Norwegian University
of Life Sciences

Master's Thesis 2020 30 ECTS
School of Economics and Business

Implications of a Carbon Tax in the Norwegian Greenhouse Sector – a Case Study of Wiig Gartneri

Erlend Svebestad and Heidi Botheim
Master of Science in Economics

ACKNOWLEDGEMENTS

This thesis marks the end of a two year master's programme at the Norwegian University of Life Sciences.

We would like to thank our supervisor Olvar Bergland for providing feedback and ideas that were very helpful in the creation of this study. We would also like to thank Eirik Romstad, the co-supervisor for this project. He has given us continuous highly appreciated feedback and support, both academic and linguistic, and has been a valuable resource in this process.

Further, we would like to thank Wiig Gartneri for providing data and guidance during the process. We would also like to thank Norsk Gartnerforbund and Lyse for assisting with technical issues.

Finally, we would like to thank our friends and families for valuable contributions and support throughout the study.

Ås, June 2020

Heidi Botheim and Erlend Svebestad

ABSTRACT

This thesis examines the effects of implementing a carbon tax on the greenhouse sector in Norway, with a specific case study of Wiig Gartneri in Rogaland. The sector is currently exempt from such taxation under the reasoning that carbon dioxide, through photosynthesis, serves as a production input. However, carbon emissions greatly surpass what is required in production, and it is questionable if an exemption can be upheld indefinitely.

Our first research question relates to a scenario where no cost-effective alternative exists, where we look at the elasticity of natural gas demand. By treating the carbon tax as a constant increase in the price of natural gas we find that short term price fluctuations do not affect Wiig Gartneri's demand.

Our remaining research questions relates to the profitability of three specific technologies we deem promising. These are solar thermal collectors, biogas and woodchip combustion. To examine these technologies, we rely of net present value analysis of energy related expenses over the lifetime of the project and measure the results against a reference scenario.

Our findings show that, despite providing the lowest levelized cost of energy, solar thermal collectors are not a profitable option. This is because of the greenhouse dynamics, where the collectors primarily produce in the summer where carbon dioxide is most scarce.
Further, we find that while not requiring any initial investments, biogas requires a substantial price drop for it to become cost competitive in the foreseeable future.

Finally, despite providing energy at a higher per energy cost than natural gas, the only cost decreasing alternative for the greenhouse is woodchips. This is because the biomass, despite being regarded climate neutral, emits more carbon dioxide than natural gas per energy output. This technology therefore provides a double benefit for the greenhouse, as it decreases expenses regarding both liquid carbon and carbon tax.

Key words: Carbon tax, greenhouse sector, renewable energy, natural gas, net present value analysis

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

CO_2	Carbon dioxide
CO2-eq.	Carbon dioxide equivalent
CSP	Concentrated solar power
EU	European Union
GW	Giga watt
GWh	Giga watt hour
kNOK	Norwegian kroner in thousand
kW	Kilowatt
kWh	Kilowatt hours
LCOE	Levelized cost of energy
LNG	Liquified natural gas
M^2	Square meters
MW	Megawatt
MWh	Megawatt hour
NGF	The Norwegian Gardener Association
NIBIO	Norwegian Institute of Bioeconomy Research
NOK	Norwegian kroner
NPV	Net present value
NVE	The Norwegian Water Resources and Energy Directorate
TTF	Title Transfer Facility
TW	Terawatt
TWh	Terawatt hour
USD	US dollars

1. INTRODUCTION

A survey mandated by the EU commission, shows more than 90% of Europeans agree that climate gases should be decreased to a minimum in order to make EU climate neutral by 2050 (European Commission, n.d.). Norwegians are also becoming increasingly aware of climate change, though not to the same extent as in the EU, with over 75% being at least worried, according to a survey done by European Perceptions of Climate Change (EPCC) in 2016 (Steentjes et al., 2017).

A current political goal is to phase out fossil energy sources by 2030 (Haugstad, 2020). For Norway to reach its domestic and international climate commitments, Norwegian climate policies need to become more stringent. It is therefore natural to expect policymakers to increase taxes on carbon emissions, and to include previously tax-excluded sectors.

Emissions from Norwegian greenhouses have declined substantially in the past 20 years, primarily due to natural gas replacing more carbon intensive fossil fuels for main energy input. Further reductions are likely to be necessary. Excessive emissions, although not being priced yet, is a cost for society, while greener and renewable alternatives are becoming more cost competitive.

The greenhouse sector is an energy demanding part of the Norwegian agriculture. The greenhouses require large amounts of heat, primarily from fossil fuels, and electricity for growth lights. Carbon dioxide (CO_2) is also an input as nutrition for the crops through photosynthesis, and liquid CO_2 is therefore purchased and injected in periods where the exhaust gas from the heat demands is insufficient to cover demand. Increasing the CO_2 levels within the greenhouse enhance growth through photosynthesis by 15-40% (Agri-e, 2018), dependent on crops. The Norwegian greenhouse sector is currently exempt from a carbon tax, because of the role CO_2 serves in increasing production.

The greenhouse sector has showed great willingness to commit to increased energy efficiency and emission reductions for the past two decades. Between 1999 and 2012, the Norwegian Gardener Association had a goal to reduce the energy consumption from 980 GWh to 840 GWh, which was completed. They further extended this goal, to reduce total emissions by at least 40 % and the total energy consumption with 15 %, by 2020 (Hamre, 2013).
Further, in June 2019, the Norwegian farmer's associations signed a climate agreement with the Norwegian government, in which they commit to increase the absorption of carbon in

agriculture and reduce greenhouse gases with a total of 5 million tonnes CO_2 eq. from 2021-2030 (Bondelaget, 2019). This agreement assumes enough emission reductions, which upholds the existing exemption for the sector from the carbon tax.

This thesis examines the which alternatives exist if a tax on climate gas emissions is implemented on the greenhouse sector in Norway. The thesis is written in cooperation with Wiig Gartneri in Orre, Rogaland, Norway's second largest greenhouse. Its main crops are tomatoes, cucumbers, root vegetables, plants and flowers. The greenhouse has provided us with detailed data regarding the dynamics of energy and CO_2 requirements. This reflects willingness in the sector to face the climate challenges.

In addition to examining the direct effect of a tax implementation, we will compare different alternative technologies that Wiig Gartneri may utilize as a response to the additional tax burden. The motivation behind our thesis is that climate action is becoming ever more pressing, and it is therefore questionable if any single industry can rely on being exempt from carbon tax indefinitely.

The greenhouse sector in Rogaland is somewhat unique, seeing as it is the only region with access to natural gas. Because of this unique operational framework, the results are likely to be limited in providing insights domestically. We therefore primarily aim to offer insights that hold within the region.

1.1 RESEARCH QUESTIONS

If the carbon tax is well designed, it should theoretically make it cost beneficial for the greenhouse to change its actions by making some previously costly, less climate impactful technologies relatively cheaper. To examine if this holds, we initially need to calculate the counterfactual case for comparison. What is the case if the tax is imposed and the greenhouse does not implement new technologies, but only changes production as a response. In a basic supply and demand framework, the effect is visualized by an upward shift in the supply curve, and a subsequent decrease in output. The tradeoff between increased prices and reduced output is dependent on the elasticities of the curves.

If new technologies are so immature that the tax is merely accepted as an extra cost, without contributing to a change in behavior, it could be argued that the policy does not work. This is an argument brought forward by NGF, who claims that “*It will only be a fiscal tax without* *any climate gains and with large adverse effects for many Norwegian gardeners*." (NGF, 2018). This is an interesting point considering the expressed political goal to increase self-sufficiency of food in Norway.

The above is the justification for our first research question:

1. *What is the effect of the tax if there exist no cost-effective alternative technologies to combustion of natural gas?*

After producing an estimate for the counterfactual, we analyze Wiig Gartneri's different alternatives to optimize energy usage if a carbon tax is imposed. The first technology we consider is solar thermal collectors. As with several renewable technologies, production is neither constant nor easy to adjust, and the scope of such an investment must therefore be analyzed with respect to energy requirements, but also the greenhouses carbon dioxide demands. Wiig Gartneri has a cultivated field bordering its property, and at the edges closest to the greenhouse the field is reportedly quite unproductive. The alternative cost of using this area for solar thermal collectors is therefore small. Installations on rooftops will not be considered as the firm is concerned with the fire hazard of such an installation. Accordingly, our second research question is:

2. *Are solar thermal collectors cost effective given tax implementation?*

The second alternative we will consider is to replace some of the natural gas with biological based energy, such as biogas or woodchip combustors. While still emitting CO_2 when combusted, these emissions are collected from atmospheric CO_2, and are therefore perceived to be carbon neutral.

This leads us to our third and fourth research questions:

3. *Is biogas an alternative to natural gas, given tax implementation?*

4. *Is woodchip technology cost effective as a supplement to natural gas?*

1.2 ORGANIZATION OF THE THESIS

The organization of this thesis is as follows. Chapter 2 provides background information on the greenhouse sector in Norway and Rogaland, the natural gas market, and the purpose of climate instruments. In chapter 3 we describe the methodology of the thesis, and the technologies we analyze. Chapter 4 describes the data used and provides a forecast for natural gas prices. It also contains a statistical analysis of the data provided by Wiig Gartneri, with the purpose of obtaining an estimator for the short-term price elasticity of natural gas demands. The following chapter contains our analysis, where we will do a profitability analysis for solar thermal collectors, biogas, and woodchip combustors. Chapter 6 presents results from our analysis, followed by a short discussion, while in the final chapter we conclude the thesis and offer our concluding remarks.

2. BACKGROUND

2.1 THE GREENHOUSE SECTOR

Greenhouse production accounts for a significant share of the total agricultural value in Norway. In 2018, there was in total 309 greenhouse farms with 171 hectares of greenhouse area. Since 2010 the number of greenhouse farms has declined by 51% (Statistics Norway, 2019b). The average size of the greenhouses has however grown to more than twice the size in 2018 compared to 2006, and the productivity has increased, resulting in increased production (Knutsen et al., 2019). The Norwegian climate has contributed to Norwegian greenhouse vegetable farmers achieving the higher crop yields than for example the Netherlands and Spain (Danielsen, 2019). Compared to the Netherlands, Norway achieved 50% larger crops per m^2.

The greenhouse sector is central in Rogaland. The region account for 92% of the domestic tomato production and 32% of the cucumber production. The total added value from the greenhouse sector was 324 million in 2017, a 16% increase from 2014 (Knutsen et al., 2019). The employment in the sector is estimated to be 700 full-time work equivalents (Knutsen et al., ibid.).

In 2017, there was an increase in the duty-free quotas between Norway and the EU for agricultural products. According to the European Economic Area (EEA) agreement, the terms of trading agricultural products are to be revisited every two years, with the aim for gradual liberalization (Stortinget, 2019). If the development of international competition for agricultural products continues in the same direction as it has for the past two centuries, the greenhouse sector will have to expect even stronger pressure when it comes to costs and prices, accompanied by increased competition because of higher imports. Subsequently, increased imports may create unpredictability in the sector. In 2018, the import of tomatoes grew to 6177 tonnes, from 5886 the year before (Nordsletten, 2018). This is however, still a relatively small fraction of total consumption, as tomato consumption per person is between 15-20 kg. annually (Amundsen, 2019), which implies that total domestic consumption is approximately 93748 tonnes.

2.1.1 ENERGY CONSUMPTION

Norwegian greenhouses consumed a total of 0.56 terawatt-hours (TWh) energy in 2018 (Statistics Norway, 2019a). Greenhouses are energy intensive because it is necessary to uphold high temperatures and enough lighting for plant cultivation. Subsequently, energy for heating and growth lights are the most important and high cost inputs (Agri-e, 2018).

The greenhouse must continuously adjust the environment for the crops. This consists of keeping the right temperature, sufficient lighting and carbon dioxide levels, and an appropriate humidity. A balanced internal environment is important to optimize yields and the quality of the crops. The crops utilize CO_2 along with water and light for photosynthesis, where these inputs are converted into nutrition, with oxygen as a byproduct. In a traditional ventilated greenhouse, added CO_2 is lost because it disappears through roof hatches. So is heat and excess humidity. The ventilation is necessary to adjust the internal energy balance.

Carbon dioxide and water vapor are the exhaust gases from the burning of natural gas. This is distributed into the greenhouse by pipelines. While the marginal benefit of additional carbon dioxide is diminishing, it is still positive even for high concentrations (Blom et al., 2002). This is not the case for humidity however, as too humid greenhouse air may facilitate algae growth and undesired insect breeding (Peterson, 2018). The greenhouse must therefore be ventilated when humidity levels become too high. This takes care of the excess humidity, but at a cost as carbon dioxide and heat are lost (NGF, n.d.). Three to four times as much CO_2 is supplied than what is generally needed for optimal growth because of ventilation (Gjessing, 2018). The continued balancing of heat, CO_2 and humidity is maintained with electricity, fossil fuels, and injection of liquid CO_2, with some renewable fuels as a fringe heat provider.

In Rogaland, the only region in Norway that utilizes natural gas in greenhouse farming, natural gas amounted to about 177 gigawatt-hours (GWh) in 2010 (Statistics Norway, 2011). Figure 2 below shows the dependency on natural gas in Rogaland. The fuel makes up for over half of the region’s energy requirements. Biofuels, propane, electricity and oil makes up the remaining heating demand, while electricity is also used for the growth lights.

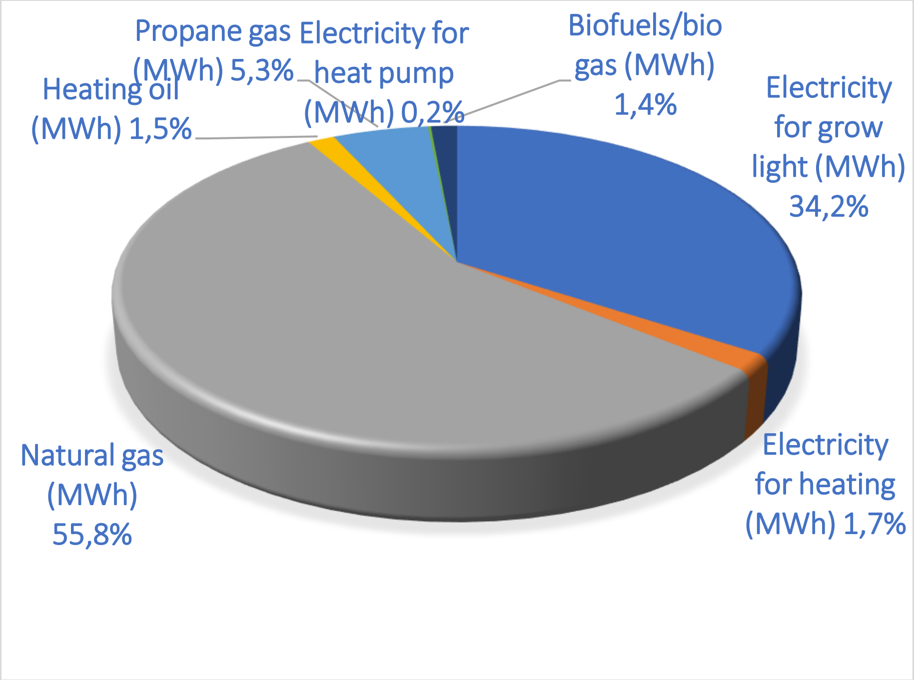


Figure 1: Energy consumption in greenhouses in Rogaland (2010) (Statistics Norway, 2011)

After 2010 data on energy utilization is limited. It is therefore hard to say how the figures above have changed the past ten years. However, according to NGF, the use of natural gas in 2017 was about 153 GWh, a decrease of 13% from 2010 levels (Pederstad, 2018). More recent numbers from Statistics Norway, show that 130 GWh of natural gas was used in agriculture in 2018, which implies that natural gas usage is slowly decreasing (Statistics Norway, 2019a). This can be the result of more producers having started operating all year-round. The growth lights used in year-round production also emits heat, reducing the need for other types of heating. This gives higher electricity consumption, with a subsequent reduction in the use of natural gas (Gjessing, 2018).

2.1.2 EMISSIONS

Greenhouse gas emissions in Rogaland were close to 4 million tonnes CO_2-equivalents (CO_2-eq.) in 2010, a 25% increase since 1991, which is significantly higher than the average in the rest of the country. The manufacturing industry is responsible for about half of these emissions (Rogaland fylkeskommune, 2010). In the current regional climate- and energy plan for Rogaland, authorities aim to achieve three main goals. These are: invest in 4 TWh renewable energy (of which 350 GWh is biogas), reduce energy consumption by 20%

compared to 2005 levels, and reduce greenhouse gas (GHG) emissions to 750 000 tonnes CO_2-equivalents (excluding the manufacturing industry) by 2020 (Rogaland fylkeskommune, ibid.).

During the past two decades, the use of natural gas has replaced a large share of oil and electricity for heating greenhouses in Rogaland (Statistics Norway, 2019a). In the early 2000s, there was an increased willingness among politicians to expand the use of natural gas. They argued it would reduce the amount of CO_2-emissions, as well as reduce local air pollution and give increased energy flexibility and supply. Moreover, it acted as a source of CO_2 for greenhouse farming. This resulted in more than a hundred greenhouses in Rogaland getting access to natural gas through pipelines by 2006 (Bævre et al., 2006).

