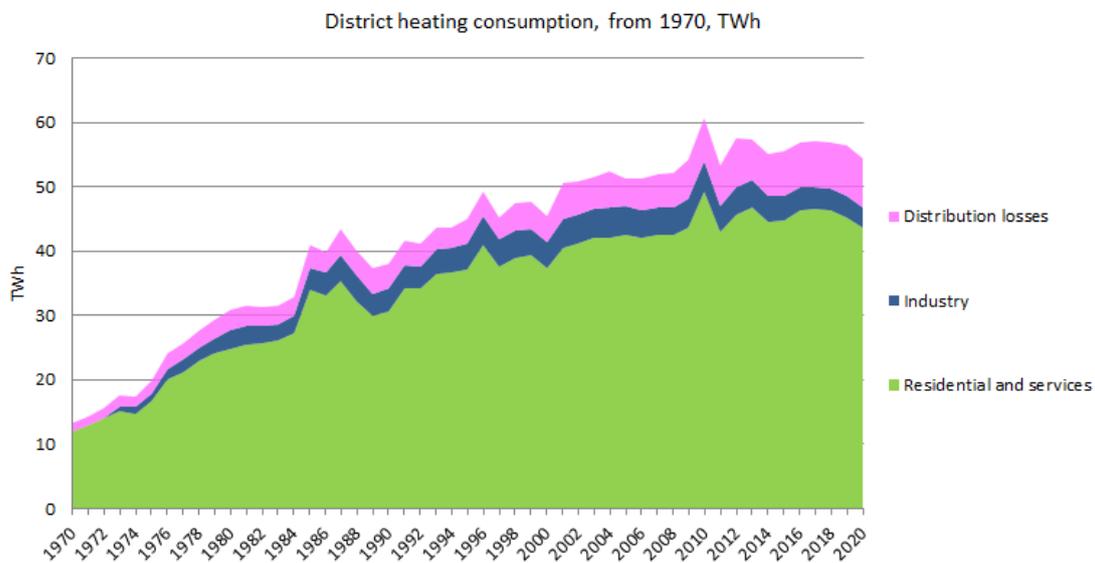


Figure 2.1: Consumption data for district heating between the years of 1970 to 2020 according to the Swedish Energy Agency[7]

In Sweden around 70% of the district heating energy comes from biofuels or waste heat, meanwhile less than 5% of the energy stems from fossil fuels. The DH in Sweden could therefore be considered as mostly renewable based.[7]

2. Theory

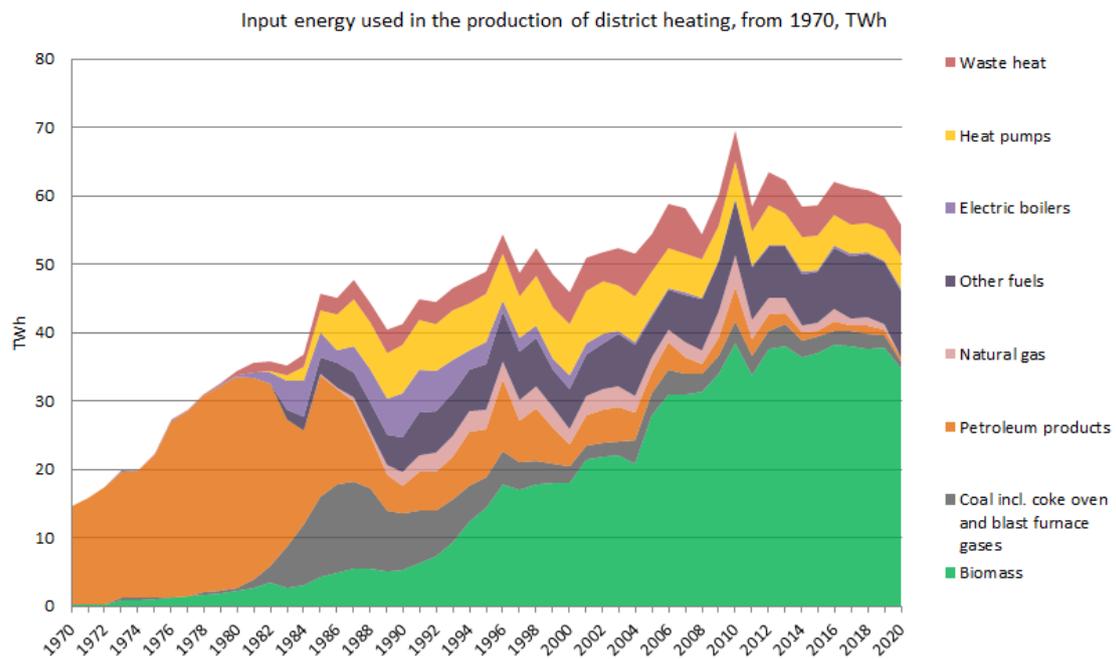


Figure 2.2: Input energy used in district heating in Sweden according to the Swedish Energy Agency[7]

2.1.1 Heating Market

The first District heating system (DHS) was introduced to Sweden in 1948 in Karlstad[4]. During the 20th century the amount of DHS grew and today around 55% of all heating stems from DH[4]. Although clearly the market leading technology DH has tough competition especially in the form of heat pumps. Heat pumps has two main users, multi-family dwellings and single family residential buildings. Although over 90% of multi-family dwellings are connected to a DHS around 13% of them has decided to install some kind of heat pump in order to have more control of their heat supply[4]. This poses a problem to DH companies as they lose revenue due to lowered use of DH.

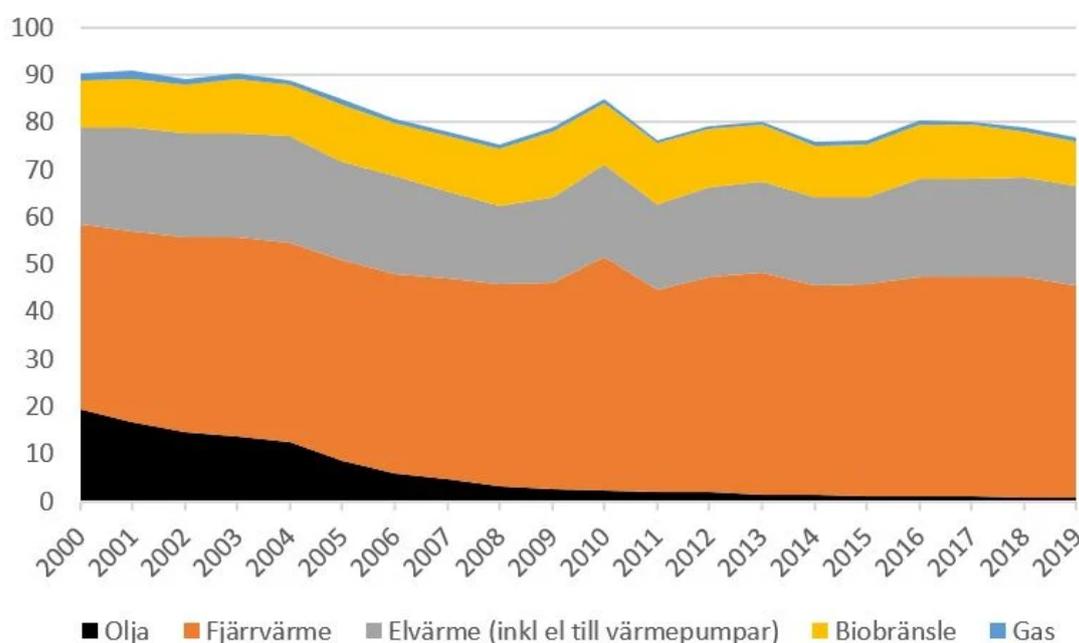


Figure 2.3: The share of different heat sources for heating in Sweden in the year 2019 according to the Swedish Energy Agency[8].

2.2 Pricing of DH

Historically DH companies have been owned by municipalities. Due to the Swedish Municipal Act these companies was therefor not allowed to set prices resulting in profits[4]. This changed in 1996 when, in conjunction with the electricity market deregulation, this clause in the Municipal act was removed and the pricing became market based[4]. There are however some weaknesses to this idea. In practice the DH companies have a natural monopoly on DH in their area that makes it difficult for customers to find alternative DH suppliers[5],[9],[10].

2.2.1 Price components

Fredriksen and Werner[11] and Rydén et. al[5] writes in their work about different price models used in the DH industry. They mention that these price models has different price components that the customer pays for depending on different aspects. To give a better understanding of the pricing of DH these will be presented in this section. According to [11] and [5] there are four components that are most commonly used in DH price models. These are a fixed component, an energy component, a power component and lastly a flow component

Fixed component

The fixed component is a yearly cost (SEK/year) that the customer pays monthly[11]. This cost is paid in order for the customer to be able to utilize the DH system. Since it is a fixed cost it also does not depend on the heat use of a building and is therefor a secure revenue stream for DH companies in times where the need for heating might be lower than expected and thus gives some financial security to the companies.

Energy component

The largest share of a DH customers total cost comes from the energy price component. The energy component is best explained as the price paid by the customer for the use of one unit of heat. It is often charged in (SEK/kWh) and is a variable cost. Most DH companies decides to vary the price of energy depending on season[11]. Often it is divided in to Winter, Spring/Fall and Summer. By having different prices for different seasons the price reflect the price of production and is therefor often higher during winter due to the increase of heat demand which leads to more expensive fuel being used[11].

Power component

Another component is the power component. The purpose of the power component is to cover the costs of production and distribution needed to deliver the heat to the customer and is often charged in SEK/kW[11]. If measured the price of the component is often determined based on the highest daily average load during the year before. This can give consumers an incentive to spread out their power demand which will benefit the system.

Flow component

The fourth and less commonly used component is the Flow or Return temperature. This component charges customers for the amount of water needed for the building to get the required energy. The price is given in SEK/m³. The component is often used in order to combat inefficient heat exchangers since the entire system becomes more inefficient if the return temperature is to high. It can be expressed as a price per volume flow or be directly linked to the return temperature of a building[11]. This price component gives an incentive to increase the energy efficiency in order to keep the costs down.

2.2.2 Nils Holgersson report

In order to combat the natural monopoly some interest organizations, such as Hyresgästföreningen Riksförbundet and Bostadsrätterna, has come together to create the Nils Holgersson report[12]. The report is published annually and presents price differences between DH networks among other things. One thing the report has presented is that the prices of utilities of multi residential buildings has increased more quickly than the customer price index (KPI) as shown in Figure 2.4

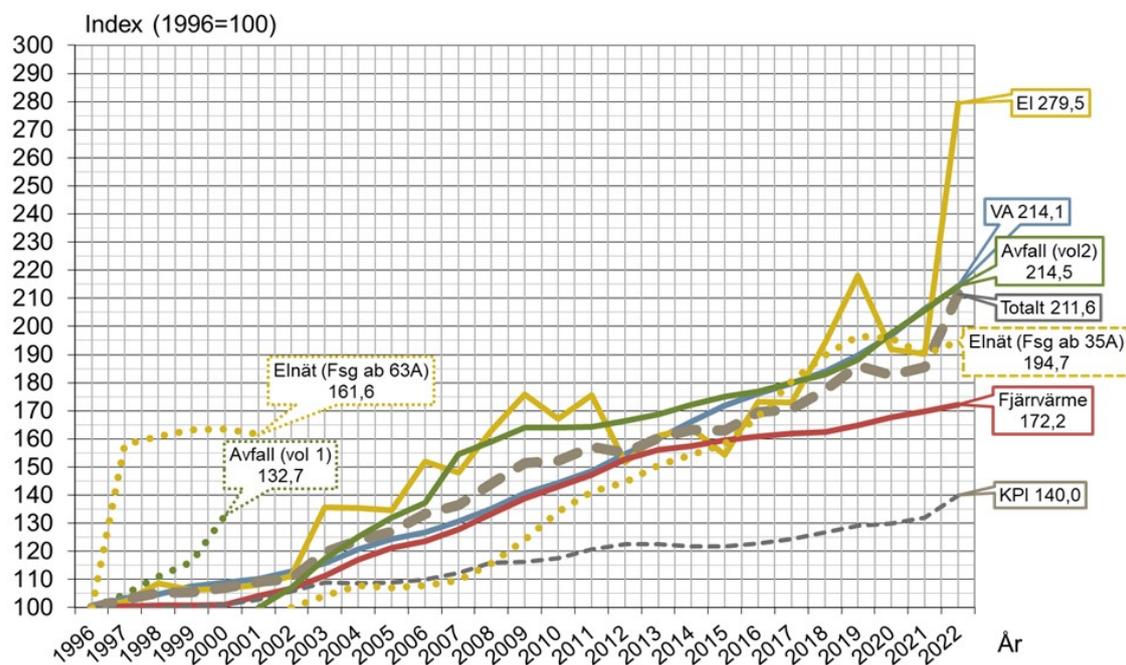


Figure 2.4: Price development of household utilities from 1996 to 2022 compared to the KPI according to the Nils Holgersson report[12]

With these reports the Nils Holgersson group wants to start discussions and debates about pricing which hopefully leads to price reductions.