A study done by Bioforsk, "*Greenhouse gas accounting for Norwegian greenhouse products*" (2010) found that the average emission was around 4 kg CO_2 eq. / kg tomato produced on the four tomato producing greenhouses included in the study. Natural gas accounts for close to 93% of the total emissions of producing 1 kg. tomatoes, and adds 3.8 kg / CO_2 eq. per kg. tomatoes produced. Replacing natural gas with a renewable energy source would give significant reductions in greenhouse gas emissions in the tomato production. The other inputs in the production are close to insignificant when it comes to emissions, they each contribute to 0.07 CO_2 eq. / kg. or less (Verheul and Thorsen, 2010).

2.2 CLIMATE INSTRUMENTS

There exist numerous policy instruments to incentivize certain behavior for production and consumption of greenhouse related products. Non-economic instruments include certificates of origin, such as "Nyt Norge", which assures consumers that the product is produced and processed in Norway. Products can also be labeled ecological and receive "nøkkelhull"-branding if they are healthier than its closest substitutes.

As for economic instruments, where our primary concern lies, politicians can choose between subsidy- or tax-based policies, in addition to tradable permits to influence behavior. In this section, we describe the mechanism of schemes that affect climate behavior.

The theoretical reasoning for taxing carbon emissions is to correct the market failure that the negative externality of unpriced emissions provides. Helm (2005) states that in a world of perfect information and under the control of a welfare maximizing government, economic incentives would not be necessary. Regulators can set production such that welfare is maximized, and subsequently the amount of pollution optimized such that the marginal damage of emitting is equal to the marginal cost of reducing emissions. Equilibrium is then reached as mitigation is equally costly as the monetized damage of additional emissions. As perfect information however is rarely the case, taxation of negative externalities is required for prices to reflect the true social cost of a good. Given that the tax rate is set equal to the marginal damage, it is a cost-effective measure to reduce the impact of the undesired activity.

Alternatively, policymakers may put a ceiling on emissions in a sector, sectors or a geographical area. This is the case for the EU emission trading system (EU ETS), where emissions are capped, and permits are traded at a price so that agents reduce emissions as long as their marginal reduction costs are less than the permit price. Expensive mitigation does not take place as it is less costly for firms to purchase permits. While taxes are price based, and emission permits are quantity based, the two yield the same emissions reductions if the emission price and quota cap is set optimally.

Norway is part of the EU ETS through the European Free Trade Association (EFTA) agreement. Not all sectors are however included in the emission trading scheme. Norway can design its own tradable permit system for sectors not part of the ETS, or tax the remaining sectors. Cap-and-trade systems can easily be implemented in multiple countries by making a joint emission trading area for all participating countries. If some governments are more ambitious than others, there will be differences of opinions in what the cap should be, and compromises will have to be made. This is largely the case for the EU ETS, where the quota price has historically been low due to an excess number of quotas. The price has in recent years increased somewhat, but for February 2020 the price was 25.5 euro (≈259 NOK) per ton, significantly lower than the Norwegian valuation at 545 NOK per ton, which is the general Norwegian climate gas emissions tax rate for 2020.

Emission taxes allow governments that are more ambitious than what the quota price reflects, to individually tax emissions from sectors under the quota scheme, so that the quota price plus tax equals the Norwegian valuation for damages. Cost effectiveness entails that the carbon emission price should be the same for all sectors. Optimality requires that the emission price equal the economic valuation. For sectors that are not under the EU ETS, this implies that the Norwegian emission tax should be 545 NOK per ton, with possible adjustments in the tax rate if the tax also impacts other externalities. For example, the fossil fuel tax in Norway implies an emission tax rate above the valuation, partly because more expensive fossil fuel reduces car traffic, and hence also the number of traffic accidents and emissions of particular matter from tire and road wear.

Taxation of climate gas emissions have existed in Norway since 1991. As climate gases are global externalities, carbon taxation is challenging both in calculating the appropriate tax rate that reflects the marginal global damage and avoiding carbon leakage through differences in tax rates between countries. Such taxation is appropriate for sectors that are currently not under a cap and trade scheme, or where the quota price does not reflect the true marginal damage of emissions.

Official Norwegian report 2015:15 (NOU 2015:15) *"sett pris på miljøet"* unanimously recommends that all current exemptions are abandoned. This includes both full exemption and sectors with reduced tax rates. The proposed tax rate is 420 NOK per ton CO_2-equivalents, which was the general tax rate for carbon emission at the time of the report (2015). The tax rate for 2020 has increased to 545 NOK per ton, and politicians promise it will keep increasing by 5% annually until 2025 (NTB, 2019). The recommendation from the report to tax all emissions equally is in accordance with the polluter pays principle. The report further reasons that emissions which give the same environmental damage should be taxed equally across sectors for cost effectiveness reasons. If other political objectives are the reason for varying tax rate across activities or sectors, other instruments that do not weaken the incentives to reduce emissions should be used to achieve these goals. Such political goals are for instance protectionism of national activities and international competitiveness, threat of carbon leakage, and maintaining economic activities in remote rural areas with a weak economic base. Activities connected to domestic food supply ticks on each of the points, and food production is therefore currently exempt from the tax. Agricultural activities are instead often subsidized. The greenhouse sector is one such activity and in addition has its specific reasons for exemption in that CO_2 is required for photosynthesis, and the national aim to produce and eat more healthy, green food (NGF, 2018). In addition, emissions from this sector have been halved since 2000 (NGF, ibid.). This reduction is mainly the result of a transition from oil and coal to less carbon intensive natural gas for heating purposes.

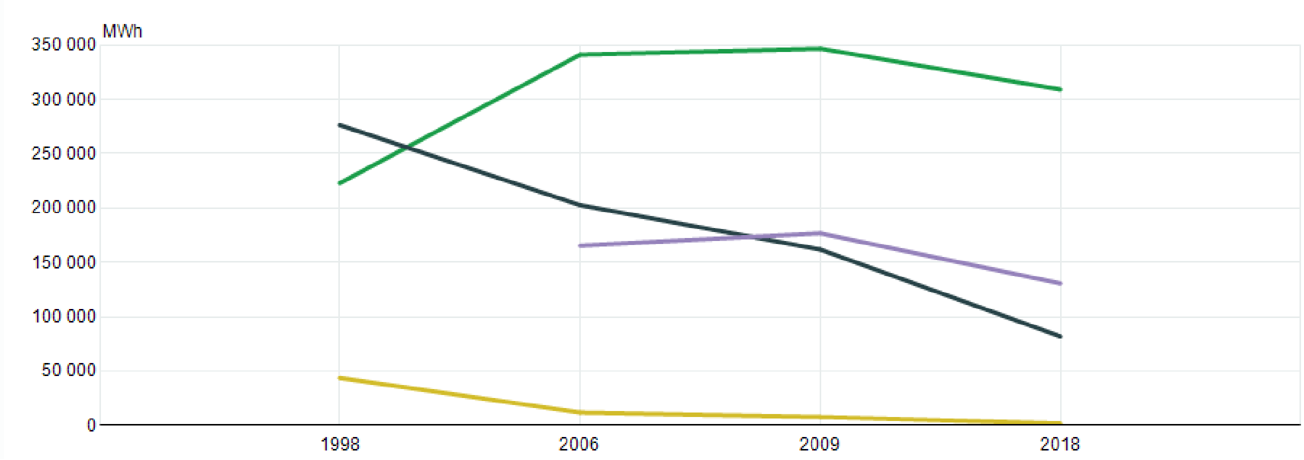


Figure 2: Energy consumption in greenhouses, statistics variables, and year (Statistics Norway, 2019a). From top: electricity for growth light, electricity for electric boiler, natural gas and heating oil.

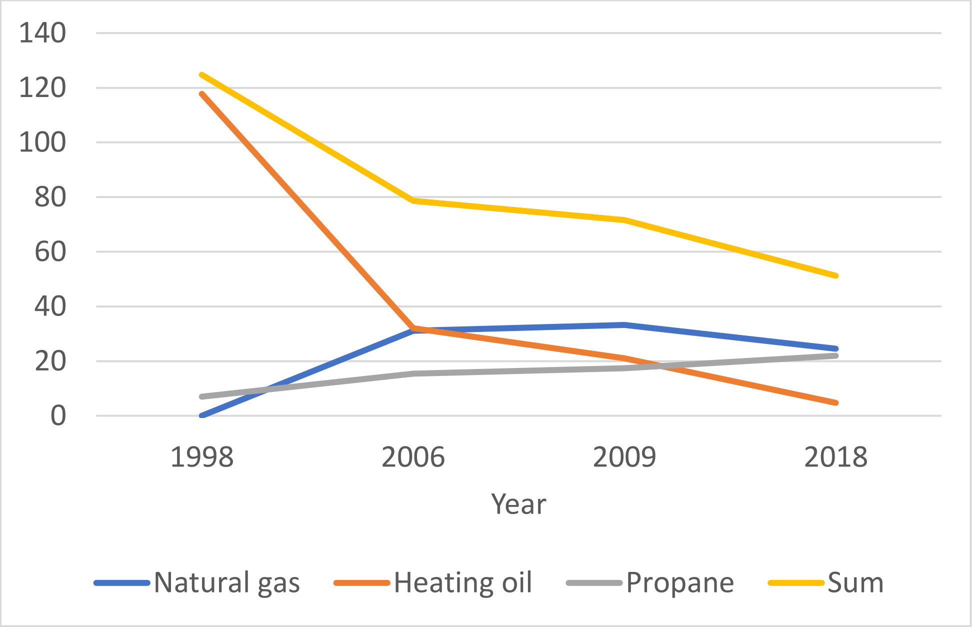


Figure 3: Historical CO2 emissions greenhouses (tonnes) (Statistics Norway, 2019a).

For this paper, we assume that taxation of emissions from the greenhouse sector will happen eventually, and that the greenhouses should adopt a focus on emission reduction for both social and expected future economic reasons.

2.3 NATURAL GAS MARKETS

Seeing as natural gas is the primary heat provider for Wiig Gartneri, we will provide a short introduction to natural gas markets and what factors affect the prices. The main markets for natural gas are in the US, Europe and southwest Asia. These markets are characterized by high transport costs, and the price is therefore largely determined by regional supply and demand. The recent increase in fracking technology and horizontal drilling has contributed to low prices in the US compared to Europe. Increased production in the US influence European prices, in that it works as a price ceiling. European prices cannot exceed US prices plus the cost of transport. Within Europe, competition in supply varies across regions. In north-west Europe, competition has evolved between different suppliers, while other areas rely heavily on Russia to cover their natural gas demands (Correljé, 2016). Acceptance of carbon emissions as a contributor to global warming also affects the market, through renewed energy and environmental policies, and pricing of emissions through the cap-and-trade system.

The European market for natural gas has been restructured over the past 20 years, as regulation and interventions are required due to market power exploitation by producers, wholesale and retail companies which prevented market efficiency. Such exploitation is possible due to the high transport costs, which makes local/regional monopolies or oligopolies possible as gas is a natural resource only some countries have access to. The distribution segment of the natural gas market is also characterized by high initial investment costs in pipelines, and strong economies of scale. These are the conditions for a natural monopoly, and government interventions are therefore required for the market to be efficient.

Geopolitical factors also affect the market, such as implementation of new member states in the EU and worries that the EU is too dependent on Russian gas. Tensions between Russia and Ukraine are also worrisome for the EU, as a major pipeline supplying Russian gas to Europe goes through Ukraine.

Fluctuations in the price of natural gas comes from changes in demand and supply. While geopolitical factors, regulations and rules affect prices, the main factors for price fluctuations are natural variations in demand due to changes in temperatures. Natural gas can also be stored to dampen short term fluctuations in demand and contributes to offset some of the effect that increased demand would otherwise have on prices. On the supply side, liquified natural gas (LNG) makes the markets more integrated as this technology allows for long distance shipping of gas. The costs of LNG consist of the liquefaction/gasification process, which are considered expensive, and a variable cost as a factor of shipping distance, which is considered small. LNG thus becomes competitive at sufficiently high gas prices.

3. METHOD AND THEORY

Our choice of method is based on the four proposed research questions, which addresses the choice of technology under a carbon tax in the greenhouse sector. To be able to assess the different alternatives on equal grounds, we conduct a net present value (NPV) analysis. After identifying cash flows from the different alternatives, we find the optimal investment decision. Because of constraints with regards to energy and CO_2 requirements, we use the solver function in excel as this allows for constrained optimization. The NPV provides the economic base for choosing between investment projects.

3.1 THE DISCOUNT RATE AND NET PRESENT VALUE

When having to choose between consuming now rather than later, most of us will prefer to consume now. This preference consequently adds a price to time. This makes the time aspect important, because even though we have benefits and costs happening in the future, the decision must be made today (Hansjürgens, 2004). Moreover, this makes the calculation of net present values important, because it accounts for the time value of money.

The discount rate is the price on consumer impatience that ensures comparability between data from different years. This is done by calculating future values of cash equivalents ranked in the monetary value at a particular point in time, usually today (Hagen, 2011). The discount rate includes the consumer impatience trade-off between periods and uncertainty about the future.

A major challenge is to find the correct discount rate, i.e., the interest rate that makes us indifferent between consuming today or at some future time. A study by Hagen (ibid.) on the discount's rate time structure finds that the optimal choice of the discount rate is affected by the macroeconomic development over time and the associated uncertainty. In general, uncertainty includes the project's contribution to future welfare, and the decision maker's preferences.

The value to defer consumption is usually considered to be constant, but the risk will vary between projects (NVE, 2003). According to NVE (ibid.), the two most important factors to consider when determining the degree of risk is the co-variation of the income of the project and the national income, and the share of fixed costs for the project. In addition, the NVE study points out that it is important to consider the possible utilities for a project, as several applications will conduce adaptation and flexibility, and thus reduce risk.

The NPV method allows to evaluate projects in a consistent way over time, and subsequently, the criteria for choosing between the different alternatives will also be consistent. The procedure is logical, and the reasoning are easy to understand. The NPV is one of the main ways to evaluate an investment.

$$\mathrm{NPV} = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_o$$

Equation 1

The NPV is equal to the sum of the discounted cash flow (C) in time t minus the initial investment costs (C_0). By discounting the cash flow of the beginning of the base year, we get the present value, and by subtracting the initial investment costs, we get the net present value of the project.

The economic decision rule is to implement a project if the NPV is positive, or in the case of multiple alternatives: choose the alternative with the highest NPV. A negative NPV indicates a net loss, i.e., that the costs are greater than the benefits. However, in cases where the uncertainties are large, or the externalities are difficult to estimate, it may still not be desirable to go through with the project. Hence, a positive NPV is not synonymous with a desirable measure. (Volden, 2019).

The NPV criterion is often highly sensitive to the chosen discount rate, i.e., the minimum economic compensation for consuming later, rather than now. The opportunity cost is a related perspective as the investments made in a project yield an alternative income stream for the future through the interest returns on savings. Bank savings are commonly used as a reference as they are the risk-free alternative to the project investment (NOU 2012:16).

The required rate of return, the discount rate, will also reflect the risk linked to the project. At high risk projects, the required rate of return will be high, and a low risk project will accordingly have a lower required rate of return.

There is no clear answer as to what the correct discount rate is, and there is substantial disparity in the choice of discount rate. Different assumptions and different values produce different required rates of returns. The Ministry of Finance in Norway suggests using a discount rate of 4% for projects with moderate risk, and for projects with a lifetime up to 40 years. This assumes a risk-free rent of 2% and a risk premium of 2% (NOU 2012:16). The ministry also points to the fact that some projects are more vulnerable to changes in economic conditions, to which they suggest increasing the risk premium, resulting in a discount rate up to 6%.

Some of the weaknesses with the NPV method, is that it assumes that the project must be implemented today, though in reality the investor has more choices. It also assumes that all input parameters are known such as the appropriate discount rate and annual cash flows. However, all variables will be subject to uncertainty.

3.2 RISK AND UNCERTAINTY

The usual practice is to calculate the NPV before the project is implemented. The time horizon for projects is often between 20-40 years, and a lot can change during this period, such as the emergence of new technologies, and changes to the economic conditions. Consequently, the calculated NPV is subject to uncertainties, especially linked to factors well into the future (NVE, 2003).

The necessary risk adjustments are commonly split into two categories, systematic risk and unsystematic risk. The systematic risk is the risk related to the economic conditions beyond the control of the project. A change in the economic conditions can result in great differences for the input prices of the project. The unsystematic risks are the risk that is within the project’s control, the base conditions can for example differ from the assumptions made. The former is accounted for in terms of adjusted values (NVE, ibid.). Adjusted values take account of risk to the costs and benefits, and probability of occurrence of events or changes that are expected to influence the profitability of project alternatives are assigned.

The latter is accounted for in the discount rate, by adding a risk premium which takes the economic conditions into consideration. However, project specific risk such as uncertainty regarding policies, industry, and costs, can and should be dealt with through a more transparent way. This can be done through changing the variables that are subject to uncertainties, which are specific for the project. An example is conducting a sensitivity analysis.

The future cash flows will always hold some uncertainty about the values we predict. If the data in the analysis changes, the result of the analysis will naturally change too. In a sensitivity analysis, one or two factors change their base value at a time. The purpose is to find out how sensitive the predicted NPV are to changes in the base assumptions, such as the discount rate, number of inputs/outputs, and costs of inputs. The analysis is considered robust if the sign of the net benefits stays the same, and the results will thereby hold greater confidence (Boardman et al., 2018).

3.3 TECHNOLOGIES

For the following section we present the current primary heat provider for Wiig Gartneri – natural gas. We also describe the three alternative technologies we intend to study further, solar thermal collectors, biogas and woodchips. Our choice of technologies is based on what we deem feasible given the location, available resources, and potential for emission reductions.

3.3.1 NATURAL GAS

Natural gas is a by-product of oil production, and consists mainly of methane (Lundberg et al., 2019). The fuel is delivered through pipelines, and is available where natural gas is brought ashore, near major transport lines, or storages for LNG (liquid natural gas), which is the case for Rogaland (Sidelnikova et al., 2015). It is considered a fossil fuel, because of its fossil origin, formed by the decomposition of organic matter (Lundberg et al, 2019). Natural gas is used for energy purposes, among other things, in households and industry and is considered as a less climate impactful fuel that for example oil and coal. This is because the level of sulfur is low, and it is possible to achieve almost complete combustion which allows natural gas to emit less CO_2 than other types of fossil fuels. Additionally, natural gas is lighter than air, and if a leak were to occur the gas would rise to the sky lowering the risk and extent of on-site accidents. However, both methane and carbon dioxide are considered as harmful greenhouse gases, and the use should be limited (Sidelnikova et al., ibid.).

Extending 2019 yearly figures 593 GWh of natural gas is currently used for permanent heating purposes in Norway, where 301 GWh is from agricultural buildings. This adds up to 65.881 tonnes CO_2 (Norwegian Environment Agency and NVE, 2020). Lyse Neo delivers

134 GW to greenhouses in Rogaland, where natural gas is used for heating, both for base- and peak load. 52% of the greenhouses that use natural gas for heating, also utilize the exhaust CO_2 for growth enhancement. The value of this is however unknown, because it will not only work as an increase in expenses, but also increase growth and thereby increase profits (ibid.). The flexibility in the use of natural gas and its fairly low costs explain why natural gas is widely used in Rogaland.

3.3.2 BIOGAS

Biogas is a fuel produced through the processing of organic waste in an anaerobic environment. This is an environmentally friendly alternative to natural gas by converting organic waste which would otherwise rot into energy. Biogas can be used for electricity, heating, or transport fuel. When it is only used for heating purposes, the gas is burned in gas boilers. The existing natural gas infrastructure can be used provided that the biogas connected to the pipeline grid. The CO_2 from combustion of biogas can also be used to enhance growth in the greenhouses, in the same way as natural gas (Lind, 2017; Ellingsen & Filbakk, 2016). However, the latter is still under development as some modifications to the biogas is required for the exhaust CO_2 to be useful (Lind, ibid.).

In contrast to other European countries, Norway has limited gas infrastructure which serves as a hinder on developing a biogas market. The existing infrastructure is mainly located around Stavanger and Haugalandet. In addition, many countries have used biogas for electricity production, but Norway have a low electricity price and a high share of renewable energy, further decreasing the competitiveness of biogas (Norwegian Agriculture Agency, ibid.).

The production of biogas has increased for the past few years but is still at a lower level than other Scandinavian countries. Half of the current biogas production in Norway is upgraded biogas, which makes it applicable as biofuel in the transport sector. Sewage sludge and organic waste (mainly food waste) make up a significant share of the raw materials to produce biogas today, and in recent years new plants put into use new resources, such as livestock manure and fish silage (Norwegian Environment Agency, 2020).

Though upgraded biogas has the same attributes as natural gas, the utilization of biogas for industry and heating purposes is marginal. Analyses done by Norwegian Environment Agency (ibid.) shows that biogas has a difficult market situation today, because of competing renewable alternatives. Seeing that fossil gas for heating of greenhouses is exempt from CO_2-

tax, fossil fuels has a cost advantage compared to other renewable alternatives. District heating, heating pumps, and electric boilers are also cheaper than biogas. Therefore, market development for biogas depends on the future costs both for biogas and other renewables (Norwegian Environment Agency, ibid.), in addition to government incentives such as carbon tax.

With an already existing and well-established gas infrastructure in Rogaland, a transition to biogas is believed to be easier and cheaper than in other parts of the country. In addition, natural gas can work as a backup when necessary (Lyse, 2017). Biogas will help "decarbonize" the gas sector, which is a goal in the EU's climate strategy, "A European Green Deal". Development of biogas will also contribute to a circular economy based on organic waste and reduce emissions from storage of livestock manure (Norwegian Environment Agency, ibid.).

In 2018, the production and consumption of biogas was 500 GWh. By 2030, the estimated potential for biogas production is 2600 GWh, predominantly by using food waste and livestock manure. The potential for consumption is probably even higher (Norwegian Environment Agency, 2020). The consumption of natural gas was approximately 150 GWh in 2018 for greenhouses. Østfoldforskning and ENOVA have estimated that there is potential for 600 GWh of biogas production in Rogaland (Mathisen, 2019).

In addition to the extra costs, access to biogas works as a barrier for it to completely enter the market. However, the greenhouse sector in Rogaland, already has an established market for biogas, which can contribute to lower costs. Furthermore, Rogaland has access to large amounts of raw materials through livestock manure suitable to use for biogas production, which makes them one of the regions with the highest potential for the use and production of biogas (Pederstad et al., 2018). Biogas can be used to replace natural gas for heating purposes in greenhouses, and it will normally not require any major changes regarding operation, as natural gas boilers are suitable for biogas (Norwegian Environment Agency, 2020). This property combined with the CO_2 residue from biogas makes the technology appear suitable for the greenhouse industry.

The use of livestock manure for biogas production can aid in reducing GHG-emissions. Co-treatment of livestock manure with other raw materials can contribute to increased utilization of resources and stability in biogas production. Currently, only 1% (70 000 tonnes) of the manure resources is used in biogas production. GHG-emissions are reduced in three ways: less emissions from methane and nitrous oxide from storage of the manure, biogas replaces fossil fuels, and bio residue replaces mineral fertilizers. However, there are still some barriers for any significant increase in the use of live-stock manure due to high transport costs, and challenges with profitable disposal of biogas and bio residue. Moreover, significant investment costs and low biogas yield per tonnes of manure are barriers to increasing the use of livestock manure for the production of biogas in small scale plants, and uncertainty among the users whether the subsidy scheme for the delivery of livestock manure to biogas plants will continue (Norwegian Agriculture Agency, 2020).

Using bioenergy will thus help to improve the environment, reduce fossil fuel dependency and provide energy flexibility. Annual consumption of bioenergy increased from 10 TWh in 1990 to 14.2 TWh in 2017. Households using firewood made up for the greatest share of the consumption (5 TWh), followed by the industry using woodchips and other woodwork for combustion in production processes (Energifakta Norge, 2019). Norway aims to further increase the use of bioenergy, to 30 TWh, mostly by more harvesting of trees, and through better utilization of residual products (NIBIO, n.d.b).

3.3.3 WOODCHIPS

We also assess the possibility of using woodchips as a fuel. As the prices of natural gas are rising, and the agricultural sector has available resources for bioenergy, it is possible that it will contribute to economic profitability as well as emission reductions. A possible drawback is the challenge of having a well-functioning market. Suppliers claim that the profitability of woodchips decrease with distance to the consumer, and that a possible cutoff for profitable delivery is at 80-90 km (Andersen, 2014). Local markets are therefore dependent on enough actors, which raises questions about the security of supply (Tvedt et al., 2012). The access to raw materials is not a constraint, as the current production of woodchips covers for half of the target for 200 GWh forest-based bioenergy in the region, and the remaining can be covered for by harvesting 25% of the forest growth in the region (Andersen, 2014).

The growing demand for bioenergy has accordingly created a market for secondary raw materials from wood, which has resulted in an expanding market for solid biofuels. In 2016, the use of bioenergy was 16 TWh, of which 14-15 TWh was biomass from forest (Pederstad et al., 2018). Today, about a million cubic meters of woodchips are traded in Norway, but the potential is even greater (NIBIO, n.d.b). The growth of the forest is larger than what is harvested, and according to NIBIO, the additional growth in 2016 of forests was 25 million cubic meters, while only 11 cubic meters were harvested. This gives the potential for sustainable production of bioenergy from the forests.

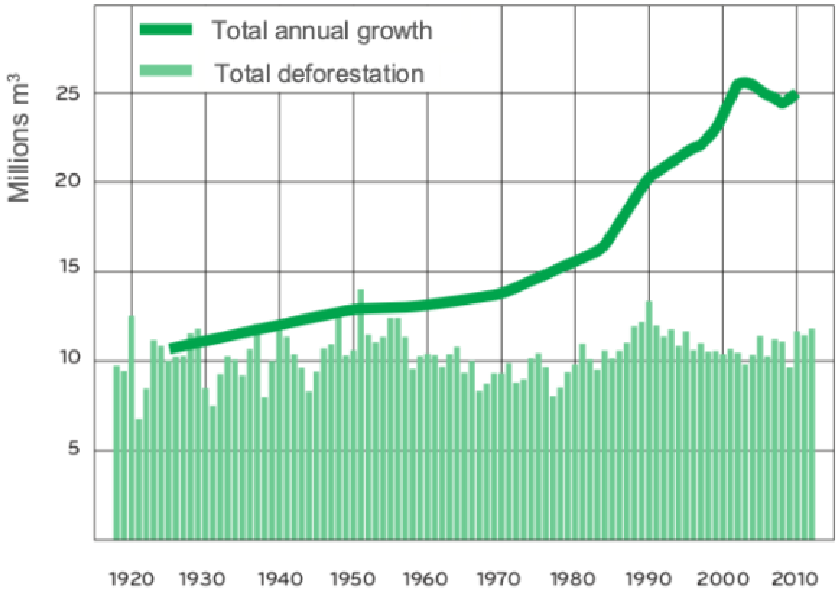


Figure 4: Total annual growth and total deforestation in Norway, 1920-2010 (NIBIO, n.d.b)

Woodchips containing more than 35% moisture are considered wet woodchips. Combustion boilers used for dry woodchips, are not also suitable for wet woodchips. This is because wet chips need a longer combustion chamber and more masonry. The advantage with burning dry woodchips is that it attains a greater calorific value on the fuel, which gives less volume to handle. Additionally, the efficiency of the boiler is greater, and it is often cheaper with boilers meant for dry woodchips. However, the disadvantage is having continuous access to dry wood. For example, raw wood residue can contain up to 55% moisture. Gains from decreasing moisture from 30% to 20% can be up to 600 kWh per ton, and subsequently decrease storage costs (NGF, 2014). However, drying is costly because it is electricity intensive and requires additional handling.

3.3.3 SOLAR THERMAL COLLECTORS

Because Wiig Gartneri requires large amounts of both electrical and thermal energy, both solar panels and solar capture technologies are interesting options for a greenhouse. The sun supplies more energy in an hour than the world can consume in a year, however, the challenge is to utilize this energy in an efficient, cost competitive manner. For this purpose, solar harnessing technologies can be separated in photovoltaics (PV) and thermal solar collectors.

PV technologies converts the energy from solar radiation to electricity through photovoltaics. Such production is beneficial in that the electricity is produced where it is consumed, and therefore no transmission losses occur. Usually industry and private homes that utilize PV technology are connected to the regular grid as well. This secures supply in periods with low production, as well as allowing for surplus production to be sold back to the grid in high production periods, which reduces waste or makes expensive battery technology obsolete. Such consumers are commonly referred to as “prosumers” (producer/consumer).

The appropriate scale of such an investment is dependent on the investor’s own consumption. The solar producer often faces worse prices when selling back to the grid and should therefore not aim to achieve self-sufficiency with respect to energy for all or close to all periods.

Solar collectors transform the energy from the sun to heat and may provide 400-450 kWh heat per m^2 solar collector area annually, depending on type of collector (Rosvold, 2019). The heat accumulated in the collector is transported as a heat medium, typically hot water or air to a thermal energy storage tank. In cold environments, if water is used as the heat medium, glycol must be added to prevent frost in the pipes (Rosvold, ibid.).

A thermal solar collector construction, as is the case for solar PV, requires high initial capital investments, while costs of operation and maintenance are low. Given that the primary energy requirements for the greenhouse are lighting and heat, both solar panels and heat collectors appear like solid options to consider. However, we will only consider thermal solar collectors for this paper. There are two main reasons for this.

First, the greenhouse utilizes very large amounts of both electricity and thermal energy, and for solar technology to offset one of this to some substantial degree, heat collectors appear like the better option given areal constraints. This is because heat collectors having a significantly higher efficiency in harnessing solar energy. While the efficiency of solar panels is constantly getting improved through technical innovation, it currently ranges at 15-20 % which is quite below that of solar collectors which are in the range of 50-70 % (Energiverket, n.d.).

Second, thermal collectors are more appealing because it directly offsets heat which would otherwise have been produced using natural gas. Since the thesis is written in the light that a carbon tax is likely to be implemented, focus will lie with the measure that will directly reduce emissions.

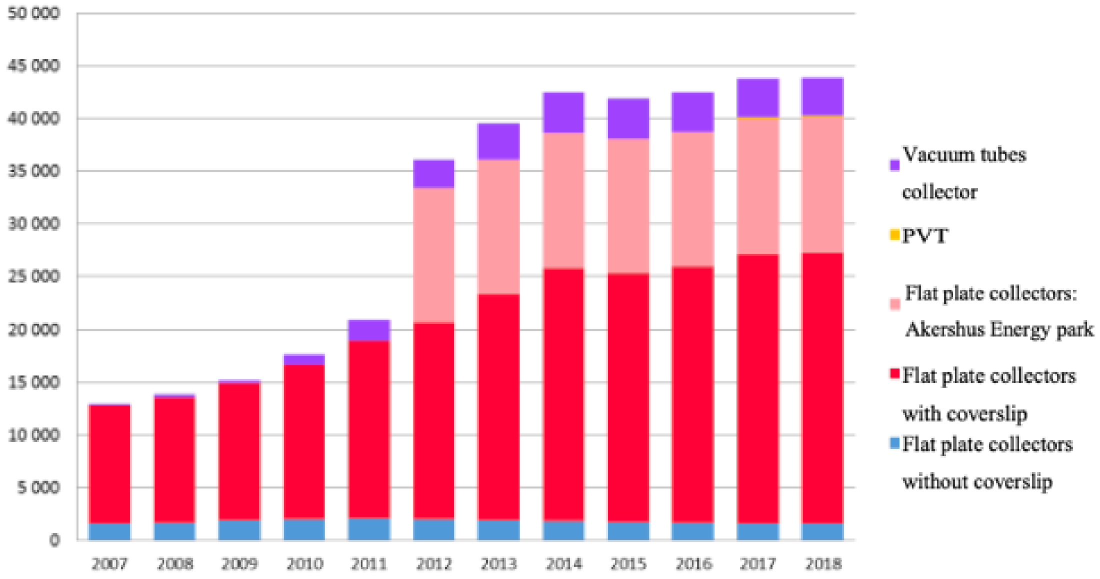


Figure 5: Accumulated solar collector area in Norway (m2) (Solenergiklyngen, 2019)

In Norway, the increase in net solar thermal collectors was only 0.2% from 2017 to 2018, with very low increases in the years before as well. This accounts for approximately 4% of capacity being depleted annually. The numbers are however somewhat uncertain, as providers are many and the plants delivered are small. In addition, increase in plants purchased over internet have increased, which makes the market less monitorable. The most notable increase in cumulative capacity was in 2012, with the opening of Akershus Energipark – a 13.000 m^2 solar collector park.

4. DATA

In this chapter we introduce the dataset that Wiig Gartneri provided us with and describe which methods we have used to prepare the dataset for further analysis. Moreover, we describe how additional data have been acquired, which assumptions have been made regarding these, and how the data necessary for further analysis have been generated.

The dataset contains observations with intervals of 5 minutes for 2019, totaling at 105 120 observations for each variable. The variables include energy usage distributed by electricity and natural gas, carbon dioxide requirements, the percentage filling of the buffer tank, and liquid carbon dioxide injections.

While the energy provided from natural gas is used solely for heating and carbon dioxide injection purposes, electricity is required primarily for the growth lights. We do not have information regarding the distribution of electricity for heating or growth lights, but according to Anders Sand in NGF, few greenhouses with access to natural gas use electricity for heating, and if they do, it is a very small share (A. Sand, personal communication, 24. March 2020). We therefore assume that all of the required heating comes from natural gas.

4.1 NATURAL GAS

4.1.1 CONSUMPTION DATA

We summarize the data by months and divide by 12 to obtain kWh as unit of measure. Summarizing the result by month gives monthly natural gas consumption for 2019.