2.2.3 Prisdialogen

Another project that acts in the interest of customers and tries to strengthen their position on the market. The organization does this by connecting customers with their DH company. The DH company then reports their price changes to Prisdialogen which then communicates them to the customer in order for them to give feedback on the changes. This makes it possible for both customers and DH companies to be satisfied with changes in price and a more stable, predictable and reasonable price level.[13]

2.3 District heating in Norway

The district heating sector in Norway is not as big as those of other Nordic countries with a share of 11% as of 2015[14]. The reason for the low share of district heating in Norway is the fact that historically the availability and affordability of electricity has been good enough to be used as a source of heating[14]. The largest customers of district heating is the service industry with a total share of 62% in 2015.

The pricing of district heating in Norway differs from that of Sweden. Due to the connections being partly mandatory for newer buildings there has been a mandatory limit on the price of DH. This limit means that the DH cannot be priced higher than the costs of alternative heating sources[14]. In reality this often means that the price of district heating can not be higher than that of electricity including taxes.

2.4 Price elasticity

Price elasticity is the measure of how consumption of a certain product changes with a change in price of said product. It is calculated as shown in Equation 2.1

$$Elasticity = \frac{\%change\ in\ consumption}{\%change\ in\ price} \quad (2.1)$$

A products demand is deemed to be elastic if the absolute value calculated from Equation 2.1 is > 1 and inelastic if < 1 [15]. If a products demand is elastic it means that a price increase can result in a loss of revenue due to the demand change being too large. The opposite is true for an inelastic product where the demand will decrease a bit but the average revenue will likely increase[15].

If a producer knows the price elasticity of their product they have a larger possibility to price their product correctly. It can also be applied before the release of a new product in order to have the correct manufacturing plan.[6]

2.4.1 Price elasticity of district heating

A literature study was performed in this thesis. The literature study first focused on finding information about the price elasticity of district heating. While searching for articles it became clear that this is a price elasticity of district heating is not examined as much as price elasticity of other energy systems such as electricity. This could be due to the fact that DH is not as common outside northern countries[2]. There are however, some articles that fill the criteria of examining the price elasticity. The results from these articles are quite unanimous in that district heating and energy in general is an inelastic product throughout the world. The specific number of elasticity does differ however. These numbers are presented in Figure 2.5.

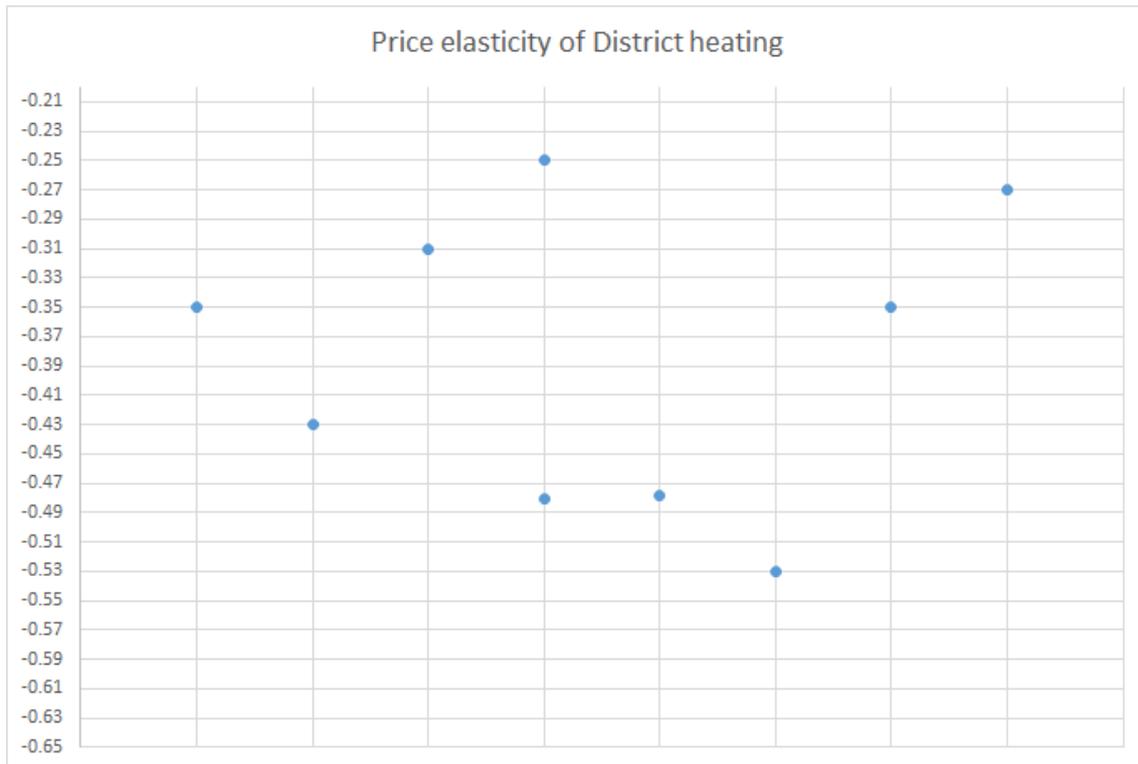


Figure 2.5: Elasticity of district heating found in the literature. The values are taken from left to right from [17],[18],[19],[10],[20],[21],[22] and [23]. When two dots are on the same vertical line there are two values given in the article.

The figure shows that the calculated price elasticity of district heating in literature is between -0.25 and -0.65. The figure also shows that different values are given by two articles. These articles look at the difference between the elasticity of single family residences and the elasticity of a multi family residences. The results of these articles both showed that the single family residences had a higher elasticity than those of multi family residences [10],[21]. The articles explain this by pointing to the fact that single family residences have access to other means of heating such as using firewood or installing heat pumps to a larger extent. Another reason according to Hellmer [10] is the fact that single houses have access to individual metering and are therefore able to react quicker to price fluctuations.

Another trend in literature was that the price elasticity seems to vary depending on education and income [24]. Where a higher income for a household would result in lower elasticity. This is not unexpected since a greater income allows for more wiggle room of costs and since the indoor temperature is important for everyday comfort it will not be the first thing that people with a higher income reduce in order to save money. According to Lim, Min and Yoo [20] however, an increased income will not mean much of an increase in energy use. They estimate that a one percent increase in income will result in a 0.033 percent increase in energy usage.

Income and the type of residence are not the only things that affect price elasticity of district heating however as time does as well. This is often talked about in

literature as short-run elasticity and long-run elasticity. Short-run elasticity is the immediate respond to the price change where the customer has not been able to find a substitute. The long-run elasticity is the elasticity when looking over a longer time period where it can be assumed the customer would have had enough time to evaluate options to procure the product by other means. Lim, Kim and Yoo[25] takes a look at the elasticity of the demand for residential heating from DH in Korea. They present a short-run price elasticity of -0.7 for the period 1988-2013 while they found that the long-run elasticity was -1.253. Both of these numbers are higher than those presented in Figure 2.5. The long-run elasticity even suggests that the use of district heating will decrease at such a rate in relation to price increase that the income of the DH company delivering the heat would lower than before the price increase. Trotta, Hansen and Sommer[21] also looks at the long-run elasticity and they find it to be -0.638 which is lower than both the short- and long-run elasticities found in [25] and more in line to what is shown in Figure 2.5. Even though the elasticities are quite different the trend still applies that DH customers are more responsive if the price increase is long lasting.

2.4.2 Price elasticity of electricity

The price elasticity of electricity was also examined as some articles put the elasticity of space heating (heat pumps and or DH) against the elasticity of electricity to examine the different impacts on the entire energy system. Schulte and Heindl[26] examined the price elasticity of the two on the German market and found that the elasticity of electricity and space heating is -0.431 and -0.5008 respectively. According to Ghalwash[18] the elasticity of electricity is -0.61 while the elasticity for DH is -0.43 as shown in Figure 2.5. It is quite interesting that the two articles estimates the elasticity of the two energy carriers as they both can fill the same function but the elasticity of the demand is different. The main reason for this is probably that they are acting on different markets where electricity provides option in terms of what company supplies the electricity while the district heating is more bound to the supplier due to the nature of the DH market. Schulte and Heindl[26] looks at the elasticity in Germany while Ghalwash[18] looks at the Swedish energy system. Sweden has an overall colder climate than Germany which could mean that the need for heat is larger there than that of Germany. Customers in Sweden are therefor less likely to be willing to lessen their consumption of heat than the customers of Germany.

2.4.2.1 Use of Price elasticity

The findings of explicit use of price elasticity for district heating in literature is quite limited. The closest examples of this is demand response. The main reason for price elasticity not being taken into account while setting prices seems to be due to how the existing price models work. [27],[28] and [29] all examines the DH price models and points out some of their flaws and talks about how they are not giving incentives to users to care about their energy usage. The articles also talk about that new price models should be tested in order to see how the price models could

give more incentive to react to price changes.

Another way to use price elasticity is the way that energy companies are utilizing it in the electricity market. In Japan after the earthquake resulting in the Fukushima disaster utilities examined how the price of electricity could be used in order to lower demand during peak hours[30]. There the energy companies announced prices of electricity an hour or a day ahead to larger customers. The price was significantly higher during peak demand hours which then gave incentive to consumers to not use electricity in order to save money[30]. This is also visible in the current energy crisis where the Swedish electricity price reached its all time high in 2022[31] and the average prices has increased substantially[32].

There are also cases in the electricity market where the price instead is used to give incentive for customers to use more electricity[33]. In cases where the demand is low but the production is high due to for example a large production from wind turbines, it is better to pay users to use the electricity instead of having to turn larger non-intermittent sources of due to their startup time[33]. This also happens as there is no existing storage of energy that is cheap enough in order to justify using[33].

2.5 Price elasticity modeling

Price elasticity modelling could be important for a DH company when setting prices. Generally a DH company sets a budget for both costs and income where the goal is that their income covers their costs. Often the increase in price is 2% [13] to cover raising costs in salaries and fuel. Sometimes however, there is a larger investment happening or some form of maintenance with a high cost which could result in a larger price increase. This is where price elasticity may become a factor to account for. Since the DH company is not really aware of what the price elasticity is they can not be quite sure what the response to the price change will be. This means that there is an uncertainty if the costs will be covered by the income.

When modeling for price elasticity it is important to use normalized energy use. This is to remove the weather dependency from the network in order to find the expected energy use without knowing the weather. If normalized energy values are not used there will be irregularities such as unusual cold or warm weather which can skew the results.

As a basis for the calculations in this thesis the normalized years calculated by Utilifeed's algorithm EnergyPredict is used. This software takes historical weather and energy data and creates models that accurately predicts the energy use for each building for any weather scenario based on the measured use. The algorithm can for example create model based on the energy use and weather in 2022 and calculate what the energy use would have been for the same building in 2000 to 2022. The average energy use of this period is then taken as the normalized energy use for a building or for the entire DH network. As the expected energy use is

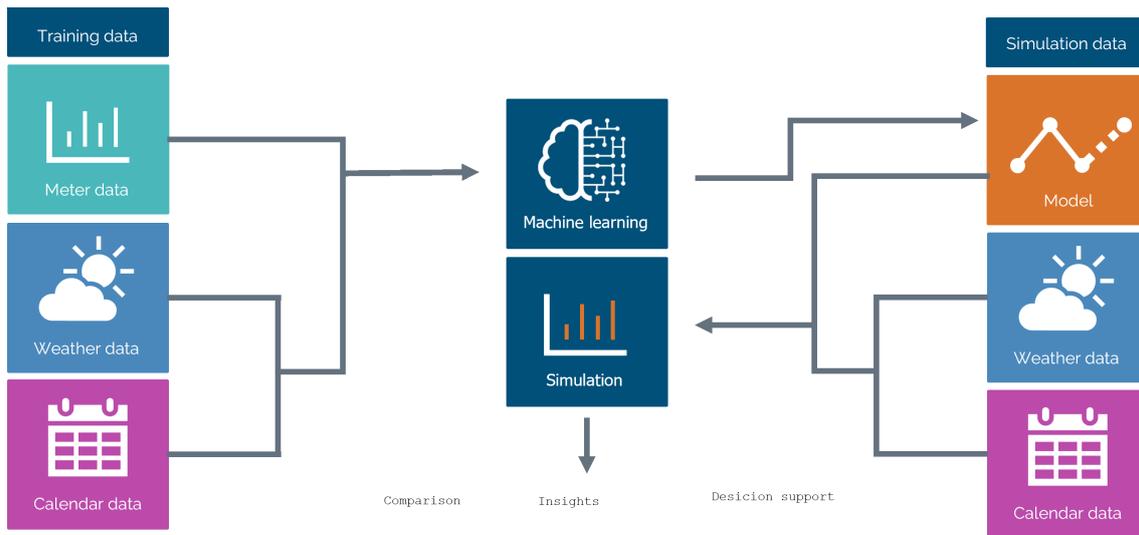


Figure 2.6: Overview of Utilifeed’s machine learning pricing platform

pre-calculated it does not show the reduction in energy use. This thesis therefore tries different methods of implementation to evaluate the difference of simply using elasticity values found in literature versus calculating the historical elasticity for the network in order to see the value of more advanced calculations versus simpler.

In this project weather data is taken from the Swedish Meteorological and Hydrological Institute (SMHI) and goes back twenty years. The energy and price data used in the project is taken from a real life network in order for the project to give a better understanding of real life elasticity.

3

Methods

There were three main methods used in this thesis. The first one was a literature review where information about the district heating market, its pricing, price elasticity and use was researched. Secondly an interview study about the use of price elasticity in the industry was conducted with two employees at different Nordic district heating companies. Lastly a method of implementation of price elasticity was evaluated and tested in order to see its relevancy and function in the industry. The implementation is done on two networks, one located in Sweden and one located in Norway. One key difference between the Swedish and the Norwegian network is the fact that no single family houses are included in the Norwegian network due to the lack of high resolution data available. Instead the Norwegian network includes a Multi Family residential house with Individual Meters (MFIM) to see the impact this makes compared to the non-individual metering done in most multi family residences.