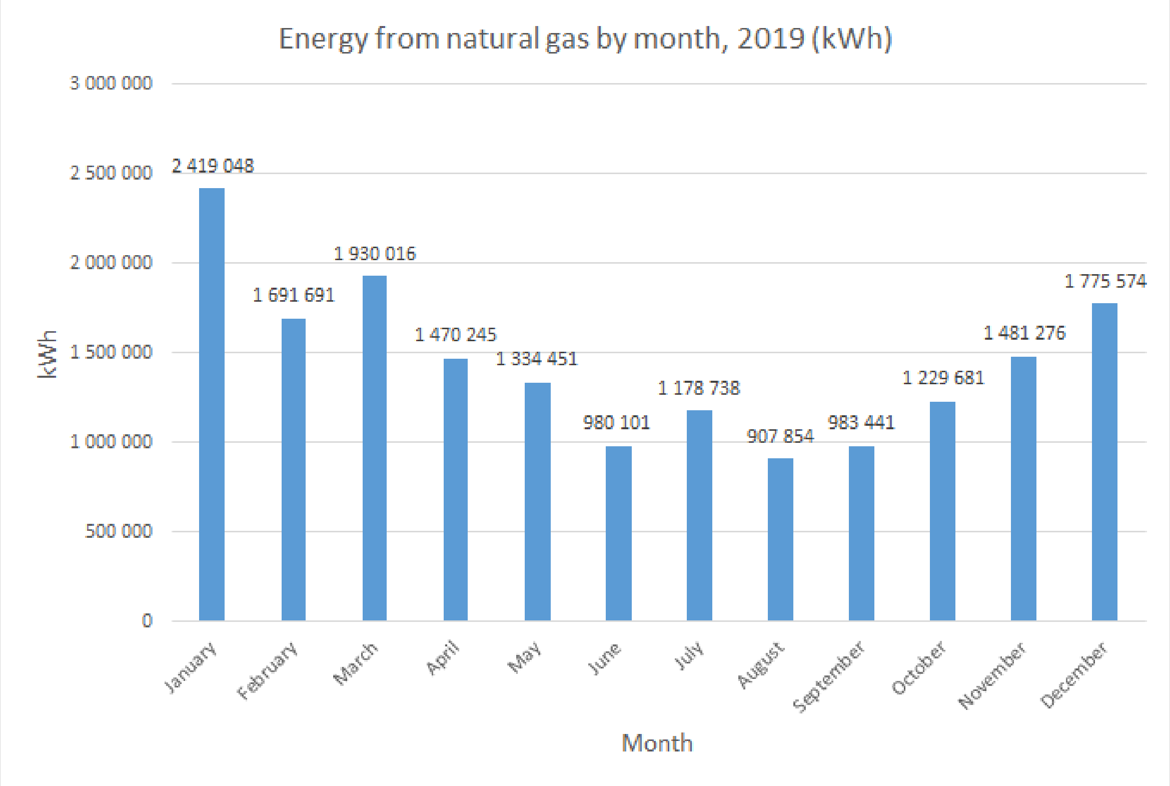


Figure 6: Energy from natural gas by month in 2019 (kWh) (F. Ringsevjen, personal communication, 29. Jan. 2020)

This consumption totals to 17.4 GWh. Naturally, as the energy is required for heating of the greenhouse, more natural gas is consumed during colder months in the start and the end of the year.

4.1.2 EMISSION DATA

When combusted, natural gas emits 58 gram CO_2 per megajoule energy There are 3.6 Megajoules in one kWh, and one kWh of natural gas therefore emits 208.8 gram CO_2 (Naturgass Nord, n.d.). However, sources vary slightly regarding emission factor of natural gas. Wiig Gartneri assumes an emission factor of 200 gram/kWh, and we will adopt this assumption.

From this emission factor, we estimate the CO_2 emissions from Wiig Gartneri in 2019. From natural gas combustion, 3476 tonnes of CO_2 was emitted. From the dataset we estimate that 1604 tonnes was injected back into the greenhouse to enhance growth, while the rest was directly emitted without any additional benefit. In addition, the greenhouse purchased 312 additional tonnes liquified CO_2 for injection to account for the mismatch in when CO_2 is generated and when it is required. Wiig Gartneri currently face a price of 1.64 NOK per kilo liquid CO_2 (F. Ringsevjen, personal communication, 19. March 2020)

The demands for heat and CO_2 are also seasonally dependent, with CO_2 being more valuable in the summer months when growth is high. This gives a situation where a lot of CO_2 is emitted without providing additional benefit to the greenhouse in cold months. This relationship is depicted in the figure below.

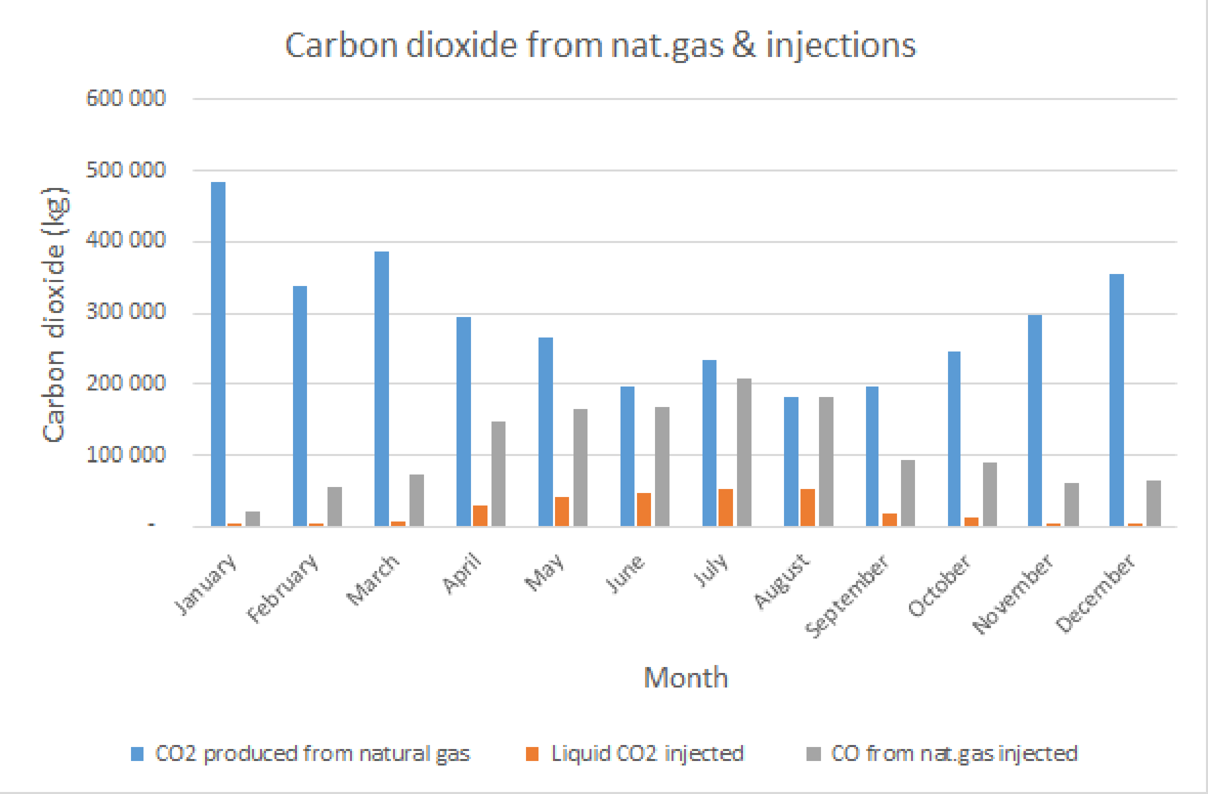


Figure 7: Carbon dioxide from natural gas and injections (2019)

The figure shows how liquid CO_2 is utilized to adjust the CO_2 concentration in the greenhouse especially in warm months. It also shows that most of the CO_2 from natural gas is injected in these months, while the share in the winter is very low.

From these data, we estimate the injection ratio for each month. This ratio shows how much of the CO_2 from natural gas combustion provides additional benefits by enhancing growth.

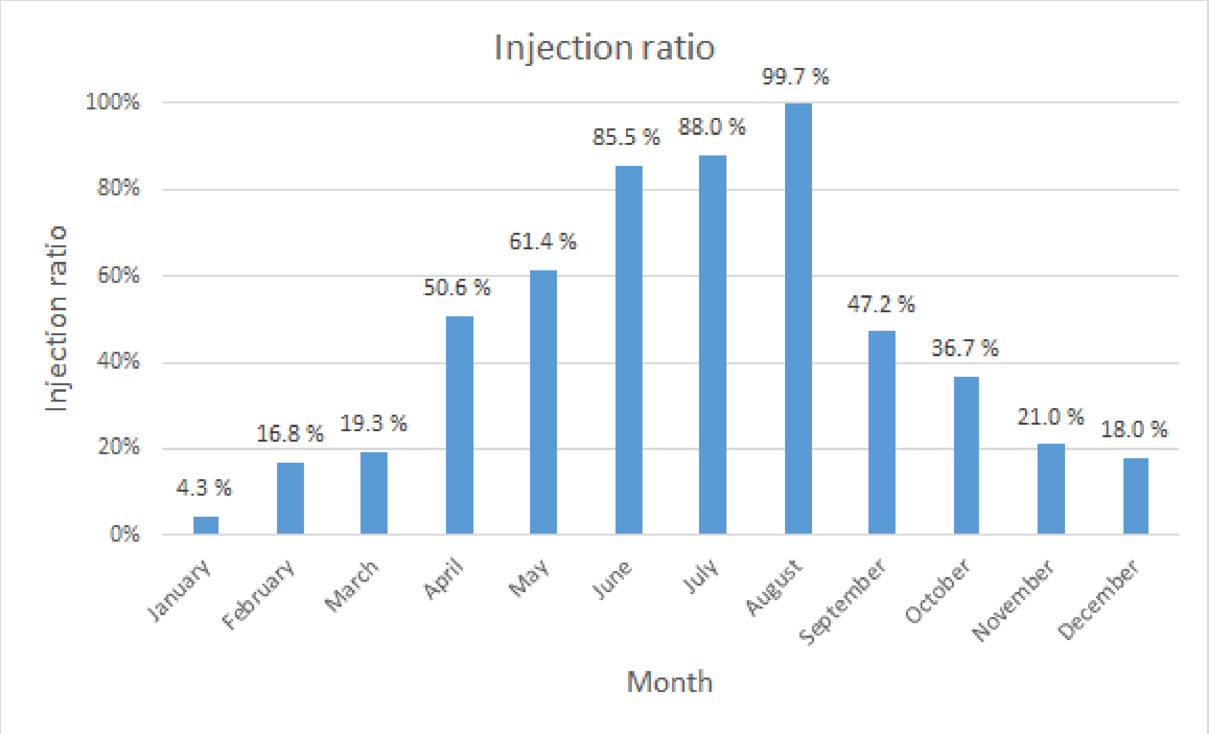


Figure 8: Monthly injection ratio

The estimated injection ratio is useful in later analysis. If a decision is made to invest in alternative technologies that provides less CO_2, additional liquid CO_2 must be purchased. Every kWh from a non-emitting energy source will, beside offsetting a kWh from natural gas, also decreases CO_2 injections. If an average kWh is replaced, this decrease is assumed equal to the amount of CO_2 generated by a kWh of natural gas, times the injection ratio for the relevant month. Replacing a kWh in January is therefore more beneficial than a kWh in August, since in the latter case the full CO_2 amount must be replaced, implying additional costs in greenhouse operations. Subsequently, a technology that provides more CO_2 per kWh than natural gas will decrease liquid CO_2 purchase.

4.1.3 NATURAL GAS PRICE AND EXPENSES

Due to corporate secrecy, detailed data of the prices that Wiig Gartneri face for natural gas is unavailable to the public, and some assumptions regarding this must be made. These will be based on the menu pricing that Lyse provides on their webpages, which includes different pricing schemes for industrial customers based on their annual purchase (Lyse, 2020). The price menus range from industrial customers with an annual purchase of less than 150 000 kWh, to the highest range that is production industries with an annual consumption of 700 000 kWh or more. This latter menu is described by Lyse as fitting for “larger, industrial production industries, whom in Lyses opinion have different opportunities in the market than what is covered by the standard prices" (Lyse, ibid.). Given Wiig Gartneri's high annual consumption, we assume that they fit the large user profile, and therefore face the terms stated 700 000+ kWh contract. It is a possibility that Wiig, due to surpassing the 700 000 kWh threshold by more than a factor of 2, faces even more beneficial terms.

The relevant menu, named production company plus, consists of the following prices:

Natural gas production plus	
Monthly fee	3 200 NOK
Base price	7.2 øre/kWh
Monthly median price Platts propane FOB NWE HIGH	x øre/kWh
Transportation	40 USD/ton

Table 1: Natural gas prices for industrial production companies (Lyse, 2020)

The variable element of the price is indexed against Platts propane north west Europe. For simplicity, we will use spot prices at the Title Transfer Facility (TTF), Rotterdam. TTF is the largest virtual hub for natural gas trading in Europe and is therefore likely to properly reflect the prices Wiig Gartneri faces. The reasoning Lyse states for indexing the price against propane is that "there does not exist a stock exchange for natural gas in Norway" (F. Lædre, personal communication, 27. March 2020). Indexing the price in a commodity with a separate price for the north west European market makes sense, if there exist regional price differences within Europe.

For our purpose however, we will assume that there are none such price differentials, and that the natural gas spot price at TTF is an appropriate natural gas price measure. The reasoning for this simplification is that data from TTF are freely available through Datastream, while data regarding Platts propane are behind a paywall.[1]

---

[1] The School of Economics and Business, NMBU subscribes to Thomson Reuters Datastream, and the data is therefore freely available for students.

From the 17.4 GWh Wiig Gartneri purchased in 2019, and based on each month's purchase habits, prices at TTF, and the relevant currency exchange rates, we have estimated the expenses for natural gas in 2019.

In summary, the greenhouse spent 4 390 910 NOK in 2019, with the different cost components being distributed as pictured in the figure below.

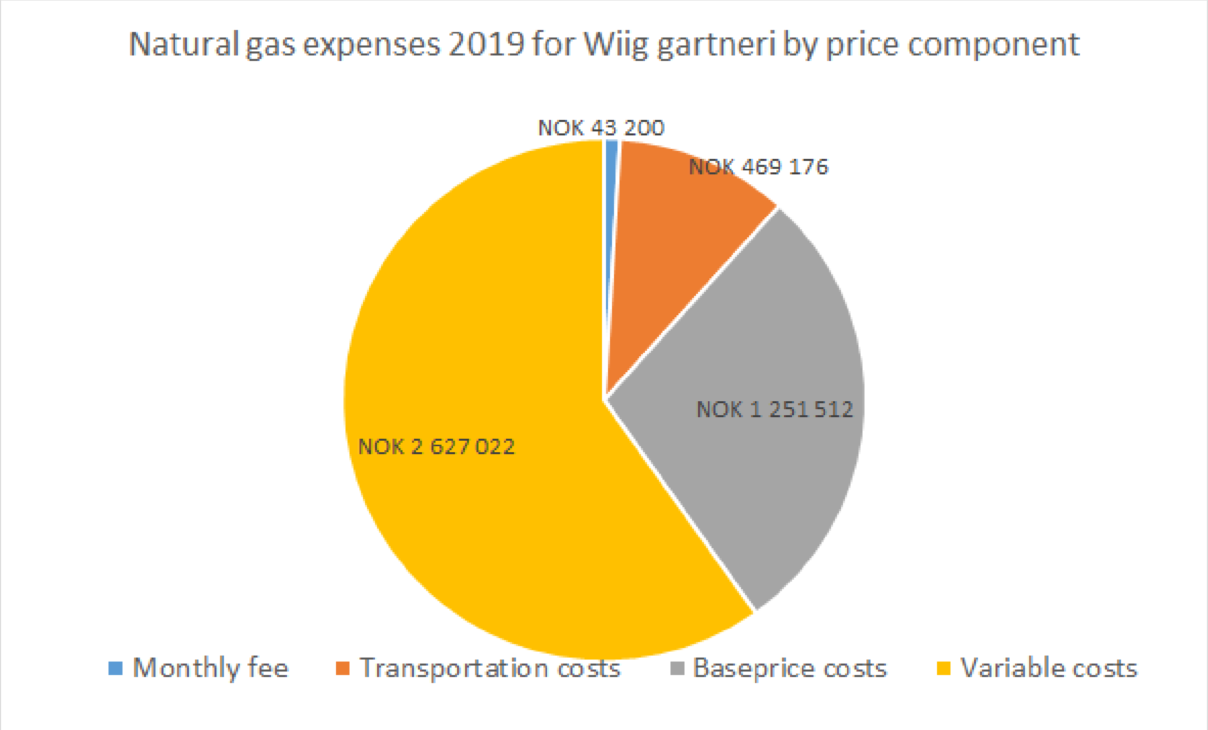


Figure 9: Natural gas expenses by price component (2019)

The expenses correspond to an average kWh price of 25.3 øre. Due to high competition in supply between the US and Russia, 2019 was a year with very low gas prices in Europe. Natural gas prices are forecast to increase over the next years (Diaz & Bertelsen, 2019).

4.2 PRICE FORECASTS

While most strong analytical reports concerning forecasting of natural gas prices being behind paywall, the World Bank provides a forecast for expected annual prices from 2020 every year until 2025, and for 2030. In addition, in the summary of the "European Gas Market Forecast - Annual Report 2019", Aurora Energy Research mentions that the average price at TTF is expected to increase to 29.8 euro/MWh in 2040 (Aurora Energy Research, 2020).

With these datapoints, and assuming a linear price increase between data points that are not subsequent, we have estimated average annual prices for 2020-2045. As 2040 already is concerned with large uncertainty in the price estimate, we have assumed that the price after 2040 follows a random walk, and that the expected price for each year beyond 2040 therefore is equal to the price in the previous year. Seeing as natural gas is a non-renewable resource, a more precise estimate would be to let it follow a Hotelling price path beyond the horizon of available forecasts. The simplification of assuming a random walk should not be to impactful in the analysis however, as cash flows in the later periods have low present value.

Solar thermal collectors have an expected lifetime of 25 years, and we therefore need an estimation of gas prices until at least 2045. The prices and forecasts converted to øre/kWh based on the annual 2019 NOK/USD exchange rate 8.8037 (Norges Bank, 2020) is depicted below.

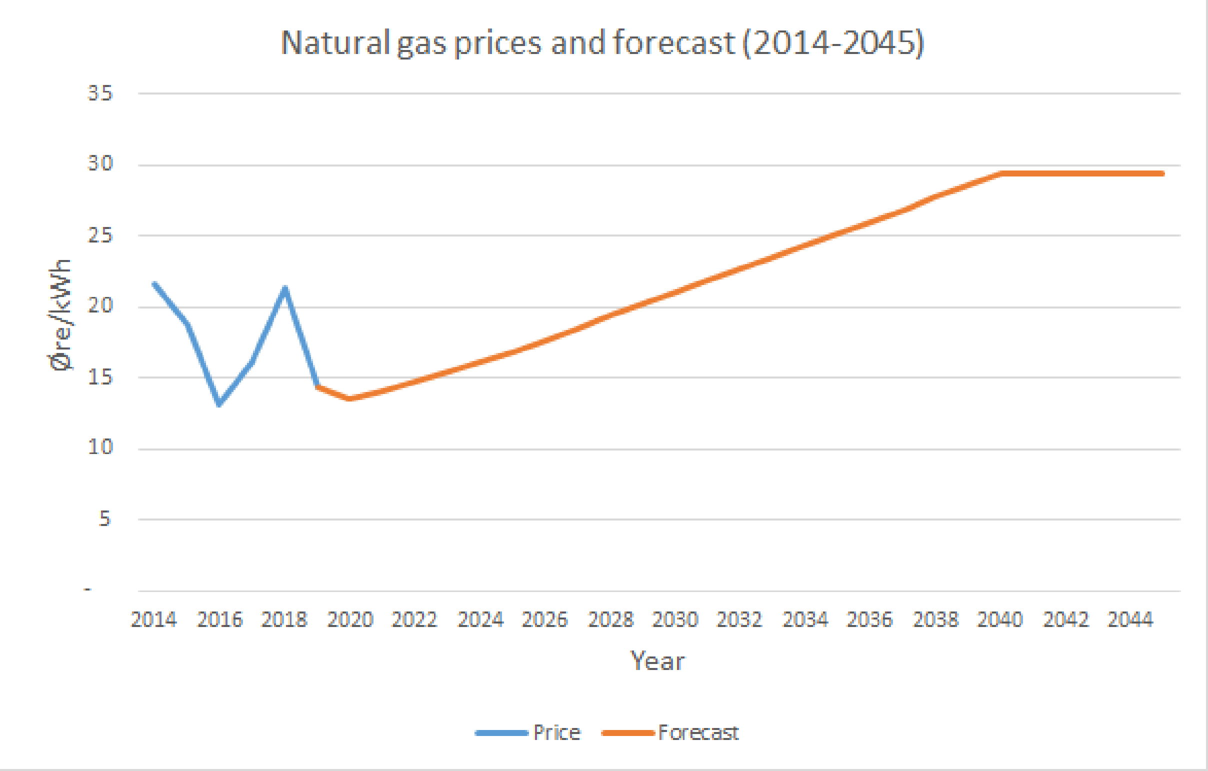


Figure 10: Natural gas prices and forecast (2014-2045)

With natural gas demands that Wiig have varying across months, some variations in the monthly price forecast must be implemented because the price variations within a year are not random. For this, the average historical price variations will be used. While such a method loses out in that the most extreme fluctuations from the annual average price are evened out, this is assumed to not matter as the analysis these data are prepared for is over several years. The obvious strength of this approach is its simplicity.

For this, we have used the annual average price for each year from 2010-2019 and estimated how the price for each month differed from the annual average. Based on these average fluctuations, we have established an overall average fluctuation for each month.

The results are depicted below.

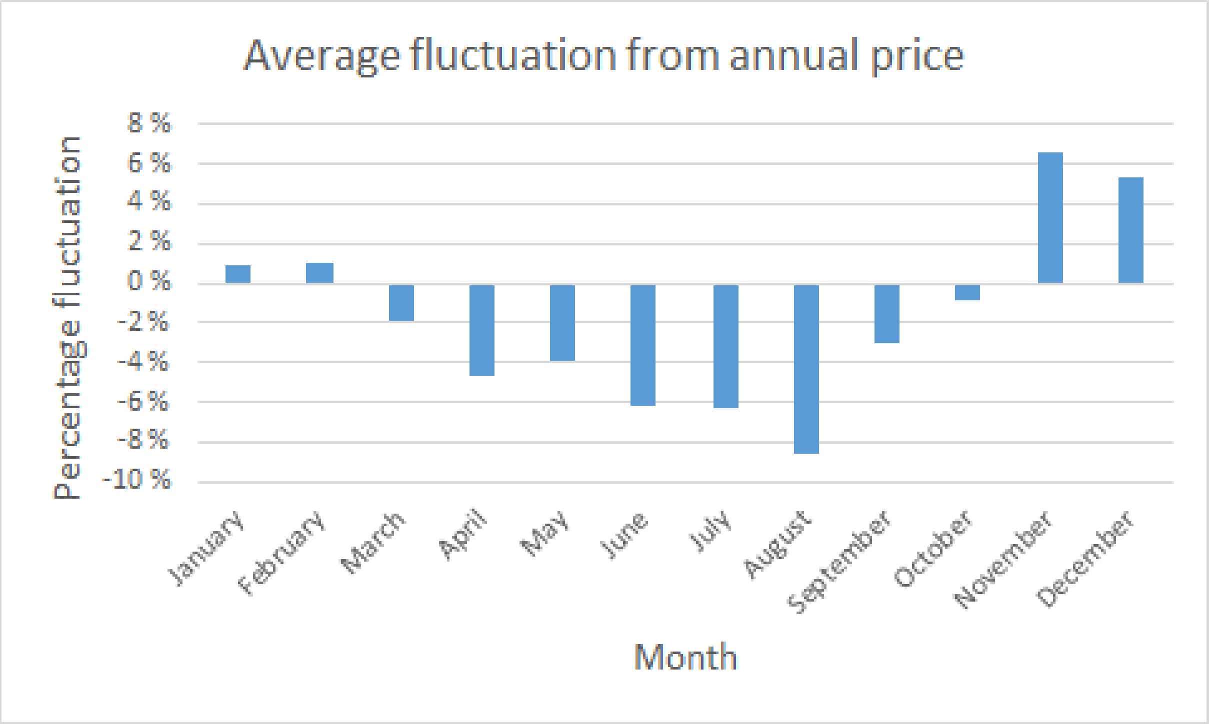


Figure 11: Average natural gas price fluctuation from annual price

These fluctuations will be added to the annual prices, providing a matrix of monthly forecast natural gas prices that will be used for further analysis.

4.3 WEATHER DATA

A primary factor in determining natural gas consumption is the weather. In addition to the temperature obviously being important, solar irradiance will also affect the demand for heating as the greenhouse utilizes solar rays through the greenhouse effect. Both temperature and solar irradiance will be included in establishing a base year for natural gas consumption. Solar irradiance will also be important in measuring the benefits of solar based energy providing technologies.

The necessary weather data is downloaded from NIBIO's agricultural meteorological service (NIBIO LMT, 2020) from the weather station at Særheim. This is the closest weather station to Wiig Gartneri, approximately 8.25 km northeast of the greenhouse.

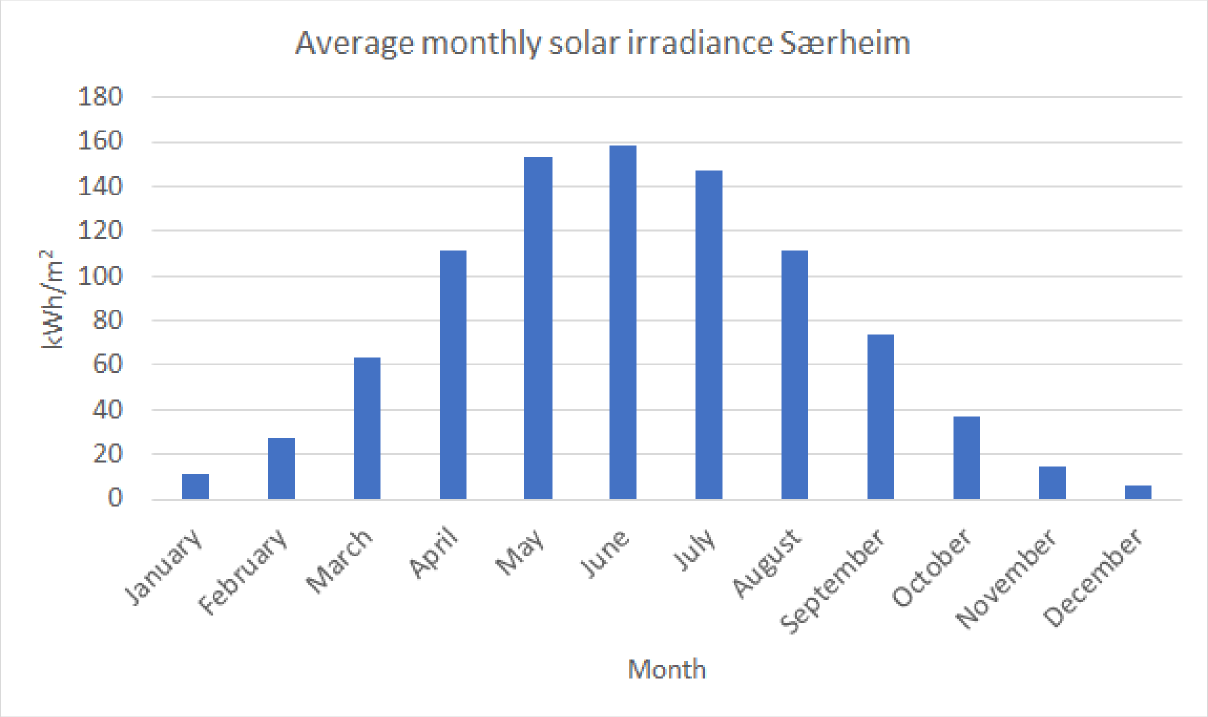


Figure 12: Average monthly solar irradiance measured on Særheim (kWh/m^2) (NIBIO, 2020)

Based on solar irradiance data from 2010-2019, we estimate the average monthly solar irradiance per square meter (m^2). The results are based on hourly data, which are summarized into monthly averages. These data should therefore give a good idea how much energy Wiig Gartneri may expect from possible investments solar thermal collectors.

We have also measured how the temperature observed for 2019 deviate from a ten-years average. This difference become relevant in establishing a base year for analysis later.

4.4 TIME SERIES REGRESSION

In establishing a base year in terms of natural gas consumption, we rely on statistical analysis of the data we have obtained. The purpose of this analysis is to establish an average year in terms of natural gas consumption and weather data, as the weather is not possible to forecast. To do this, we rely on time series regression of 2019 data. A time series regression allows the inclusion of an underlying time trend, a long run evolution in the variable of interest (Diebold, 2019).

One could argue that ordinary cross-sectional regression is more suited given that only one year of data arguably has some limitations. It is difficult to establish a time trend in greenhouse natural gas demand as demand could be the result of increased efficiency for instance due to improved optimization in input usage. We do not have access to output data, and even if we did, this would probably be measured in annual output and therefore several years of data would be necessary to establish a time trend that displayed improved efficiency per output. Such an efficiency parameter would be useful in analyzing the profitability of eventual investments, as natural gas consumption in addition to all other factors also becomes time dependent.

Time series regression allows us to account for potential autocorrelation. This is due to current disturbance being correlated with one or more past disturbances (Diebold, 2019). Autocorrelation can be corrected by adding lagged variables of the explanatory variable that has autocorrelation. Omission of such a lag gives the same issues as an omitted variable problem, where the omitted lagged variable is correlated with both the explanatory and the dependent variable.

When doing time series regression, OLS assumptions differ slightly based on the sample size. In determining whether the sample is small or not, 30 is generally regarded as a cutoff point, where for samples larger than this the central limit theorem may be invoked, and sample means are normally distributed (Statistics How To, 2013). The statistical analysis follows in the next section.

5. ANALYSIS

In the following chapter we initially present the reference scenario. In establishing this, we estimate an average year in terms of natural gas consumption, with respect to temperature and the carbon tax. Following this, we compare the different technologies to the reference alternative.

Usually, the levelized cost of energy (LCOE) is used to measure the overall costs over the lifetime divided by total energy production. This allows for comparison for different energy providing technologies.

$$LCOE = \frac{\sum_{t=0}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{E_t}{(1+r)^t}}$$

Equation 2

In the equation, I is investments, M is operation- and maintenance expenditures, F is fuel expenditures, E is energy produced, t indexes they year, n is lifetime of the project (years), and r is the discount rate.

Given the greenhouse dynamics where CO_2 is vital to increase growth, this measure is not suitable. While a technology may provide energy at a lower LCOE, further investigations must be made to assess how new solution affects profitability when these dynamics are considered. We will therefore include how these interactions are altered when analyzing the different technologies, and not rely solely on LCOE for comparison.

5.1 THE COUNTERFACTUAL EFFECT OF A CARBON TAX

In establishing the counterfactual scenario, we aim to examine which variables explain natural gas consumption. To achieve this, we rely on a time series regression analysis in STATA. The analysis is done on the data provided to us by Wiig Gartneri, as well as the weather data we presented in the previous chapter.

Two goals are sought by this statistical analysis. In establishing a base year for consumption, we require a coefficient for the temperature variable. This will allow us to produce an estimate for natural gas consumption under average temperatures, which we further will use as a base year for analyzing the profitability of alternative technologies.

In addition, we aim to obtain an estimator for the price of natural gas in explaining natural gas demands for Wiig Gartneri. This will provide an estimate of the ceteris paribus effect of implementing a carbon tax on the natural gas utilization of the greenhouse, by treating the carbon tax as a direct and constant increase in the price of natural gas.

5.1.1 DEMAND RESPONSE TO PRICE FLUCTUATIONS

This section describes the approach we use in the regression analysis, as well as which modifications we did to the model. Our variable of interest is natural gas, and this is our dependent variable.

As heat is the primary energy input in greenhouses, temperature is likely to be the most impactful variable in explaining natural gas consumption. Daily temperature data will therefore be included as an explanatory variable.

The price of natural gas is included as the next explanatory variable. This is one of the variables we are particularly interested in obtaining a coefficient for and should have an inverse relationship with the dependent variable according to the law of demand. Additionally, the price of electricity is included as this is the only currently available substitute to natural gas. Electricity beyond what is required for lighting is only purchased when either natural gas boilers are at full capacity and additional heat is required, or when electricity prices are abnormally low. Including electricity prices will control for these cases.

Solar irradiance is expected to be correlated with temperature. It would therefore give an omitted variable bias if it also affects natural gas consumption. Due to the previously mentioned greenhouse effect from solar irradiance, temperature alone is expected to not fully explain the weather effects on natural gas consumption

We will also include the greenhouse’s carbon dioxide demands. If these demands are high, marginally unprofitable natural gas combustion will become profitable, and we therefore expect a non-negative partial effect of this variable on consumption.

In addition, we include seasonal dummies in the model. This is to control for the possibility that natural gas demands depend on where the greenhouse is in the production process, and that the cyclical consumption is not solely attributed to temperature and CO_2 demands. We include four dummies each containing a quarter of the year.

To obtain linearity in parameters when estimating the price elasticities of natural gas and the cross-price elasticity of electricity, we will log transform these variables. As these variables refer to elasticities of input factors, they are likely to have an exponential term and a log transformation is therefore warranted. The remaining variables probably do not have a linear effect on the dependent variable, and we will also log transform the dependent variable - gas consumption. By using the Ramsey reset test we assess the validity of these transformations. We also postestimation testing to examine if the current model can be improved.

To check that weak exogeneity holds, a unit root test must be performed to assess whether the data is weakly stationary. Stationarity implies constant mean and variance and violation of this might yield spurious regression results. The augmented Dickey-Fuller test checks whether the variables contain a unit root process. The results from this test is summarized in the table below.

Variable	**Test statistic**	**P-value**	**Conclusion**
Natural gas demand	-7.96	0.00	Weakly dependent
Natural gas price	-2.3	0.19	Cannot reject unit root
Electricity price	-2.3	0.16	Cannot reject unit root
Carbon dioxide demand	-2.10	0.25	Cannot reject unit root

Table 2: Dickey-Fuller test for unit root

To transform the series into stationary processes, two options exist. If the cause for non-stationarity is a deterministic mean trend in the series, detrending the data will give a stationary series with mean zero. If on the other hand stationarity can be obtained by differencing until stationarity is obtained, the series is said to be integrated of order D, where D is the number of differences required to make the series stationary.

Trend stationary processes is often observed in processes that seemingly increase or decrease over time, such GDP and other economic variables. For our data, it appears that none of the variables is likely to have any significant time trends over one year of observations. Differencing will therefore be attempted to obtain stationary data processes.

The results from this differencing is shown in the table below.

Variable	**Test-statistic**	**P-value**	**Conclusion**	**D**
Natural gas price	-9.36	0.00	Difference stationary	1
Electricity price	-12.65	0.00	Difference stationary	1
Carbon dioxide demand	-11.14	0.00	Difference stationary	1

Table 3: Dickey-Fuller test on differentiated variables

First differencing the non-stationary variables gives the desired stationarity. We will therefore replace the original variables with the first differenced ones to avoid spurious regression.

In addition to stationarity, serial correlation must be addressed as a potential violation of time series assumptions. Without correcting for serial correlation, OLS estimators remain consistent and asymptotically normal distributed, but standard errors are biased and inconsistent. This gives difficulties in inference.