3.1 Literature review

The literature review started with setting up criterion for what kind of articles would be included in the review. These criterion is shown in the list below:

- Discussing pricing of energy
- Discussing district heating
- Discussing price elasticity
- Discussing price elasticity of district heating

In order to find articles the search engine of the Chalmers library was used. This search engine searches through a total of 176 different databases for articles and journals[16]. These databases include Google Scholar, Scifinder, Scopus and ScienceDirect. The search words that used during the study is shown in the list below:

- Price elasticity of district heating
- Price elasticity use district heating
- Price elasticity use energy
- Price elasticity of energy
- Use of price elasticity in district heating
- Elasticity use energy
- Load shifting district heating
- Sensitivity district heating
- district heating demand sensitivity
- district heating price sensitivity

- use of price elasticity
- use of price elasticity district heating

Search engines was not the only method used to find articles. Some articles was found while reading as articles referenced to previous work that had examined the area which could give a deeper understanding of the subject.

3.2 Interview study

In order to get the DH industry view on price elasticity interviews where conducted. In total 2 interviews was conducted with different company representatives. The questions asked are listed below:

- Do you know what price elasticity is?
- Do you know in what range the price elasticity for district heating is?
- Is your company using price elasticity today?
- If so, how?
- Do you think your company would be interested to use price elasticity in the future?
- How would you want to use it?
- More revenue? Incentive for customers to make their energy use more efficient? Peak shaving?

The goal for these questions was as stated above to get an industry perspective on price elasticity. In particular the perspective of use of price elasticity was sought in order to know what current and future applications could possibly look like.

3.3 Models

Three different models was used during the project as listed below.

- Simple literature model
- Advanced literature model
- Historical model

The simple literature model will use values found in literature to model changes in energy use. This model will use the same three literature values for the entire network. The advanced literature model will like the simple literature model use elasticity values found in literature. The advanced literature model will however use different elasticity values for different customer groups divided by what kind of building it is. Lastly the historical model will first calculate the historical elasticity in the network and then use the elasticity to model the energy use in a normalized year. The normalized energy use represents the most likely future energy use and is often used by DH companies when performing investment analysis, budgets, and planning. The energy use modelling will use the average price increase for the network in order to give a representation of how the elasticity might impact the energy use. For all models a cost for the customers will be calculated for the entire time period examined, 2016-2022. This cost is calculated as seen in Equation 3.1

$$Cost = \sum_i E_{use,i} * P_i \quad (3.1)$$

Where $E_{use,i}$ is the energy use and P_i is the price of energy. The costs will then be presented in tables.

3.3.1 Simple literature model

The first and simplest model is a model where three different cases of price elasticity are presented. The cases are low, medium and high elasticity. The elasticities was taken from literature and was evenly distributed from the interval shown in Figure 2.5. The resulting elasticities are shown in Table 3.1. These elasticities are then multiplied with the energy calculated by EnergyPredict, as shown in Equation 3.2 and thus gives three different possible energy uses depending on the elasticity.

$$Q_{use} = e * Q_{predict} \quad (3.2)$$

where Q_{use} is the resulting energy use after elasticity is accounted for, e is the elasticity and $Q_{predict}$ is the energy use calculated by the algorithm.

Table 3.1: Table showing the different elasticity values for the three different levels.

Elasticity	
Low	0.25
Medium	0.45
High	0.7

Table 3.1 shows the estimation levels for price elasticity for the network. This elasticity is the same for the entire network and is not related to specific price changes during days or months.

This model could be used in a way where the DH company assumes one or more of the elasticities found in literature and simply uses Equation 3.2 to estimate future energy use when setting new prices for their DH network.

3.3.2 Advanced literature model

The second model did like the first model use elasticity taken from literature with low, medium and high elasticity cases. In this model however, there was a difference made between different energy users in the network. These users was categorized in to four different categories. These are industries, commercial, multifamily residential and single-family houses. The reason for dividing energy uses into different categories are several. The first reason is that the amount of energy used varies substantially between these categories where the largest users are industrial and commercial buildings. The second reason is that the pattern of energy use varies as well where energy use in residential buildings has clear peaks and valleys of use compared to industry buildings where there is a more constant need. The third reason is that the elasticity is also different depending on what type of building it is according to the literature as discussed in section 2.4. Although literature is clear that the elasticity is different between these categories there are no given values of

elasticity and thus the elasticities were estimated to be as shown in Table 3.2 with the literature study made before hand in mind.

Table 3.2: Table showing the different elasticity values for the three different levels for the different building categories.

Elasticity	Industry	Multifamily Residence	Single-family House
Low	0.35	0.1	0.25
Medium	0.5	0.25	0.45
High	0.7	0.45	0.55

Table 3.2 shows the estimated elasticities for the different categories. Like model 1 the elasticities is not corresponding to certain events during a year.

3.3.3 Historical model

For the third model a similar model to that used by Faria, Corsi and Vale[34] is applied. They use historical data to calculate elasticity of electricity and use it to predict the behavior of customers during periods of increased prices. With the equations shown in Equation 3.3 and Equation 3.4 new energy use was calculated for the same network used in model 1 and 2 but this time with an elasticity that is historically dependant.

$$e = \frac{\Delta Q P}{\Delta P Q} \quad (3.3)$$

where e is the calculated elasticity, ΔQ is the change in energy between two chosen time steps, ΔP is the change in price between two chosen time steps, Q is the energy in the chosen time step and P is the price in the chosen time step.

$$Q_{new} = eQ_{old} \quad (3.4)$$

Where Q_{new} is the new energy use after elasticity is taken in to account, Q_{old} is the expected energy before elasticity is taken into account.

This method allows the historical data of energy use in relation to price change to be used as an estimate of how the future elasticity of energy will look as well. The method will first be applied on a network wide level where users are not differentiated. The fourth model will as stated above also use the method used in the third model. The fourth model will however use the same differentiation used in model 2 in order to see what the impact on energy demand could look like if using historical data for different customers.

3.4 How does price of electricity affect DH usage?

During the interview study a question from a DH company arose. Does the price of electricity affect the usage of district heating? To examine this, historical data taken from a real DH network was compared with electricity prices of the same period. The energy use were plotted with the electricity prices in the same graph to show if

there was any easily visible correlation. In order to verify this the correlation factor is calculated for the two variables by Equation 3.5

$$\rho_{x,y} = \frac{cov(x,y)}{\sigma_x \sigma_y} \quad (3.5)$$

where $\rho_{x,y}$ is the correlation factor, $cov(x,y)$ is the covariance of the energy use and the electricity prices and σ_x, σ_y is the standard deviation of the energy use and electricity prices. If the coefficient absolute value is between 1-0.7 it is considered that the variables have a strong correlation and if the coefficient has an absolute value of 0.3-0 it is considered to be low or no correlation.

4

Results and Discussion

In this section the results from the different parts of the thesis will be presented and discussed. First the results of the interview study is presented. Lastly, the results of the method implementation will be presented and discussed. One difference between the Norwegian network and the Swedish network is the fact that the average price increase is 31% in Norway while the average Swedish increase is around 2% for the period 2018-2022. This could make the customers more elastic in their behaviour.

4.1 Interview Study

The interview study provided somewhat expected results. Companies that were interviewed are in the present not taking price elasticity into account while setting their prices. They are however interested in the future use of price elasticity in order to understand customer behavior and being able to easier predict changes in energy use in order to secure income.

During the interviews there where some questions from the DH companies as well. One of these questions was if there is a correlation between the use of district heating increasing as a result of high electricity prices which was found as an interesting question and was investigated. The results from this investigation is presented below in subsection 4.3.5.

Another question that arose was the difference that individual metering does in multi family buildings versus when not having it. This is also investigated and presented below in the price elasticity modeling.

4.2 Swedish Network

In this section the results for the Swedish network will be presented, starting with the simple literature model, followed by the advanced literature model and ending with the model using historical elasticity. The Swedish network had an average price increase of 2% per year. In the calculations it is therefor assumed that the price would increase by 2% each year.

4.2.1 Actual energy use

In order to show the importance of using normalized energy use during price elasticity modeling, the actual energy use measured was plotted and is shown in Figure 4.1, Figure 4.2 and Figure 4.3 for single family houses, industry buildings and multi family buildings respectively.

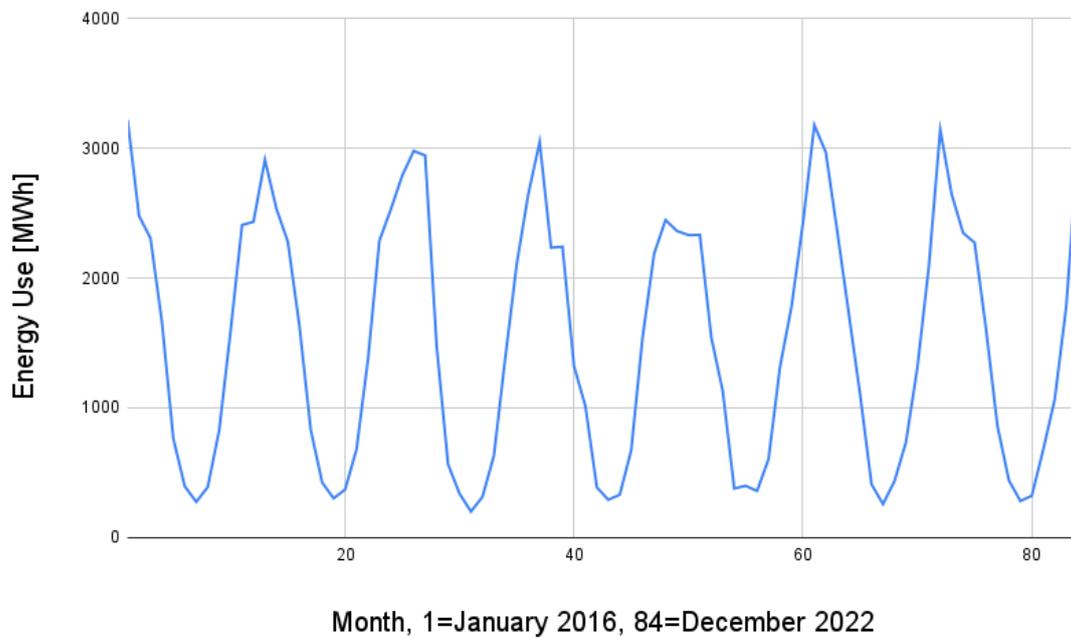


Figure 4.1: Graph showing the measured energy use for single family houses in the Swedish network.

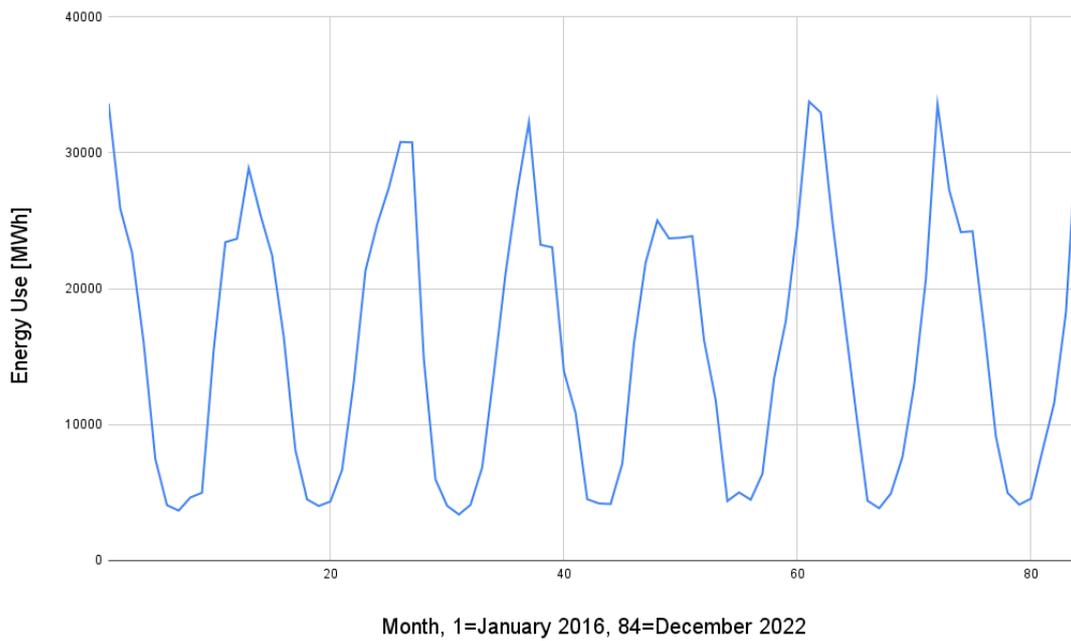


Figure 4.2: Graph showing the measured energy use for industry buildings in the Swedish network.

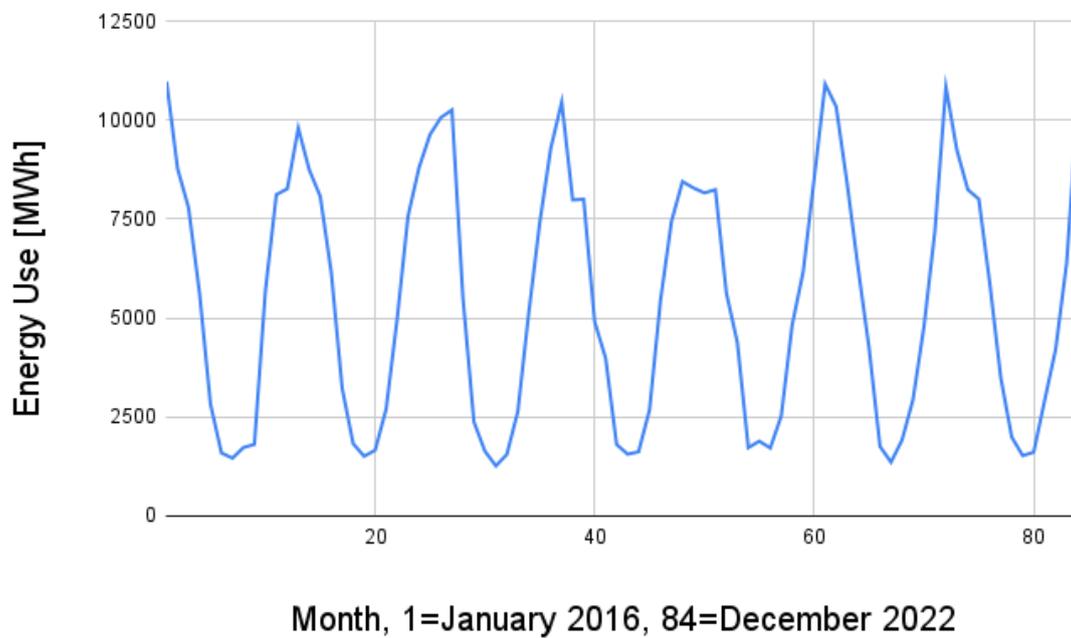


Figure 4.3: Graph showing the measured energy use for multi family buildings in the Swedish network.

In all figures one can see that there is a drop in energy use around month 48-50 which corresponds to the December 2019 and January-February 2020. This time

period was one of the mildest winters in a long time with temperature as high as 12.1°C during January according to SMHI[35]. If one would try to calculate the price elasticity with this data the elasticity would be overestimated during 2020 as the lower energy use likely stems from the mild winter rather than from that the price was increased.

4.2.2 Simple literature elasticity in Sweden

The simple literature model uses the values of elasticity as shown in Table 3.1. It multiplies the average price increase with the elasticity and then multiplies that with the energy use to give the change of energy use.

Figure 4.4 shows what the potential difference in energy use of single family houses could look like if price elasticity is used in predicting energy use for normalized energy. The elasticities used in this case is taken from a span of different elasticities found during the literature study.

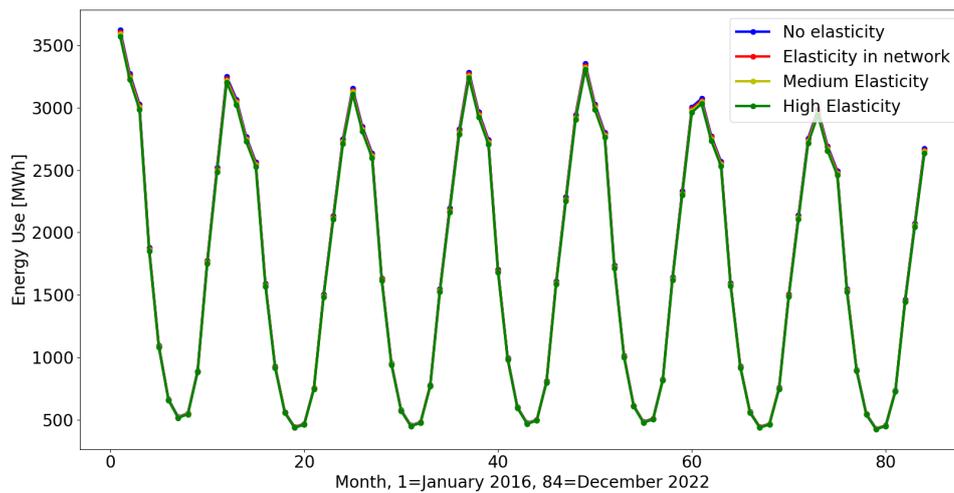


Figure 4.4: Graph showing the difference in energy use for normalized energy for single family houses depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.1. The price increase for the network is assumed to be 2% per year.

It is shown in Figure 4.4 that the energy difference, given the 2% price increase, will be quite small, around 1% average difference, which is to be expected since the elasticities found in literature points to district heating having an inelastic demand.

Figure 4.5 shows the potential energy use changes for industrial buildings during a normal year.

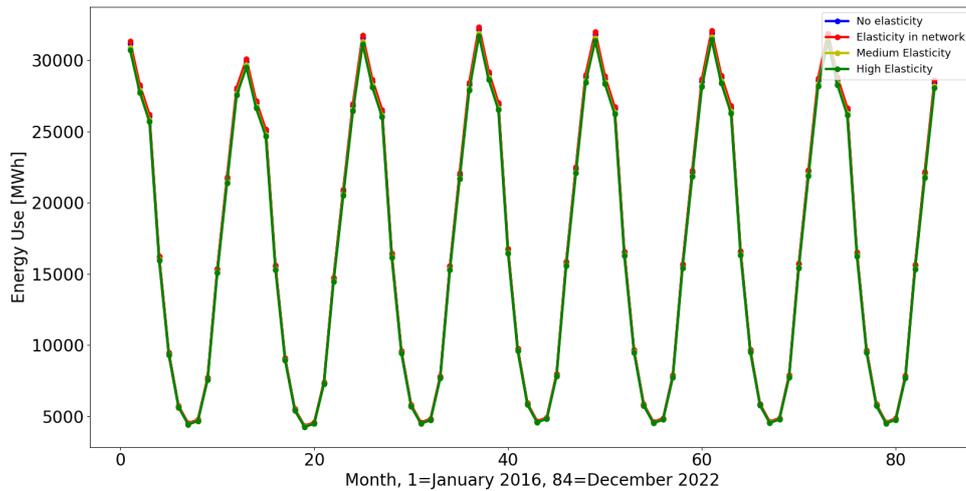


Figure 4.5: Graph showing the difference in energy use for normalized energy for industry buildings depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.1. The price increase for the network is assumed to be 2% per year.

In this figure similar results to those of Figure 4.4 can be seen where the energy use changes a quite small margin.

Results like these are also visible in Figure 4.6 where the potential energy use changes for multi family buildings is shown.

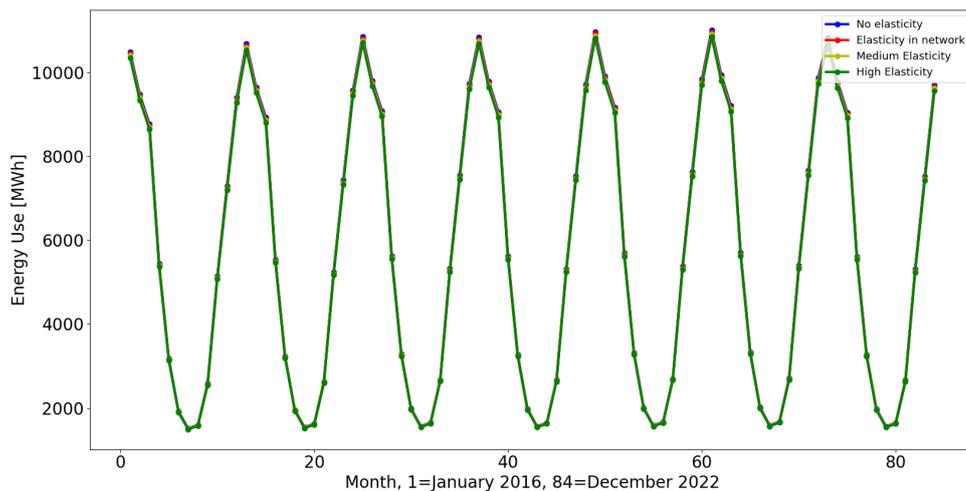


Figure 4.6: Graph showing the difference in energy use for normalized energy for multi family houses depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.1. The price increase for the network is assumed to be 2% per year.

Examining changes in energy use could be interesting in order to see how consumers act in cases of price changes, which often tends to be of the increasing kind. It is also interesting to look at what this means for district heating companies producing the energy. The effect of these changes in energy use is shown in Table 4.1. The table shows the different costs depending on what kind of elasticity is applied in the calculations and also shows what the original cost without elasticity is.

Table 4.1: Table showing the costs for the three different building categories as well as the total cost for the network depending on assumed elasticity for the time period of 2016-2022.

Elasticity /Income per customer	Single House [MSEK]	Industry [MSEK]	Multi Family Residence [MSEK]	Total [MSEK]
None	82.27	488.96	167.97	739.20
Low	81.86	486.52	167.12	735.50
Medium	81.53	484.56	166.46	732.54
High	81.12	482.11	165.62	728.85

It stands to reason that the income for the production company will decrease somewhat due to a lesser amount of energy being consumed. In the table it is shown that Industry is by far the largest customer group cost wise in the network and also has the largest quantity of change in cost. Assuming the highest found elasticity in literature the cost difference would be around 10 million SEK. All in all the difference in cost is quite small and is at a maximum of around 2%.

4.2.3 Advanced literature elasticity in Sweden

The advanced literature model uses the values of elasticity as shown in Table 3.2. It multiplies the average price increase with the elasticity and then multiplies that with the energy use to give the change of energy use. The advanced model also makes a difference on which type of customer it is that is consuming the heat and given that assigns different elasticity values.

Figure 4.7 shows the different cases of energy use depending on the assumed elasticity of single family houses.

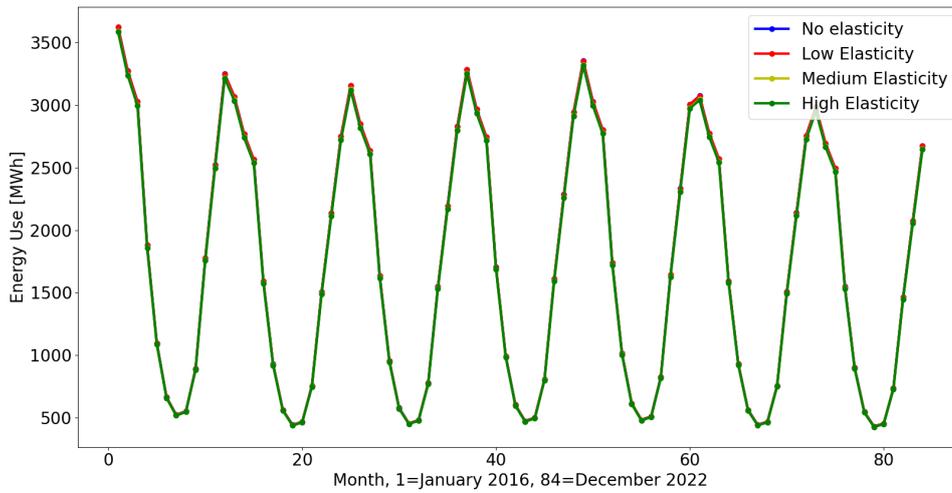


Figure 4.7: Graph showing the difference in energy use for normalized energy for single family houses depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.2. The price increase for the network is assumed to be 2% per year.

The figure shows that similarly to in Figure 4.4 the change in energy use is small.

For the energy change of industrial buildings one can look at Figure 4.8.

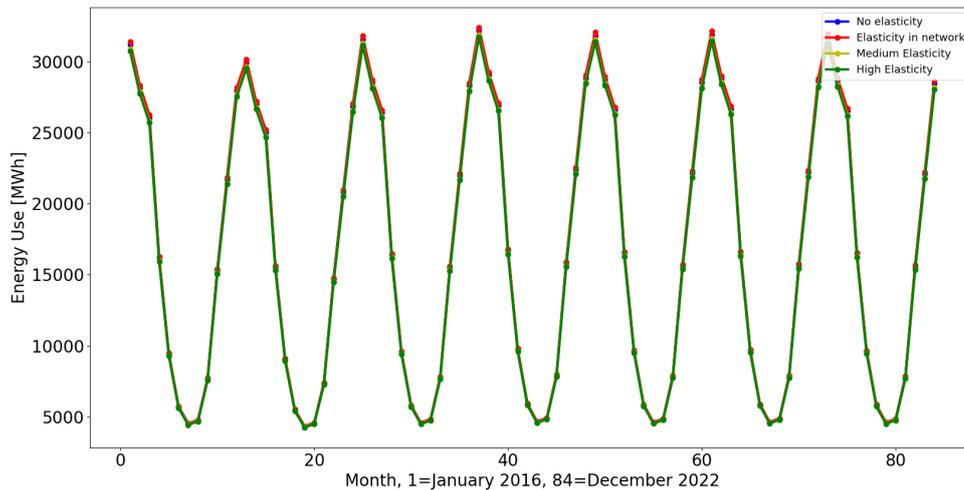


Figure 4.8: Graph showing the difference in energy use for normalized energy for industry depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.2. The price increase for the network is assumed to be 2% per year.

The figure shows that as in previous figures the change in energy use is limited with

4. Results and Discussion

very small expected differences.

Lastly, Figure 4.9 shows the energy for multi-family buildings.