To check for serial correlation the model where first differenced variables replace the original variables, we use the Breusch-Godfrey test. From the test we reject the null hypothesis and conclude that there is an issue with serial correlation. By regressing natural gas consumption on lagged value of itself, we discover that the first and fourth lagged variables have explanatory power over the natural gas consumption. The coefficient for the fourth lagged variable is however very small, so only the first lag is included in the final model.

The Breusch-Godfrey test then gives a p-value of 0.14, and we cannot confidently state that autocorrelation issues have been solved. The chi^2 value of the test is however significantly smaller than previously, and the model appears to be improved.

Finally, we perform the Ramsey reset test to check if the model is functionally misspecified. The test gives an F-value of 0.05, which strongly suggests that the model is satisfyingly specified. This supports the decision to have gas consumption, gas price, electricity price and CO_2 demands as logarithmic, while keeping temperature and solar irradiance linear. The final model thus becomes:

$$Ln\ (Natural\ gas\ consumption_t) = \beta_0 + \beta_1\ ln\ (Price\ natural\ gas_t - Price\ natural\ gas_{t-1}) + \beta_2 \ln\ (natural\ gas\ consumption_{t-1}) + \beta_3\ ln\ (Price\ electricity_t - Price\ electricity_{t-1}) + \beta_4\ ln\ (Carbon\ dioxide\ demands_t - Carbon\ dioxide\ demands_{t-1}) + \beta_5\ Temperature_t + \beta_6\ Irradiance_t + \beta_7\ Quarter1 + \beta_8\ Quarter2 + \beta_9\ Quarter3$$

Equation 3

The results from the model is presented below. Coefficients for each variable is depicted with standard errors in parenthesis. Test statistics concerning the overall model such as F-value and R squared are also included, in addition to degrees of freedom.

```
------------------------------------
                          results
                             b/se
------------------------------------
gasprice_d1                 0.377
                           (0.54)
gasconsumption_l1           0.354***
                           (0.08)
elprice_d1                  0.119
                           (0.12)
co2demand_d1                0.098
                           (0.10)
temperature                -0.041***
                           (0.01)
irradiance                 -0.006*
                           (0.00)
quarter1                    0.146***
                           (0.04)
quarter2                    0.162*
                           (0.08)
quarter3                    0.169
                           (0.09)
constant                    7.182***
                           (0.85)
------------------------------------
F-statistic                 76.53
R-sq                        0.635
dof                           354
------------------------------------
* p<0.05, ** p<0.01, *** p<0.001
```

Table 4: Regression results

The F-test examines the joint hypothesis that all explanatory variables are simultaneously zero. An F-statistic of 68.5 lets us discard this and conclude that at least one of the variables have explanatory power over natural gas consumption. Further, the model displays an R^2 value of 0.64, which further strengthens the assessment that the variations in the natural gas consumption is reasonably explained by the explanatory variables.

The first variable of interest - the price of natural gas - has a positive coefficient of 0.37. This does not make immediate economic sense, as it contradicts the law of demand. With a standard error of 0.54, the partial effect is not statistically different from zero, suggesting other factors adding noise to the natural gas demands.

A possible explanation is that the greenhouse has very inelastic short-term demand, and that other factors such as temperature and the requirement for carbon dioxide are more important for explaining gas consumption. The estimated strong and significant impact on lagged quantity gas usage suggests that temperature is more important than the price of natural gas. Another plausible, short term elasticity for the greenhouse is one where demand is very inelastic for all prices up until a certain threshold price, where another technology becomes the primary fuel for the greenhouse - or profitability is so low that to shut down production is the most optimal.

From the regression result, we cannot state that the greenhouse decreases natural gas consumption when prices increase. The energy for heat as an input in greenhouses comes with increasing returns to scale, implying that marginally reducing energy input decreases production by a larger share. This result gives some strength to the claim by Meberg in NGF (2018), that a carbon fee would only decrease profitability of greenhouses, with marginal effect on carbon emissions. We cannot state with certainty that this result holds in the long run as well, but we will assume it does when we establish our reference scenario. The implication is that natural gas demands are assumed perfectly inelastic, and natural gas consumption unchanged over the course of the analysis.

The estimator for temperature displays the expected characteristics. A negative coefficient of -0.041 implies that natural gas consumption increases when the temperature decrease. The coefficient is also significant, with a standard error of 0.01. Temperature is linear, so inference must be done as a log linear ceteris paribus effect. A one degree increase in temperature gives a change in natural gas consumption of $100 * (-0.041) = -4.1$ percent. From this result, we estimate the reference year with respect to natural gas consumption, for normalized temperatures.

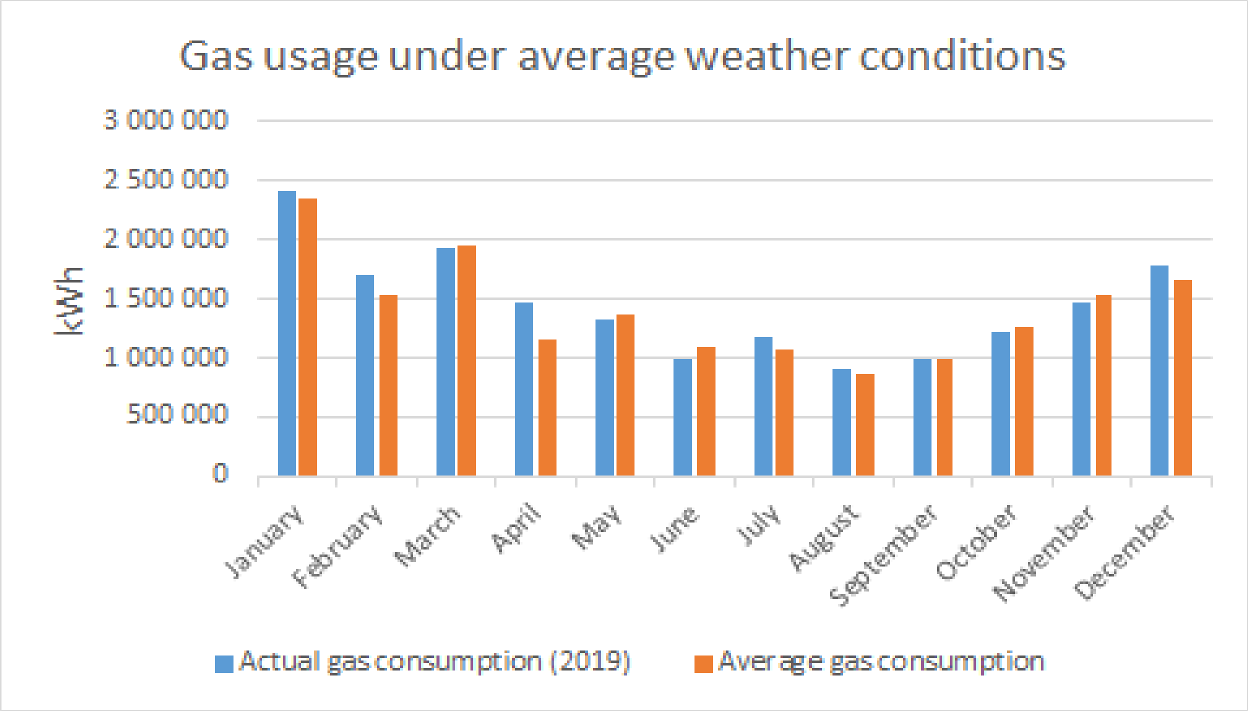


Figure 13: Gas usage under average weather conditions

The graph compares the actual natural gas usage for 2019 to that which would have been the case with average temperature, based on the estimated temperature coefficient. The resulting annual energy demand totals to 16 858 MWh, with monthly distribution depicted in the picture above. This result is useful in further analysis about existing alternatives the greenhouse has, as it allows us to normalize all years to an average year in terms of natural gas consumption. We will assume that inevitable fluctuations from this average year will even out over the horizon of analysis.

5.2 REFERENCE SCENARIO

From previous regression, we assumed that energy demands are unchanged when faced with a carbon tax. Subsequently, the burden of the tax is adopted by the greenhouse through larger natural gas expenses for all periods. The reference alternative provides us with a basis to compare the alternatives, our business-as-usual scenario. This differences between the alternative technologies and the reference scenario will subsequently allow us to estimate emissions reductions and cost savings. We will use these assumptions in estimating the cost of energy for both a 20- and 25 years period, as these are the expected lifetimes of the alternatives.

The reference scenario is our projection of the most probable outcome as a result of the current set of policies. However, it should not be treated as a forecast, but rather as a benchmark when evaluating new investment proposals for the greenhouse.

In the reference alternative, the greenhouse's annual consumption of natural gas is 16 858 MWh. In this scenario, the main assumptions are as described earlier in this chapter. This implies that no biofuel or solar thermal energy is utilized, and negligible or no change in production in response to the carbon tax. We assume that energy usage per output and injection efficiency is equal for all periods. Furthermore, we continue to use a discount rate of 4%.

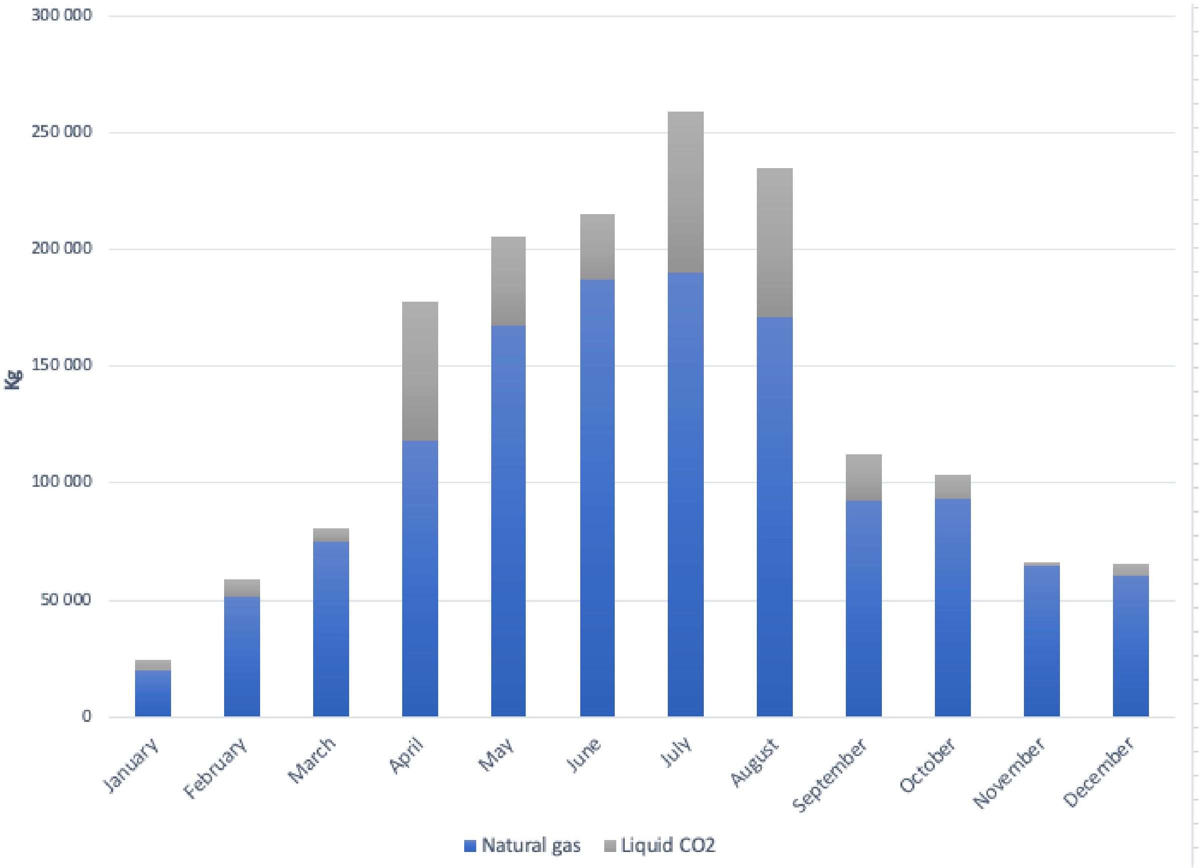


Figure 14: Share of CO2 from natural gas and liquid, annually (F. Ringsevjen, personal communication, 29. January 2020)

When using natural gas to cover for their heat demand, Wiig Gartneri is able to provide most of their CO_2 requirements throughout the year. Nevertheless, the utilization of exhaust CO_2 from natural gas combustion must be supplemented with liquid CO_2, primarily during summer.

The reference scenarios are based the forecast price of natural gas, with no efficiency improvements over the periods. The price of liquid CO_2 is assumed constant at 1.64 NOK per kg. The estimations are the sum of energy related expenses, with energy and CO_2 requirements met for all periods, where each period is one month and based on the reference year in the previous section. We also assume that natural gas covers all energy demands in all periods.

Using the assumptions above, we derive the following numbers.

Costs (NOK thousand)		Emissions (tonnes)	
Natural gas	72 539	Total emissions natural gas	67 434
Carbon tax	46 477	Liquid CO_2	6 248
Liquid carbon	7 475		
Total costs	**126491**	**Total**	**73 682**

Table 5: Costs reference alternative, 20 years, discounted

Assuming the carbon tax is implemented, and the greenhouse continues to only use natural gas to cover their heat demand, the net present value of heat energy costs the next 20 years for Wiig Gartneri is 126 491 000 NOK. The carbon tax accounts for roughly a third of the overall costs. Annual carbon emissions in this alternative is 3 684 tonnes, adding up to 73 682 tonnes throughout the economic lifetime of this project.

Costs (NOK thousand)		Emissions (tonnes)	
Natural gas	90 673	Total emissions natural gas	84293
Carbon tax	58 989	Liquid CO_2	7810
Liquid carbon	8 516		
Total costs	**158 179**	**Total**	**92103**

Table 6: Costs reference alternative, 25 years, discounted

Assuming a lifetime of 25 years, the total costs increase to 158 179 000 NOK, while carbon emissions add up to 92 103 tonnes. Because we assume that the elasticity of demand for natural gas is perfectly inelastic, the only difference in these scenarios is the cost imposed by the carbon tax. For the following sections, we will use these results to calculate the net benefits resulting from altering the energy mix. This enables us to compare the different alternatives and their profitability.

5.3 PROFITABILITY ANALYSIS BIOGAS

5.3.1 PROJECT DEFINITION

For this part of the analysis, we examine if biogas can be implemented as a cost-competitive substitute for a share of the consumption of natural gas in the specific case of Wiig Gartneri. We assume the biogas will be delivered by Lyse, the current distributor of natural gas, through the existing infrastructure. Currently, biogas in Rogaland is produced at Grødaland by IVAR (the local waste collector), who currently produces mostly biogas as fuels for filling stations, but also for industry and heating. The data used in this analysis is based on costs estimated in Sidelnikova et al. (2015), while prices for biogas are provided by Lyse (M. Bolme, personal communication, 17. April 2020).

We assume that biogas will replace a share of the consumption of fossil gas, and that there is sufficient supply of biogas available to cover the demand. Additionally, we assume that the biogas is of sufficient quality to be distributed by the existing gas infrastructure in Rogaland. To replace a share of natural gas with biogas requires no additional investments for the customers. Upgraded biogas (biogas with more than 97% methane) can be fed directly into the existing natural gas boilers. It is therefore not necessary to replace boilers or other on-site infrastructure (Pederstad et al., 2018; Norwegian Environment Agency and NVE, 2020). Wiig already has a 5 MW natural gas boiler, which we thus assume can be used for biogas.

No investment decision is therefore required by the greenhouse.

5.3.2 RESULTS

To find the optimal energy mix between biogas and natural gas, we use the solver function for each year over the economic lifetime of the project. This enables us to see at what level the carbon tax makes biogas profitable. Because natural gas and biogas share the same operating- and maintenance costs, and no investment is needed, biogas will become profitable when the fuel costs for natural gas exceeds the fuel costs of biogas.