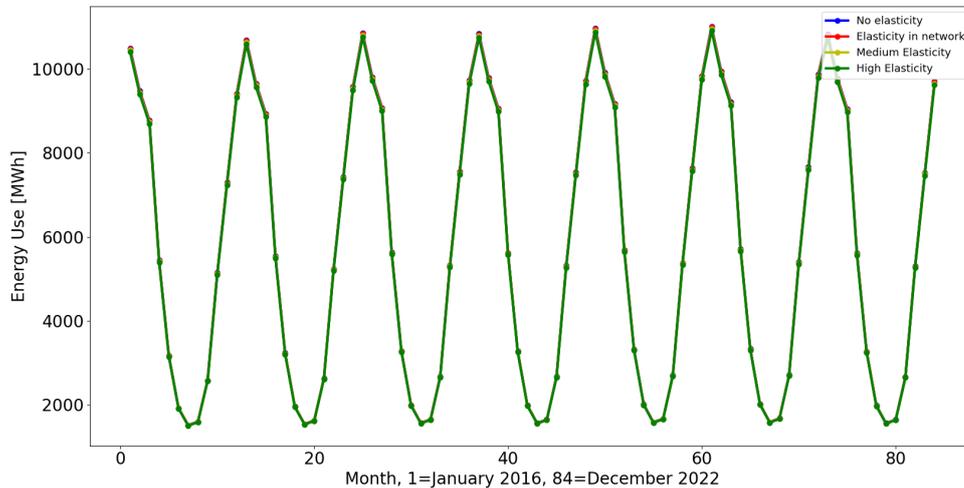


Figure 4.9: Graph showing the difference in energy use for normalized energy for multi family houses depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.2. The price increase for the network is assumed to be 2% per year.

The total cost for the network and for the individual customer groups are shown in Table 4.2.

Table 4.2: Table showing the cost for the three different building categories as well as the total cost for the network depending on assumed elasticity for the time period of 2016-2022.

Elasticity /Income per customer	Single House [MSEK]	Industry [MSEK]	Multi Family Residence [MSEK]	Total [MSEK]
None	82.27	488.96	167.97	739.20
Low	81.87	485.54	167.63	735.03
Medium	81.53	483.58	167.12	732.24
High	81.36	482.11	166.46	729.93

The total income differs little against that of the first model but is a little higher. This is probably due to the fact that the assumed elasticities of the Multi family residences are quite low. The elasticities for single houses and industries are quite similar to those of model 1 and therefore has a lower impact on the differences between the two models. One conclusion that can be drawn from comparing the two models is that the importance of assuming an elasticity for the entire network versus assuming a specific elasticity for a customer group is quite small and the results differs quite little when based on literature.

4.2.4 Historical elasticity in Sweden

The historical model calculates the historical elasticity by using Equation 3.3. Then it multiplies the average price increase with the elasticity and then multiplies that with the energy use to give the change of energy use.

The price changes in the Swedish network has historically been rather small. As mentioned before the average increase in price was around 2%. The changes are also shown in Figure 4.10.



Figure 4.10: Graph of relative price changes for DH in the Swedish network during the years 2018-2022.

Table 4.3 shows the average elasticity of the network between the years 2018 and 2022. The reason for not looking at 2016 to 2022 is due to the lack of information of prices of the chosen network before the year of 2018.

Table 4.3: Table showing the average historical elasticity for the network from the year 2018 to the year 2022.

	Single House	Industry	Multi Family Residence
Elasticity	-0.0169	0.000562	-0.000581

The table shows that the historical elasticity in the network is lower than what was estimated in literature. From literature it appeared that the industry customers would be the most sensitive to changes in prices. However, as shown in Table 4.3 the industry customer group is actually suggested to be very slightly increasing their energy use with an increase in price. The elasticity values for the industry and multi family buildings are low enough to round it to zero. Single houses however shows an elasticity that is much lower than is expected when reading the existing literature. This indicates that this group of customers are more prone to change

their energy use than the other two, the amount of change is however quite small and will probably not affect the district heating producer very much.

Figure 4.11 shows the price elasticity for each customer group comparing the month of the current year with the same month for the previous year.

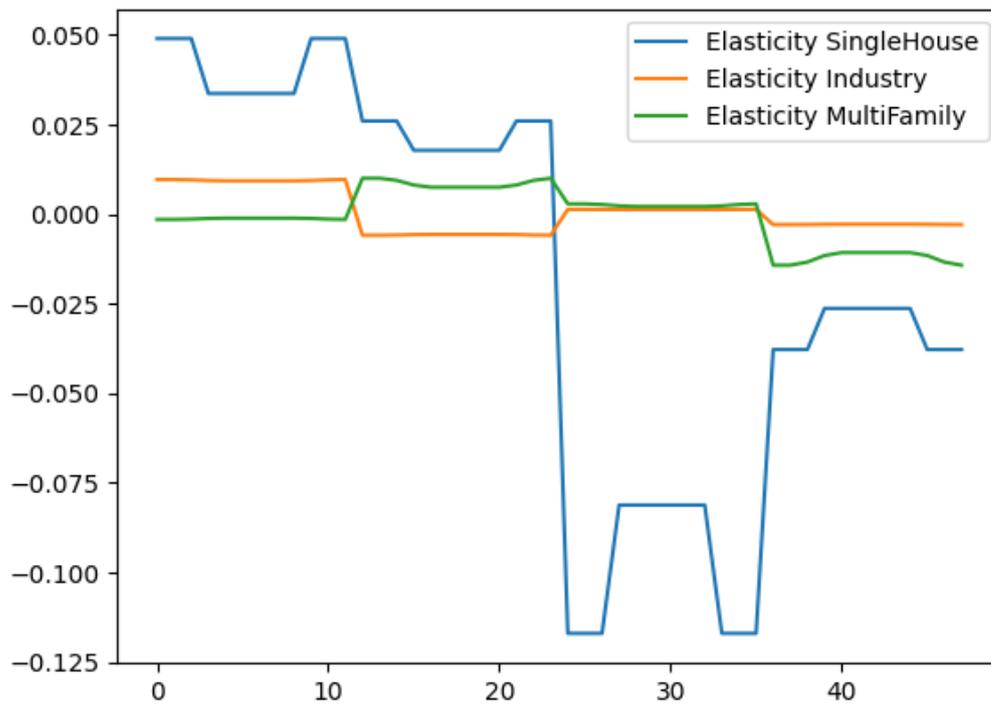


Figure 4.11: Graph of calculated elasticity between current month and the same month the previous year for single family houses, industry buildings and multi family residential.

The figure shows the elasticity month for month. For all three there is a theme with "sections" of different elasticities most notable in single house category between 2020 and 2022 where the negative elasticity indicates a decrease in energy use in response to raised prices. This can be connected to the prices given by the DH company, where in 2018 and 2019 the only price changes was an increase to the fixed cost of being connected to the network which means that the customers will not get an incentive to use less energy as the fixed cost is not affected by energy used. For the industry and multi family residences it can be seen that the energy use seem to be almost unchanged even though price increases are made.

Applying the average elasticities, found in Table 4.3, to the energy data it will be possible to see what the energy change could be for a normal year in the case of a price increase.

Figure 4.12 shows the energy for single houses with the elasticity found historically.

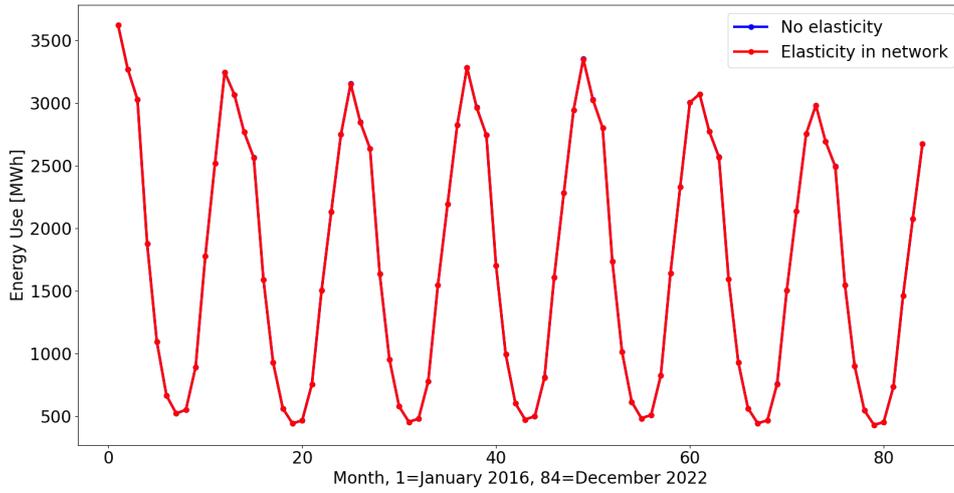


Figure 4.12: Graph showing the difference in energy use for normalized energy for single family houses depending on the assumed elasticity. The elasticity used is the ones shown in Table 4.3. The price increase for the network is assumed to be 2% per year.

As seen in the figure the energy change is minimal when taking the historical elasticity. This is not unexpected since the elasticity was shown to be low in Table 4.3. In Figure 4.13 the energy change to the industry customer group is shown with the historical elasticity.

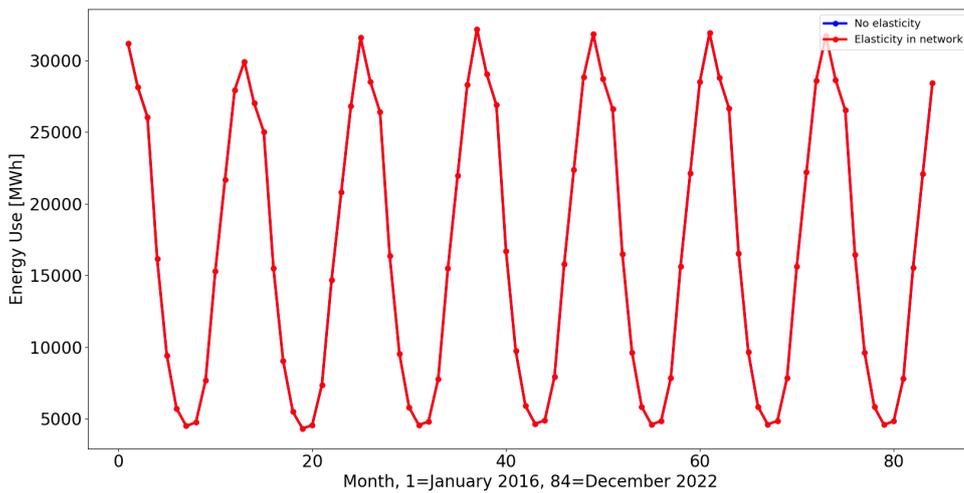


Figure 4.13: Graph showing the difference in energy use for normalized energy for industry buildings depending on the assumed elasticity. The elasticity used is the ones shown in Table 4.3. The price increase for the network is assumed to be 2% per year.

For the industry group we get a very slight increase in energy use due to the fact

that the elasticity is slightly positive.

For multi residential houses the energy change is shown in Figure 4.9.

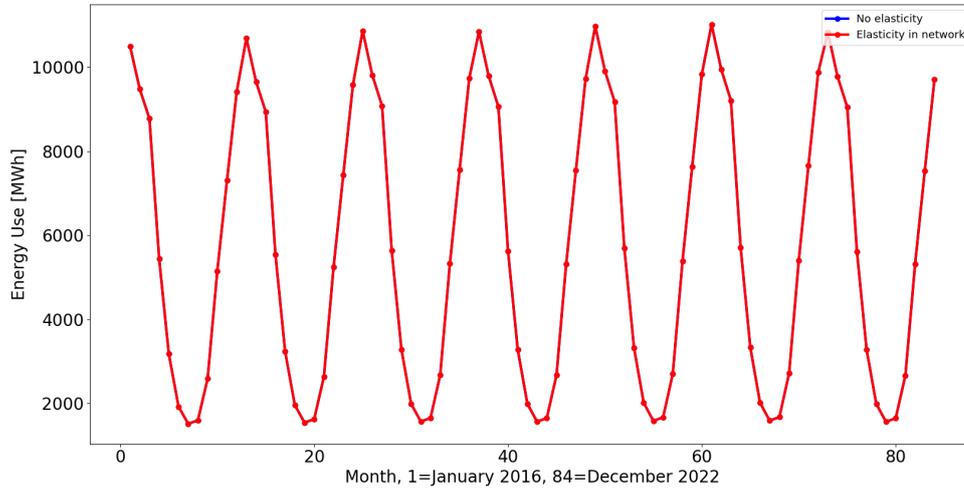


Figure 4.14: Graph showing the difference in energy use for normalized energy for multi family houses depending on the assumed elasticity. The elasticity used is the ones shown in Table 4.3. The price increase for the network is assumed to be 2% per year.

As in previous figures in this section the energy use changes is small and hard to distinguish. This is not unexpected due to the low elasticity historically shown in the network. The resulting cost changes from the historical elasticity is shown in Table 4.4.

Table 4.4: Table showing the costs for the three different building categories as well as the total cost for the network depending on if historical elasticity is used for the time period of 2016-2022.

Elasticity /Income per customer	Single House [MSEK]	Industry [MSEK]	Multi Family Residence [MSEK]	Total [MSEK]
None	82.27	488.96	167.97	739.20
Historical Elasticity	82.24	488.96	167.97	739.17

As can be seen in the table the income changes are minimal with the only visible change being the income from the single house customer group. This can be attributed to the fact that the single house customer group is the only group that had an elasticity above 0.01.

4.3 Norwegian Network

In this section the results for the Norwegian network will be presented, starting with the simple literature model, followed by the advanced literature model and ending with the model using historical elasticity. For each model there will also be an examination of the difference between having an individual meter in a multi family house versus not having it. The average price increase in the Norwegian network was 31% each year for the period of 2016-2022. This is the assumed price increase used in the models for the Norwegian network contrary to the 2% used in the Swedish network.

4.3.1 Actual energy use

Similar to the Swedish network the normalized energy use differs contrary to the measured energy use as shown in Figure 4.15

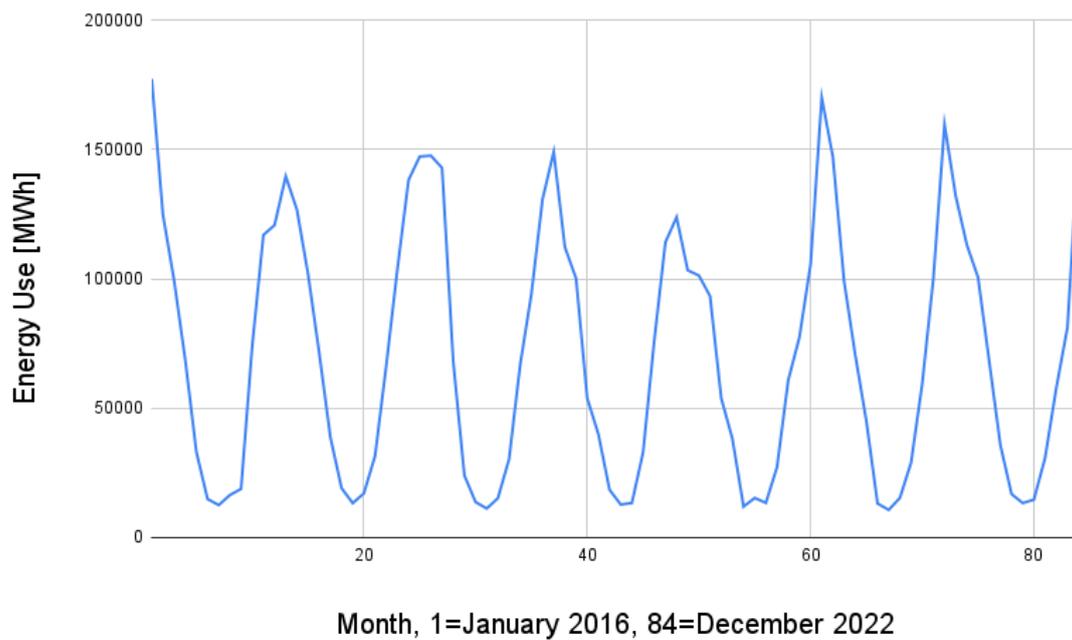


Figure 4.15: Graph showing the measured energy use for industry buildings in the Norwegian network.

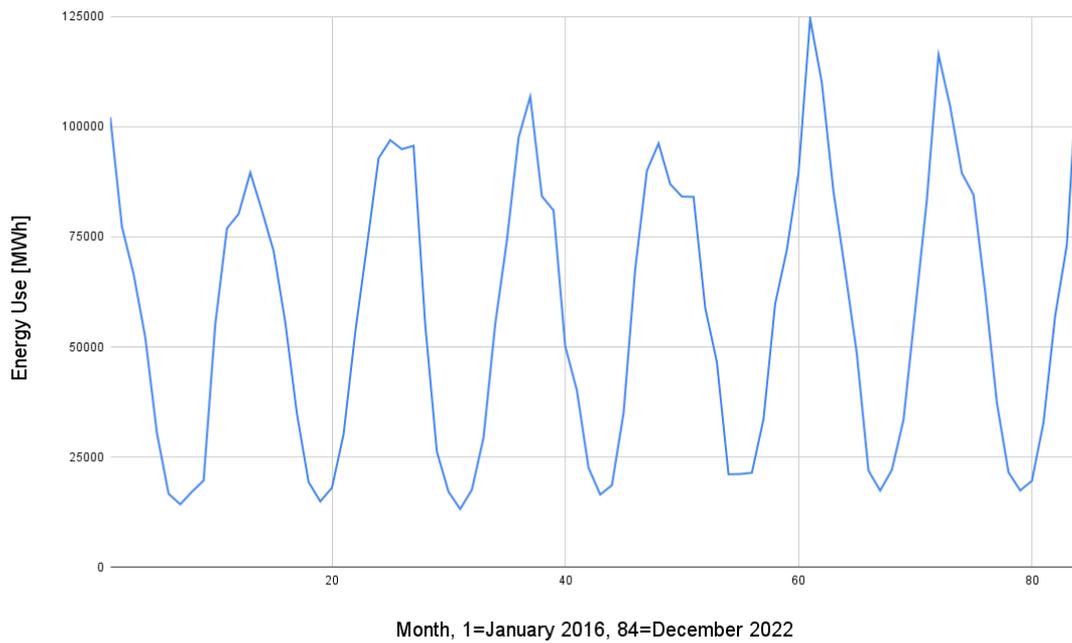


Figure 4.16: Graph showing the measured energy use for multi family buildings in the Norwegian network.

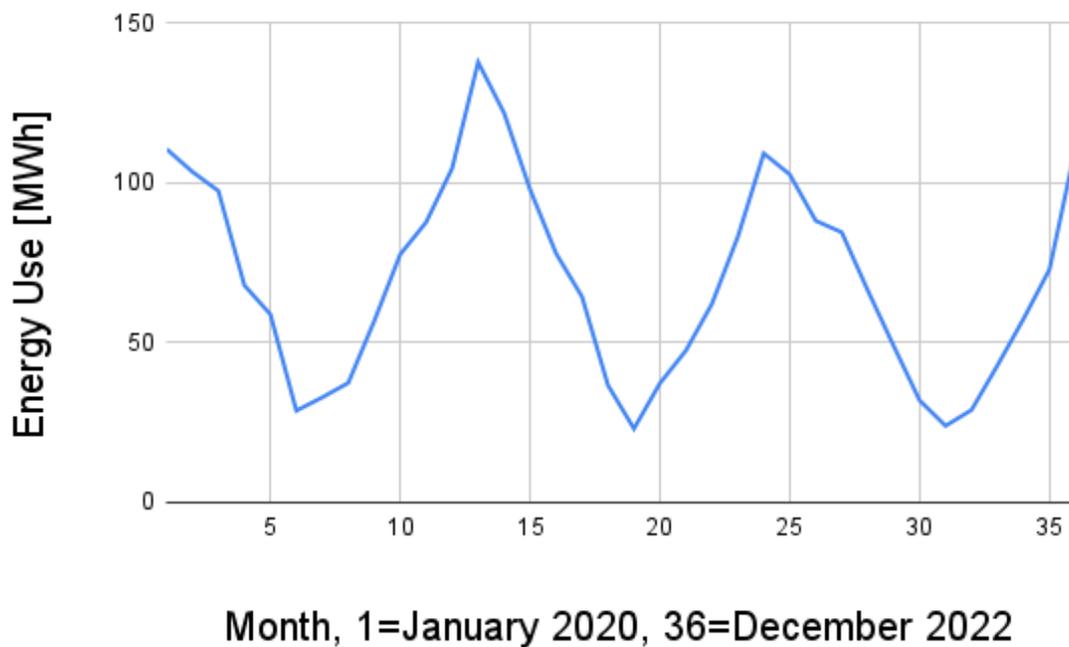


Figure 4.17: Graph showing the measured energy use for the MFIM in the Norwegian network.

The figures above shows that the measured energy varies from year to year in the Norwegian network with a decrease in energy use in 2020 similar to that in Sweden,

it also shows a rather significant peak in the turn of the year between 2020 and 2021. January 2021 was the coldest January in Norway since 2010[36], which could explain the peak in energy use. This shows similar to the Swedish network that the energy use is variable from year to year due to things outside of DH companies control and it can thus not be modelled correctly without modifying

4.3.2 Simple literature elasticity in Norway

The simple literature model uses the values of elasticity as shown in Table 3.1. It multiplies the average price increase with the elasticity and then multiplies that with the energy use to give the change of energy use.

Figure 4.18 shows the energy use for the Norwegian industry buildings.

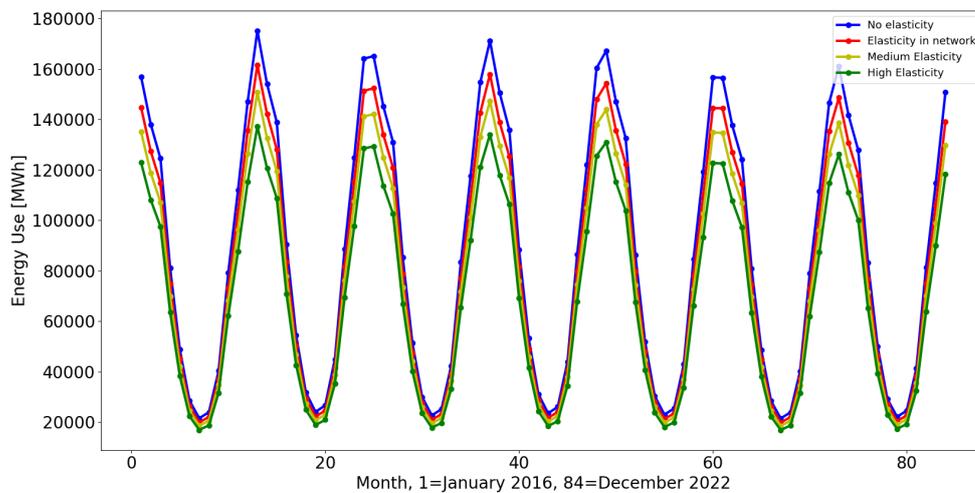


Figure 4.18: Graph showing the difference in energy use for normalized energy for industry buildings depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.1.

The potential changes is similar to that of the Swedish model 1 but are larger due to the larger changes in price.

Lastly for model 1 is the entire group of multi family residences as shown in Figure 4.19.

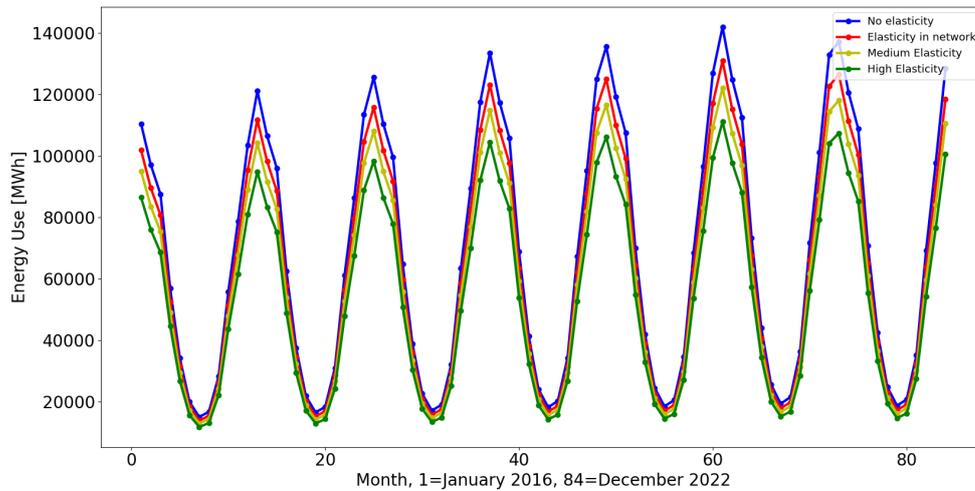


Figure 4.19: Graph showing the difference in energy use for normalized energy for multi family houses depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.1.

The elasticity from literature shows that the energy change could be quite significant. However, historically this looks to not be the case as the expected energy use for a normal year increases for most of the years with a slight decrease in 2022.

Table 4.5 shows the income resulting from different assumed elasticity.

Table 4.5: Table showing the income for the three different building categories as well as the total income for the network depending on assumed elasticity for the time period of 2016-2022.

Elasticity/Income Per customer	Industry [MNOK]	Multi Family Residence [MNOK]	Total [MNOK]
None	6816.93	9755.51	16572.8
Low	6288.62	8999.46	15287.81
Medium	5865.97	8394.62	14270.76
High	5337.66	7638.57	12984.57

As seen in the table the income differences can be quite significant depending on the elasticity. The total income could change by a total of 3600 MNOK. This is a 22% income decrease in total and is quite a bit larger than that of the Swedish model 1 in which the highest decrease was around 2%. Of course it could be expected that the income differences would be larger due to the larger average price increase of the Norwegian network.

The plot shown in Figure 4.20 shows the energy use for a multi family resident with an individual meter for all households in the Norwegian network.