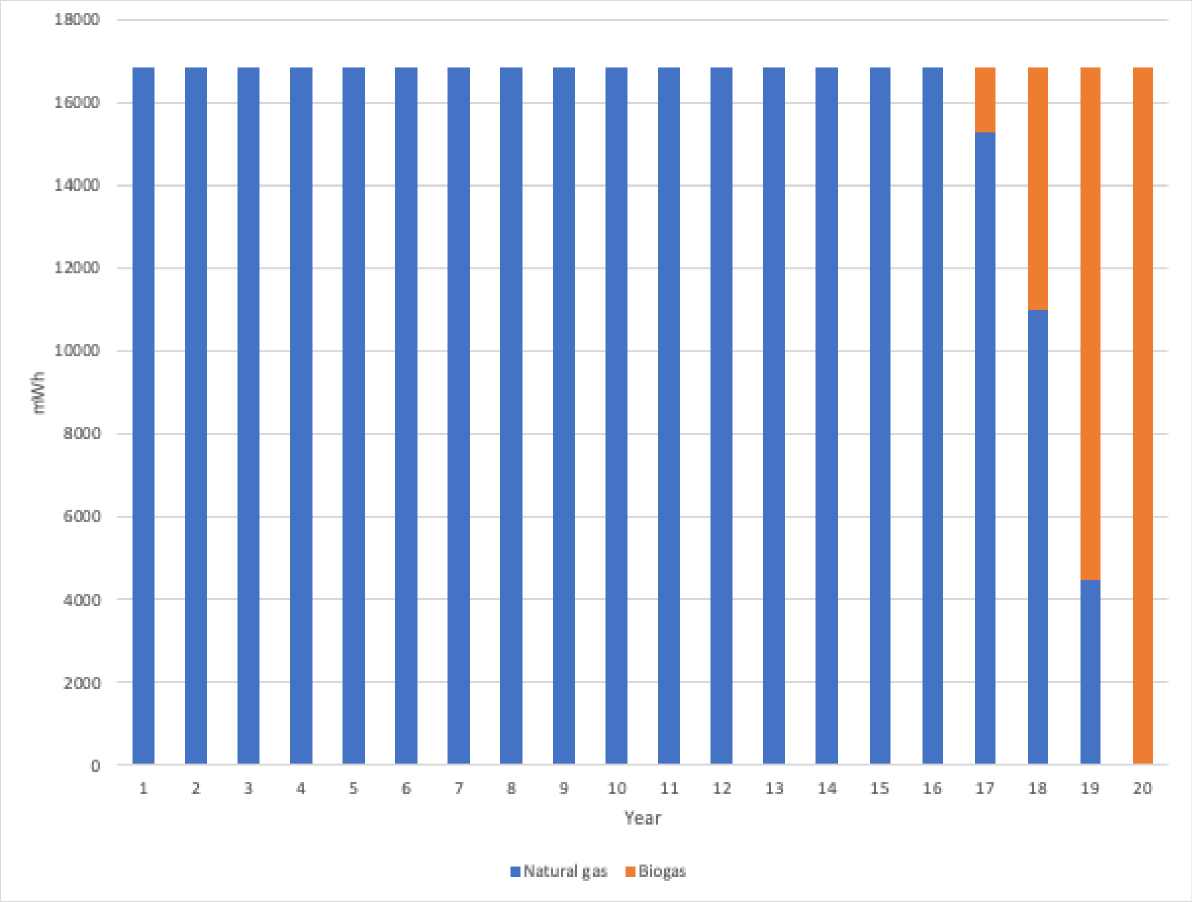


Figure 15: Optimal energy mix of biogas and natural gas over the economic lifetime (own calculations)

The figure above shows the optimal mix of biogas utilization over the next 20 years. From our results, it is evident that to minimize costs, it is most optimal for Wiig to continue using natural gas to cover their heat demand until year 16. However, in year 17, we find that it is optimal to use biogas for one month, equal to 1539 MWh. This is the turning point where the carbon tax has increased to the extent where biogas is becoming more profitable, especially in months with high energy demand. For the succeeding years, biogas becomes gradually more profitable, and the optimal use of biogas increases accordingly. In years 18 and 19, the use of biogas increases to 4 and 8 months. Finally, in year 20, we find that it is optimal to completely replace natural gas with biogas. This projection is based on a continuous increase in the real carbon tax and real price of natural gas, while the price of biogas is unchanged.

The results are summarized in the table below:

Costs (NOK thousand)		Emissions (tonnes)	
Biogas	11663	Total emissions natural gas	63486
Natural gas	72351	Liquid CO_2	6248
Carbon tax	37741		
Liquid carbon	7475		
Total costs	**129230**	**Total**	**69734**

Table 7: Costs and emissions for biogas, discounted

From the reference alternative, total CO_2-emissions have been reduced by 7320 tonnes, while total costs have been reduced slightly with 379 000 NOK.

The fuel cost accounts for more than 98% of the total costs for biogas. Additionally, the fuel costs for biogas that consumers face is indexed against the spot price of electricity, which adjusts continuously. The fuel costs will thus in practice be higher, especially in periods with high electricity prices, such as the winter months.

This analysis is based on the current market conditions. Insecurities about the biogas market, both short- and long term, works as a barrier for increased biogas production. This insecurity is reinforced by vague goals regarding future biofuels production from the authorities (Norwegian Environment Agency, ibid.).

To calculate the cash flow in this analysis, we consider the saved carbon tax expenses, when converting from natural gas to biofuels, and the overall cost savings, as the benefits. The environmental benefits of the biofuel types have been estimated through the price of carbon. The European Commission explained this choice in their report “Biofuels in the European Context” (2008) that it would be incorrect to ascribe a higher benefit than the cost of achieving the same reduction in emissions elsewhere (Edwards et al, 2008). The carbon price used is 545 NOK/tCO_2.

Year	Cash inflow/outflow biogas
0	0
1	0
2	0
3	0
4	0
5	0
6	0

7	0
8	0
9	0
10	0
11	0
12	0
13	0
14	0
15	0
16	0
17	197212
18	753939
19	1616584
20	2223358
NPV	**2 168 673**

Table 8: NPV for biogas (own calculations)

The results after summing up the inflows and outflows, is a positive NPV of 2 168 673 NOK for biogas. According to the NPV methodology, a positive NPV implies that a project should be implemented based on business criteria. Following this decision criterion, the greenhouse should slowly start to convert from natural gas to biogas in 2037. They would profit from this change, because the carbon tax will have increased to a point where the fuel costs for natural gas exceeds the costs of biogas. However, currently it is more beneficial to continue using natural gas - even with the implementation of a carbon tax. The potential carbon tax is too low to make biogas a more competitive alternative to natural gas, because of the considerable difference in the base fuel prices.

According to a study done by the Norwegian Environment Agency (2020), the current CO_2 tax rate must increase to 1600 NOK/ton, and around 2200 NOK/ton in 2030 for conversion from natural gas to biogas to become profitable. These estimates are sensitive to the repayment period.

We find that using a carbon tax of 1155 NOK/ton makes biogas profitable, resulting in a total cost of 173 842 000 NOK. However, the cost reduction is insignificant. Only 2.2% less than what the total costs would be using only natural gas, at the same carbon tax rate. A 5% increase a year would then result in a tax of 1881 NOK in 2030 (assuming year 0 is 2020).

5.3.4 SUMMARY BIOGAS

Converting from fossil gas to fossil free alternatives will result in additional costs, regardless of the alternative chosen. In this case, the additional costs derive from both increased investment costs to change the energy supply, and increased fuel costs. Upgraded biogas can be fed directly into the existing gas pipes, and thus the natural gas boilers do not have to be replaced. Hence, to replace fossil gas with biogas is technically easy, but it does however result in additional costs because biogas has higher fuel costs.

For Wiig Gartneri who is already utilizing natural gas, the least costly alternative is to continue with natural gas given today's policies. The current price level for biogas is too high. However, given our assumptions, we expect the fuel costs for natural gas to exceed biogas from 2037, because of rising carbon tax rates. Increased tax rates on fossil energy will contribute to make the fuel costs for biogas relatively cheaper. This results in a positive NPV for biogas, because converting to biogas do not require any investments, so by waiting until the fuel costs are lower for biogas, will result in a positive cash inflow for the project, and no cash outflow.

Subsequently, increased taxes on carbon can be a policy to reduce the additional costs for biogas. A binding strategy to increase the tax towards 2040 could therefore give a strong signal to potential producers and consumers (Norwegian Environment Agency, 2020). When the use of biogas is more expensive than natural gas, the market for biogas will be limited to consumers who accept additional costs for reduced emissions (Norwegian Environment Agency, ibid.).

Given today's policies the most profitable alternative for greenhouses already using natural gas to cover their heat demand, is to continue to do so. However, towards 2040, biogas could turn out to be favorable because of increased carbon tax rates.

5.4 PROFITABILITY ANALYSIS SOLAR THERMAL COLLECTORS

5.4.1 PROJECT DEFINITION

The complicating factor in optimizing the energy mix for greenhouses is the continuous requirements for carbon dioxide within the growth environment. The primary goal of an investment will therefore be to replace some of the energy requirements that come with excessive carbon emissions. Installation of solar thermal collectors decrease natural gas requirements and hence reduce greenhouses' residual CO_2 from burning. To make up for this in periods when gas combustion is inadequate in filling the CO_2 requirements of the greenhouse, CO_2 will have to be bought. The current alternative the greenhouse has for fulfilling carbon dioxide requirements is to purchase liquid carbon dioxide.

5.4.2 ASSUMPTIONS

The benefits from investing in solar collectors is the clean and, except for high capital costs, cheap thermal energy they produce. This will offset existing heat requirements, reducing natural gas combustion.

With an efficiency range of 50-70% and based on solar irradiance levels measured at NIBIO Særheim, we estimate monthly thermal energy production provided by the collectors per m^2 invested, for different efficiency ranges.

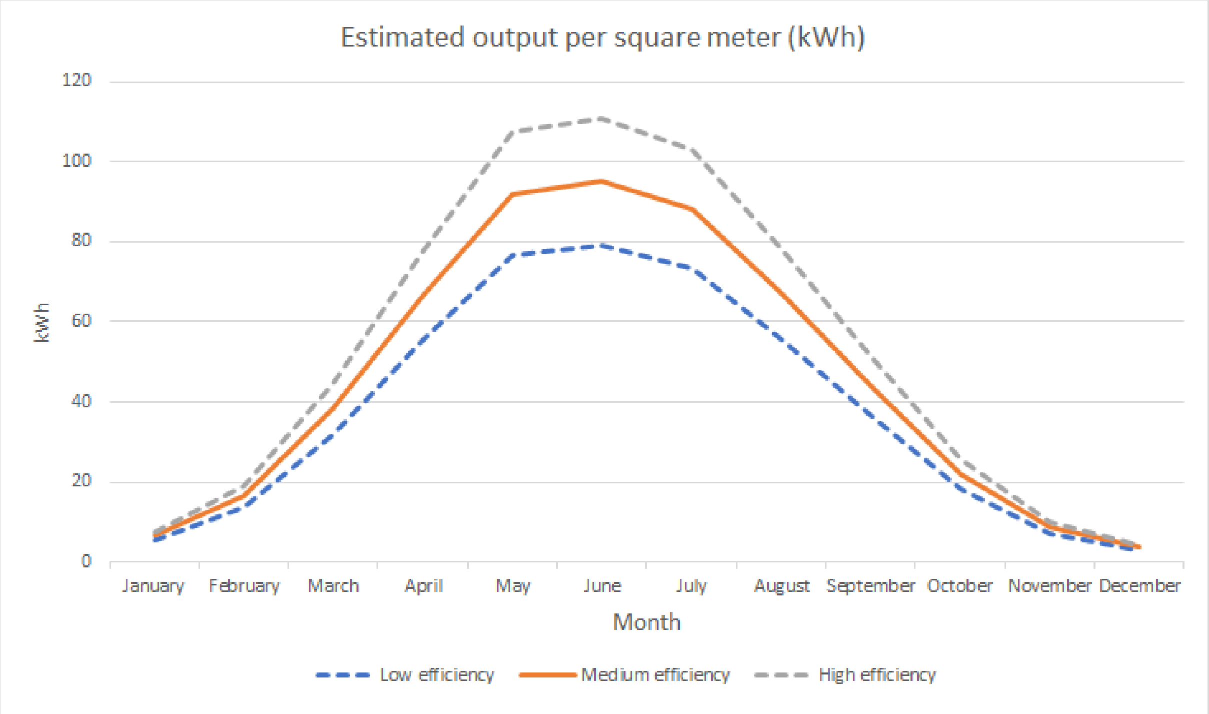


Figure 16: Estimated output per square meter (kWh) (own calcuations)

Sidelnikova et al. (2015) estimate the cost of solar thermal collectors. Their estimates range from smaller scope suited for households, to large, freestanding installations surpassing 500 m^2. We deem the most suitable alternative for an industrial actor, such as a greenhouse, to be the medium range industrial scale, which ranges from 100 to 500 m^2. The estimated cost of such an installation, based on the in between range of 300 m^2, comes at 990.000 NOK, or 3300 NOK/m^2.

This number comes with some uncertainty. For larger scale investments, the technology is still immature in Norway, and NVE base the figures on information received by Norwegian suppliers, as well as NVEs own calculations.

The costs estimated by NVE are distributed like this, for the different components of a solar thermal installation.

Industrial building, 300 m^2	**Total price (NOK)**
Materials:	
Module	703890
Piping	18810
Control systems	11880
Heat storage tank	175230
Installation	8010
Total	**990000**

Table 9: Costs distribution for investment costs of a solar thermal installation (Sidelnikova et al., 2015)

The numbers in this table is based on averages from information gathered by domestic supplies. The total costs may therefore vary from a low estimate of 713 000 NOK to a high estimate of 1 270 000 NOK.

This cost estimate also includes a heat storage tank, where heat is stored as hot water to cover for fluctuating demand. Wiig Gartneri already has access to a more than sufficiently large buffer tank (capacity 800 m^3 of collectors) for this purpose, and this cost may therefore be subtracted. Without the storage tank the total costs are reduced to 814 770 NOK, or 2716 NOK per m^2 for the middle estimate. The price of the tank makes up for 17.7% of the overall costs in NVEs estimations.

Costs for thermal collector systems have decreased substantially since 1995, with a projected learning rate of 23% (Stryi-Hipp et al., 2012). This implies that costs of investing in new technology decreases 23% every time cumulative production is doubled. The learning rate, however, is not constant and decreases as the most accessible cost reductions are achieved.

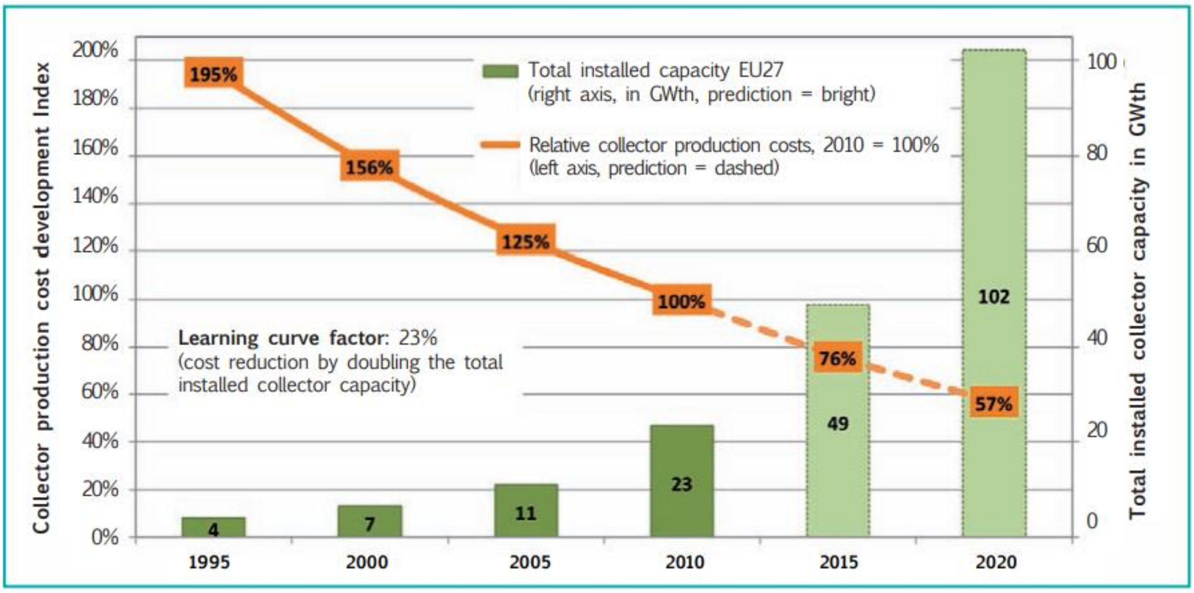


Figure 17: Collector production cost development index (Stryi-Hipp et al., 2012)

Based on the projected costs and cumulative capacity from 2015 to 2020, we see that the projected learning rate is estimated to be 18.27%, with costs decreasing 19% due to capacity slightly more than doubling. Given that these projections are accurate, we may cut additional 19% of the costs NVE estimates in Sidelnikova et al. (2015) report. The projection from Stryi-Hipp et al. (2012) is based on averages for Europe, which may be ill-suited for Norwegian conditions. While European capacity was projected to increase substantially, this has not been the case for Norway in recent years, with capacity stagnating in recent years.

For our cost estimate, we will assume that all beneficial effects that emerge in Europe will also benefit Norwegian consumers, as Europe is tightly integrated with respect to improving energy efficiency and preventing climate changes.

NVE (Sidelnikova et al. (2015), projected a likely price development for Norway.

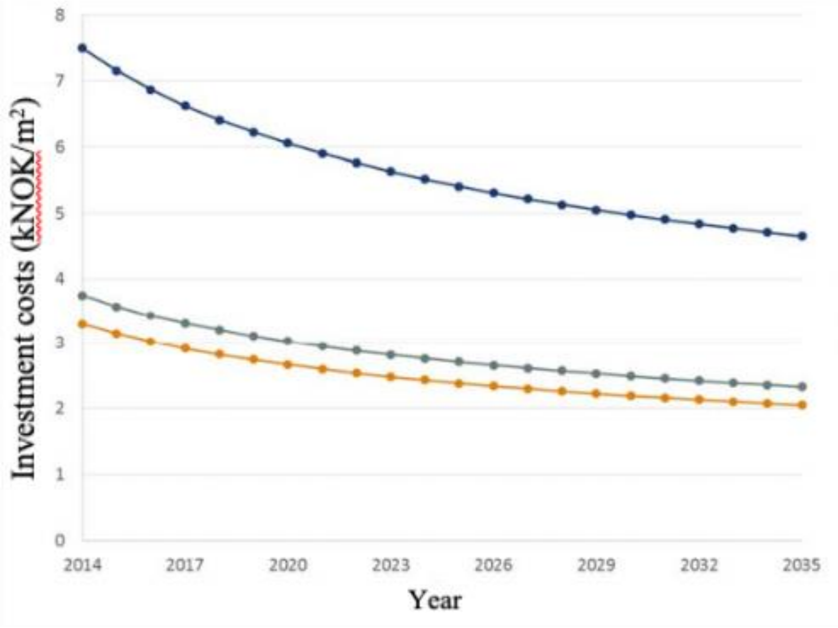


Figure 18: Development of investment costs (Sidelnikova et al., 2015). From the top: detached house, industrial building, and free standing.