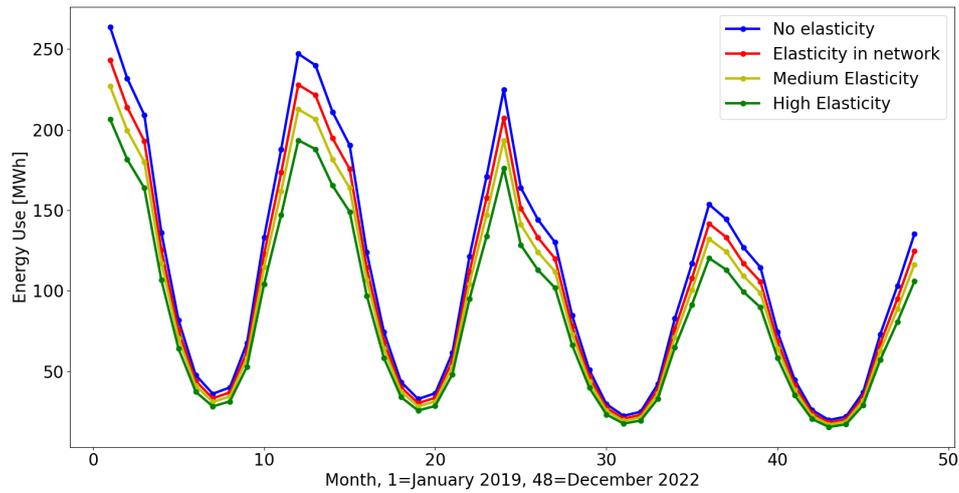


Figure 4.20: Graph showing the difference in energy use for normalized energy for individual metering depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.1.

4.3.3 Advanced literature elasticity in Norway

The advanced literature model uses the values of elasticity as shown in Table 3.2. It multiplies the average price increase with the elasticity and then multiplies that with the energy use to give the change of energy use. The advanced model also makes a difference on which type of customer it is that is consuming the heat and given that assigns different elasticity values.

For the Norwegian network with different elasticities depending on the customer groups are shown below.

Figure 4.21 shows the change for industry buildings.

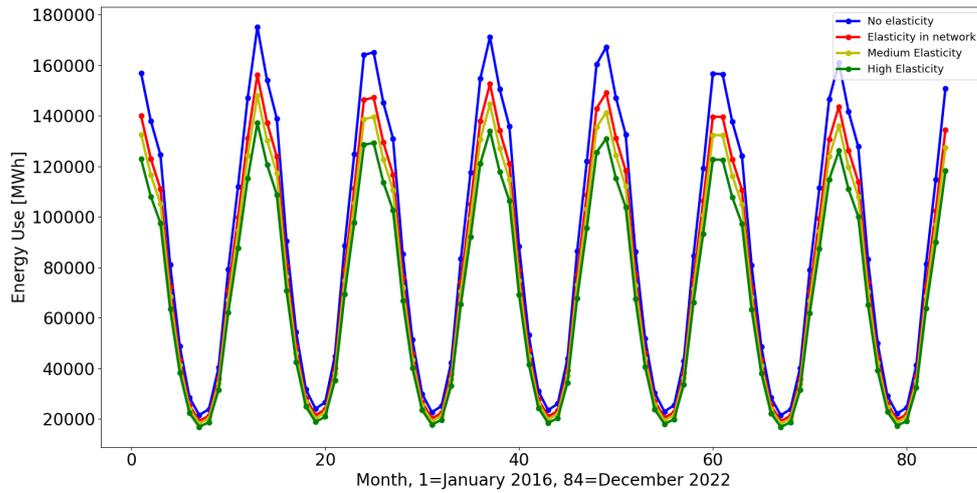


Figure 4.21: Graph showing the difference in energy use for normalized energy for industry buildings depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.2.

As seen the Norwegian industry does not differ much in trends from the Swedish models and the results for the Norwegian models are quite similar.

Similar results to that of the industrial buildings but for multi family residences can be seen in Figure 4.22.

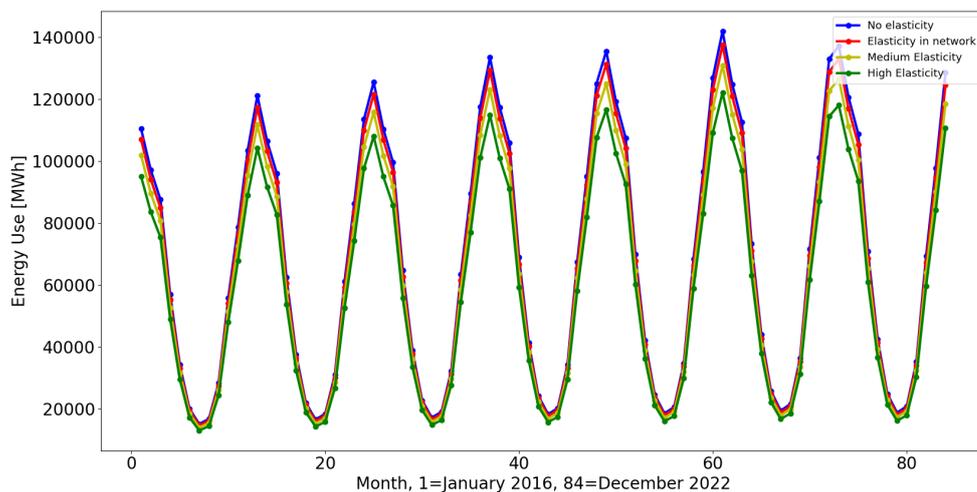


Figure 4.22: Graph showing the difference in energy use for normalized energy for multi family residences depending on the assumed elasticity. The elasticities used are the ones shown in Table 3.2.

Table 4.6 shows the income differences that comes from the different assumed elasticities.

Table 4.6: Table showing the income for the three different building categories as well as the total income for the network depending on assumed elasticity for the time period of 2016-2022.

Elasticity/Income Per customer	Industry [MNOK]	Multi Family Residence [MNOK]	Total [MNOK]
None	6816.93	9755.51	16573.10
Low	6077.29	9453.09	15530.66
Medium	5760.31	8999.46	14759.94
High	5337.66	8394.62	13732.12

As seen in the table the total difference in income for this network is higher in all cases. This is as in the Swedish case expected due to the lower elasticity that is assumed for the multi family residences. In Figure 4.23 the energy for the individual metering house is shown.

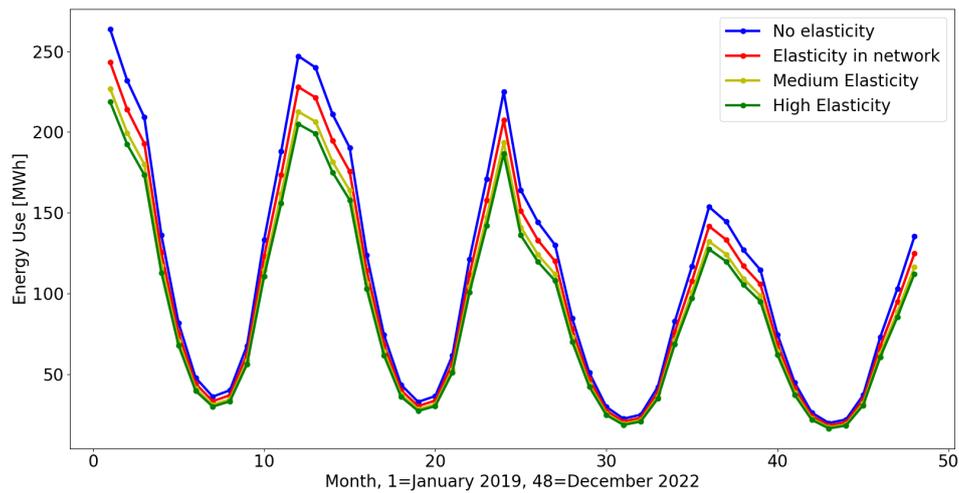


Figure 4.23: Graph showing the difference in energy use for normalized energy for individual metering depending on the assumed elasticity. The elasticities used are for single family households the ones shown in Table 3.2.

The result in the figure is similar to that of model 1. It is assumed that the elasticity for a MFIM is the same as that of a single family house in literature as they essentially are operating on the same conditions.

4.3.4 Historical elasticity in Norway

The historical model calculates the historical elasticity by using Equation 3.3. Then it multiplies the average price increase with the elasticity and then multiplies that with the energy use to give the change of energy use.



Figure 4.24: Graph of relative price changes for DH in the Norwegian network during the years 2018-2022

The price changes found in the Norwegian network, seen in Figure 4.24 varies a lot especially when compared to the Swedish prices as shown in Figure 4.10. In some cases the prices are raised 4 times compared to the same month in the previous year. While in Sweden there was no price increase close to that. The large price differences should give result in larger price elasticities in the network as the costs paid by the customers will be widely different year to year.

The elasticity month versus month for all three categories is shown in Figure 4.25.

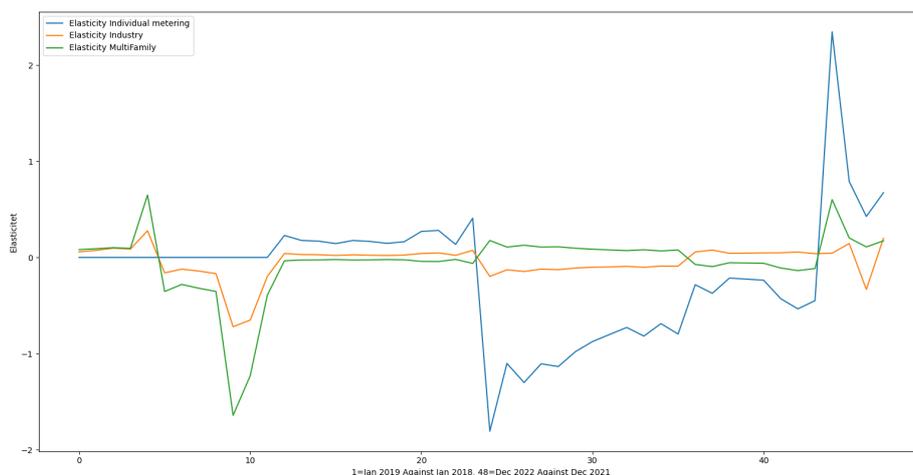


Figure 4.25: Graph of elasticity between current month and the same month the previous year for MFIM (blue line)*, industry buildings (orange line) and multi family buildings (green line). *MFIM existed from 2019

As can be seen in the figure there are certain peaks in elasticity for all three categories. In late 2019 there is a negative peak for both industry and multi family residences. After this the elasticity is around zero for almost the entire time period examined. This indicates that something special happened with the price of DH in 2019 for the customers to respond.

Looking at the individual meter one can see one negative peak and one positive peak in elasticity. This shows that the house with individual meter reacts on price changes in two ways. The negative peak around month 23 shows a strong reaction to a rather small price increase as shown in Figure 4.24. Interestingly the positive peak in 2022 comes from a small decrease in price resulting in a decrease in energy use. This could indicate that there are other factors affecting energy use. One thing that springs to mind is the fact that there was extended media coverage during 2022 about the energy prices. This could have impacted the thinking and behavior of consumers that resulted in less energy use.

In Table 4.7 the average calculated elasticity of each customer group is shown.

Table 4.7: Table showing the average historical elasticity for the network from the year 2018 to the year 2022.

	MFIM	Industry	Multi family residence
Elasticity	-0.22	0.00152	-0.0493

In the table it can be seen that the MFIM has by far the highest elasticity of all the groups and is closing in on the values suggested in literature. Table 4.7 and Figure 4.25 shows how the MFIM acts compared to the entire group of multi family residences. To shed more light on what the impact of individual meters for a new house actually does a comparison between the MFIM and a house without individual metering built during the same time period was done and is shown in Figure 4.29.

The results of using historical elasticity is similar to that of the Swedish model and are shown cased for all three cases in Figure 4.26 and Figure 4.27.

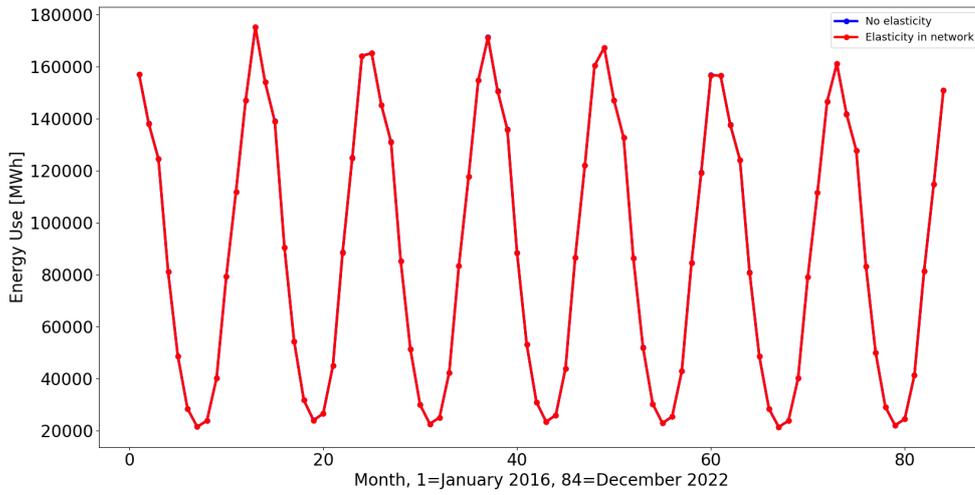


Figure 4.26: Graph showing the difference in energy use for normalized energy for industry buildings depending on the assumed elasticity. The elasticity used is the ones shown in Table 4.7.

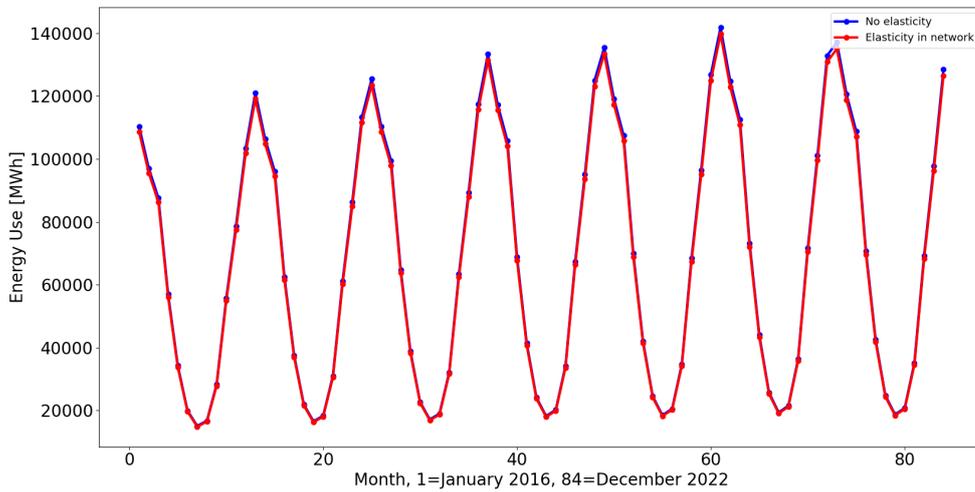


Figure 4.27: Graph showing the difference in energy use for normalized energy for multi family houses depending on the assumed elasticity. The elasticity used is the ones shown in Table 4.7.

Table 4.8 shows the resulting income from assuming the historical elasticity.

Table 4.8: Table showing the income for the three different building categories as well as the total income for the network depending on if historical elasticity is used for the time period of 2016-2022.

Elasticity/Income Per customer	Industry [MNOK]	Multi Family Residence [MNOK]	Total [MNOK]
None	6816.93	9755.51	16583.10
Historical Elasticity	6813.72	9606.40	16430.22

As expected when looking at Table 4.7 the income changes would be quite small as the elasticities are rather small. It does however give an idea of how the future income may come to change for the network.

Figure 4.28 shows the energy use for the MFIM.

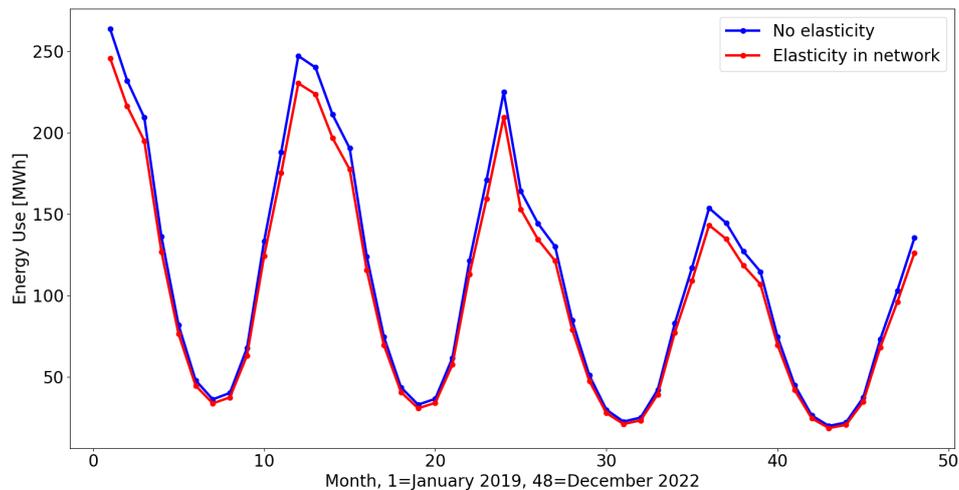


Figure 4.28: Graph showing the difference in energy use for normalized energy for MFIM depending on the assumed elasticity. The elasticity used is the ones shown in Table 4.7.

The results are quite similar to the other historical models, both Norwegian and Swedish as it would change the energy a little bit but not significantly.

The impact on price elasticity when having individual metering for a house with several households rather than not having it is shown in Figure 4.29.

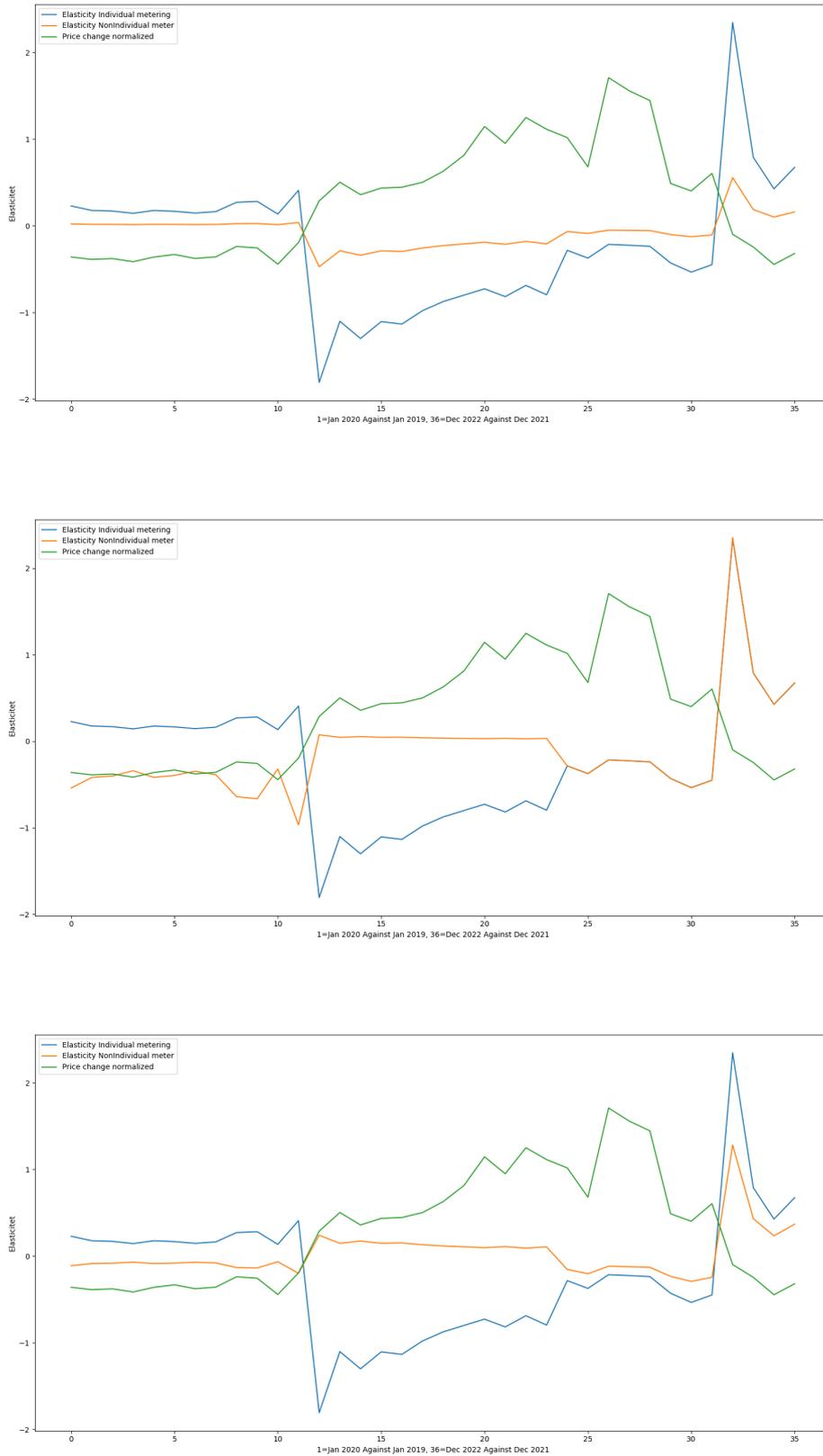


Figure 4.29: Three graphs showing the difference of two multi family houses built in the same time period. One with individual metering, (blue line), and one without it, (orange line). The green line shows price changes where a positive number implies a price increase.

As seen in the first graph of the figure the impact of individual metering is quite significant and although there is some elasticity during the same time period for the house without individual metering it is not close to that of the building that does have it. The average elasticity for the building without is around -0.07 while the building with it is around -0.22 as shown in Table 4.7.

The second graph show a somewhat similar story with the individual metering showing a larger elasticity. An interesting result though is the latter part of the graph where the elasticity value overlap completely and the behavior between the two buildings is the same. The average elasticity for the non individual meter building in this case is -0.1 which still is lower than that of the MFIM.

The third graph is similar to the first graph but has a larger span of positive elasticity indicating that this building does not in fact act on price changes that much. The first case where this elasticity goes down is shown around month 24 where a significant price increase results in the house limits their energy use to being around the same as the year before. One thing that can be seen in all three graphs is that in the case where the price is lowered in 2022 we get a positive elasticity for all buildings indicating that something other than price affects the energy use for these buildings.

4.3.5 DH vs electricity

As mentioned earlier a question about the correlation between DH energy use and electricity prices came up during the interviews. If there would be a correlation between the electricity price and the usage of DH larger consumers could work together with the DH supplier in order to run DH together with heat pumps in order to heat their facilities as cheap as possible. The daily energy use of district heating as well as the daily average price of electricity for SE3 is shown in Figure 4.30.

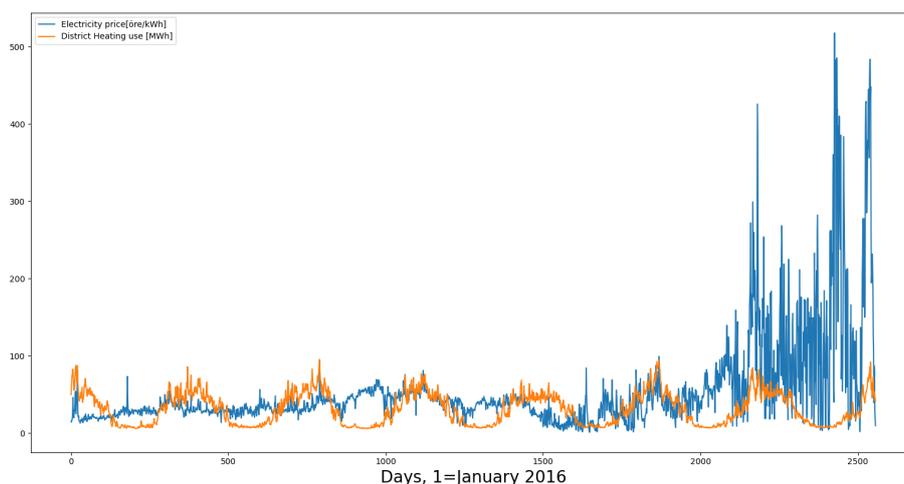


Figure 4.30: Graph showing historical district heating use and electricity prices.

The first thought when looking at the graph is that there might be some correlation

in the early years of the graph. There are some differences in the graph however that might indicate there is no correlation. For example around day 1000 where the DH use is low but the electricity price is increasing. They are especially different when looking at 2022 where the electricity prices peaked rather significantly. Another trend is that the electricity prices tends to not vary as much by season while the DH energy use clearly varies by season. Therefor the winter months, where the use of DH is high, was examined to find out if there is any correlation during this time. As seen in the graph this does not really seem to be the case either as during some winter months the electricity price was lower than the rest of the year. The correlation factors calculated during this investigation is shown in Table 4.9.

Table 4.9: Correlation factor between district heating use and electricity price, focusing on months with "winter prices".

	2016-2022	2016-2021
Full Years	0.11	0.18
Winter months	0.290	0.291
January	0.25	0.59
February	0.33	0.60
March	0.24	0.53
October	0.07	0.15
November	0.35	0.47
December	0.64	0.59

As seen in the table the correlation factor is quite low for most of the months and the year. If looking at a full year the correlation factor suggest there is no correlation present between the two variables. The same goes if looking at the entire winter part of the year. If instead looking month by month there can be some correlation found if excluding 2022 as a data point. The correlation factor indicates that there is an intermediate correlation, this could indicate that there is a relation between the two variables but it could also mean that there is another factor affecting the use and the prices. One such factor could be cold weather which drives up both district heating use and electricity use which would increase the price of fuel and thus the price of the product, in this case electricity.

5

Conclusion

In this thesis the effect of price elasticity in district heating has been evaluated and presented. The aim was to evaluate the district heating industry's need and opportunity to use price elasticity in their work.

The price elasticity was found to be very low in the networks with the highest elasticity being calculated at 0.22 for the MFIM. The results found that the DH companies can continue to operate as they do for now due to the elasticity being that low. However, the elasticity found in the MFIM shows that individual metering could be a way to go forward in the DH industry if companies want to give incentives for customers to take control of their energy use.

There are three possible theories concluded for the elasticity being this low. The first one is that the price of energy has historically been quite low and has only gone up during the latest year and the second is that the price models of district heating is not giving enough incentive for the consumer to take charge of their energy use. Lastly, the elasticity could be low due to the time period examined. The elasticity found in this period could be viewed as short-run elasticity and the elasticity might be higher if looking over 20 years instead of 6 as done in this thesis.

5.1 Going forward

Going forward Utilifeed probably do not need to include price elasticity in their model as it was found to be so low. However, another investigation could be done in about 5 years since the energy prices are likely to remain at a high level during that period which may increase the price elasticity of the customers.

If district heating companies want to give incentives for customers to lower their energy use they might want to look over their price models and maybe move to a price model more similar to that of electricity.

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