Figure 25 shows that for industrial plants the price per m^2 capacity is estimated to approach 2500 NOK by 2020, and almost reach 2000 NOK/m^2 by 2035. This estimate corresponds reasonably well with the learning rate ESTIF uses (Stryi-Hipp et al., 2012), as a 19% cost decrease from the 2015 estimate of 3300 will give a 2020 price of 2673 NOK/m^2.

We will use 2673 NOK/m^2 as a basis for our analysis. Assuming cost decreases are distributed evenly across the different components, 17.7% can again subtracted for the storage tank costs. This gives a m^2 price of 2200 NOK for the medium price range.

Limitations with respect to available areas must also be considered. For Wiig Gartneri, the most suitable option for area designation to the installation is the adjacent field. The transformation of cultivated fields into alternative usage is regulated and must be approved by authorities. We will not go into detail on the actual process of reassignment of plots, or whether it includes additional economic costs for the greenhouse. Instead, we will value the field by approximating the alternative value.

The average rental prices for land are collected annually by the Norwegian agricultural agency. It is reasonable to expect that these rental prices reflect annual economic profits per 1000 m^2 land as there are many actors in the land rental markets. Through the formula for net present value for a perpetuity, we estimate the market price by dividing the prices by the discount rate. With a discount rate of 4%, we have an estimation for the alternative value for the relevant region – Rogaland, and relevant soil type - grass farming. Prices display NOK/1000 m^2.

Low quality			**High quality**		
Low price	Med. price	High price	Low price	Med. price	High price
0	4 900,-	9 625,-	0	11 250,-	18 750,-

Table 10: Alternative value for land (Norwegian agricultural agency, 2019)

Based on data from NIBIO (2020) the field closest adjacent to Wiig contains one part of good land quality, and a larger part of medium land quality. The medium quality land piece is 24000 m^2, which is more than sufficient for any realistic investments.

As medium quality land falls somewhere in between the two pricing categories, we use the average of the high price for low quality and medium price for good quality to estimate the alternative value. This gives an additional cost of 10438 NOK/1000 m^2. We will include this cost in the profitability analysis of the solar collectors. However, a price in the proximity of 10 NOK per m^2 is less than 0.5% of total capital costs.

Sidelnikova et al. (2015) also assume a lifetime of 25 years for solar thermal collectors. We will adopt this assumption for this analysis.

Assumptions Solar thermal collectors	
Lifetime	25 years
Investment cost (NOK/m^2)	2.200
Price of liquid CO_2 (NOK/kg)	1.64
Operation- and maintenance costs (of CAPEX)	1
Collector efficiency	60%
Discount rate	4 %
Alternative value land (NOK/m2)	10.4

Table 11: Assumptions Solar thermal collectors (Sidelnikova et al., 2015; F. Ringsevjen, personal communication, 29. March 2020; Norwegian agriculture agency, 2019)

Annual energy requirements are assumed equal for all years and based on the estimated monthly requirements in the reference year.

To determine the economic effect of investing in solar technology, we will use the solver function in Microsoft Excel. The results will be compared to the estimate in the reference scenario of the heat and carbon dioxide related costs for the lifetime of the thermal collectors – 25 year. The investment will be measured against this reference scenario, with additional sensitivity analysis being investigated to account for uncertainty in the assumptions.

The model is set to minimize the sum of discounted costs over the lifetime of the project. The choice variable is the extent of solar investment, measured in m^2. The restrictions are that all energy and carbon dioxide demands must be met in all periods.

Results are presented depicting overall profitability, change in profitability per cost component, and change in carbon emissions.

5.4.3 RESULTS

With the initial assumptions, solar thermal collectors are unprofitable for all values and costs are minimized with no investment. To perform sensitivity analysis, we will therefore consider an investment of 300 m^2 for comparison.

The total cost of investing in 300 m^2 collectors, including maintenance and operation, comes at 773 358 NOK. Savings as a result of decreased natural gas purchases comes at 864 809 NOK, while carbon tax savings adds up to 183 454 NOK. Additional expenses due to increased requirements for liquid carbon however increase by 585 338 NOK, giving a total net present value of cost savings of – 310 342 NOK, or – 1 035 NOK per m^2. All figures are measured over the lifetime of the project.

The effect on carbon emissions is small, with an annual decrease in natural gas emissions of 33 tonnes. This effect is however largely offset due to 22 tonnes additional liquid carbon dioxide having to be purchased - giving a net decrease of only 12 tonnes annually. Annual emissions decline from 3372 to 3360 tonnes, a decrease of less than 1%. Recall that solar thermal collectors mostly produce thermal energy in the summer, when CO_2 is scarce. Large amounts of liquid CO_2 must therefore be purchased, which is reflected in the substantial increase in the liquid CO_2 expenses and small reductions in emissions.

The results are summarized in the table below.

Energy related expense	Reference scenario	Invest in 300 m^2 solar	Change
Solar Capex + O&M	0	773 358	+ 773.758
Natural gas	90 673 835	89 809 025	- 864 809
Carbon tax	58 989 149	58 805 695	- 183 454
Liquid carbon	8 516 470	9 101 809	+ 585.338
SUM	**158 179 454**	**158 489 887**	**+ 310 432**

Table 12: Results of investing in 300 m^2 solar collectors (own calculations)

The estimated LCOE in this scenario is 30.1 øre per kWh for solar power, while natural provides energy at an average LCOE of 34.4 øre. Energy from solar collectors come at a cheaper cost than from natural gas, which is also reflected in that the additional solar collector costs are lower than the natural gas savings in the table above. This difference is however not enough given the quite high additional liquid carbon cost compared to carbon tax savings, which showcase the dynamics of energy and CO_2 requirements in the greenhouse.

5.4.4 SENSITIVITIES

While collectors are far from being profitable with any minor tweaks to the parameters, we will still perform a sensitivity analysis to examine how large cost decrease is required for an investment to become viable. In the analysis, the costs will be divided by component to see how the different cost components work in tandem to influence the total costs.

The graphics will showcase the difference in costs if an investment of 300 m^2 solar collectors is made, compared to not investing anything. Negative curves are therefore cost savings, and decreasing curves implies increased profitability.

EFFICIENCY PARAMETER

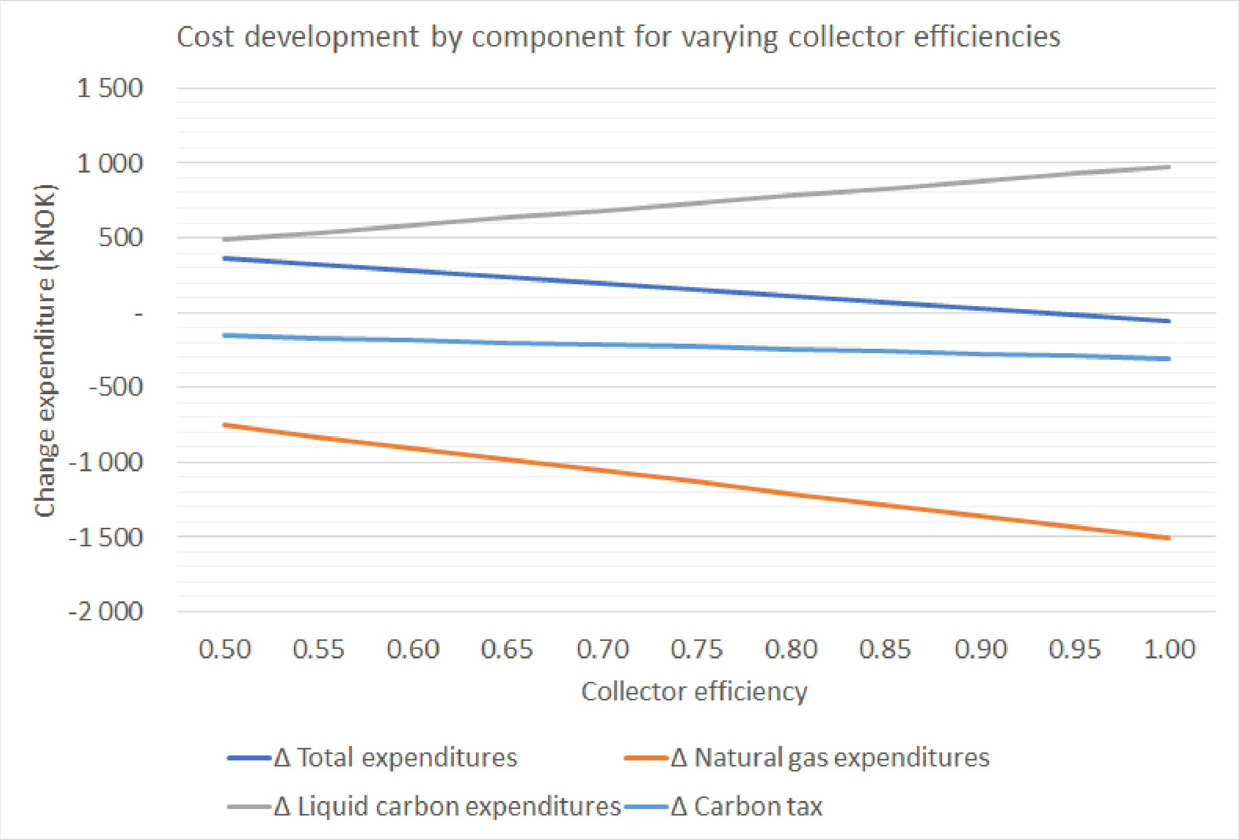


Figure 19: Sensitivity analysis efficiency parameter

From the assumed parameters and prices, we see that for increased efficiency of the solar collector's investment breaks even at 93.2% efficiency. This is depicted as the point where the line “change total expenditures” falls below 0 in the graph above. With potential efficiency capped at 100% by the first law of thermodynamics, such an efficiency improvement is technically feasible given enough time. However, it is a likely scenario that the easiest and cheapest efficiency improvements are already implemented, and that marginal efficiency improvements become very expensive when efficiency approaches maximum. The marginal benefit of one percent increase in collector efficiency is 8402 NOK.

In the figure, the offsetting effect that carbon expenditures have on total profitability becomes visible. Any efficiency increase offers the most benefits during summer. Liquid carbon expenditures subsequently increase more than if the benefit was provided in winter months, when carbon dioxide is less scarce.

INVESTMENT COSTS

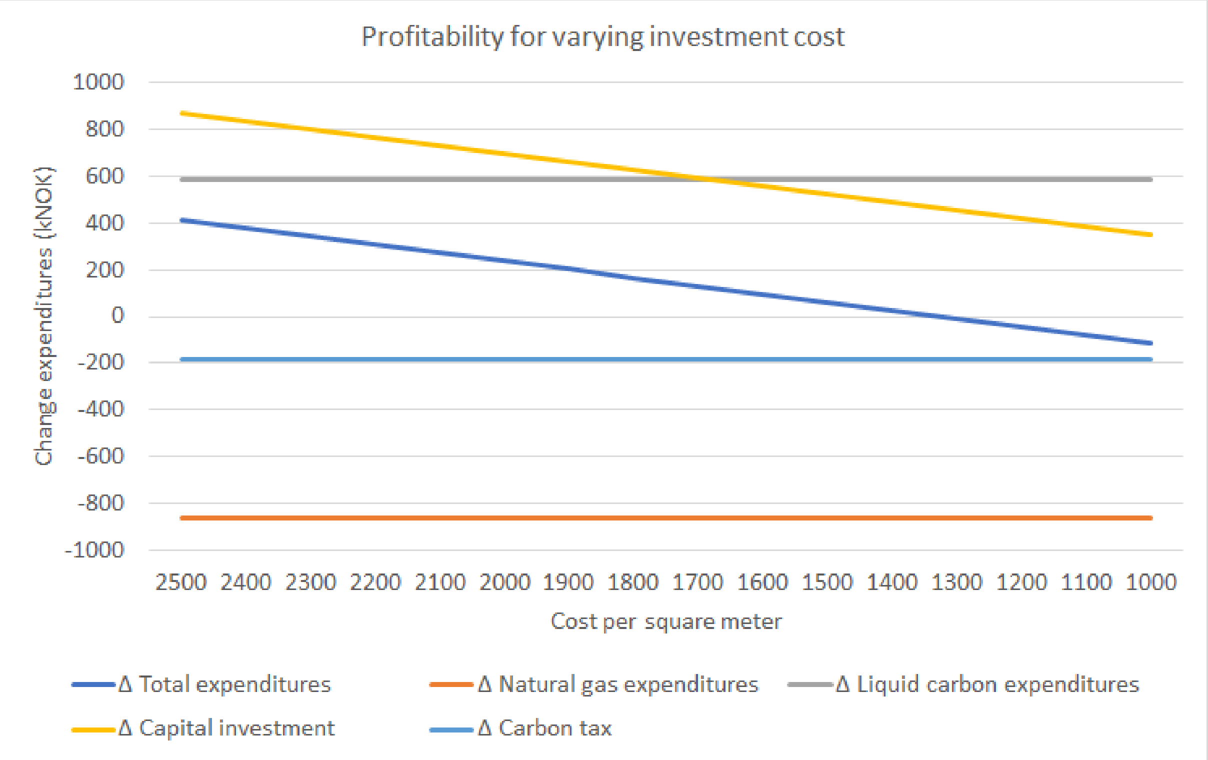


Figure 20: Sensitivity analysis investment costs

Changing the investment cost per m^2 does not change the dynamics of natural gas and carbon requirements. The only cost factor that changes is therefore the investment cost itself.

While initially unprofitable, the collectors break even with a per m^2 price of 1323 NOK, which is depicted in the figure where change total expenditures become zero. A price drop of 887 NOK per m^2 is required for the collectors to break even. This estimate takes into consideration that operation & maintenance costs decrease as a factor of investment costs, which is why the required price drop is lower than the initial NPV per m^2 investment of -931. Carbon dioxide emissions per invested unit does not change with a decrease in the investment cost.

DISCOUNT RATE

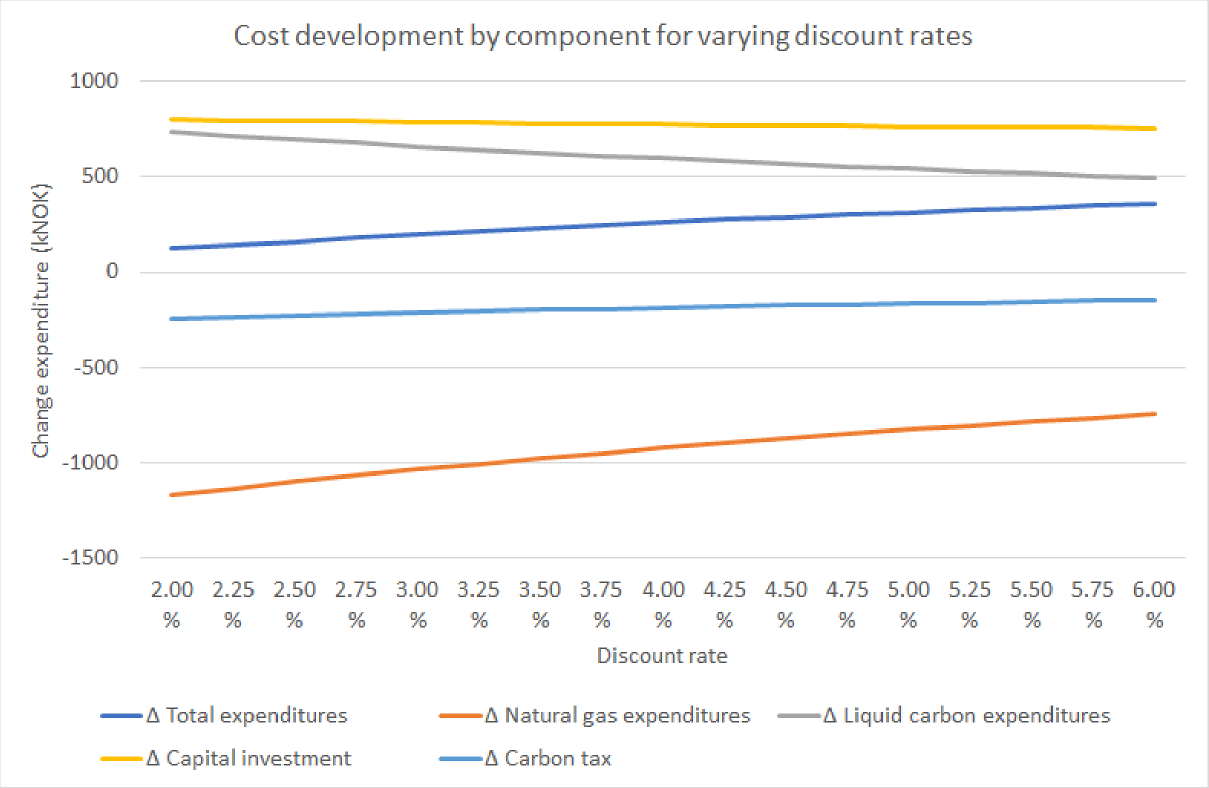


Figure 21: Sensitivity analysis discount rate

When adjustments are made to the applied discount rate, the net present value of expenditures adjusts in both non-investing and the investing scenario. The cost difference for all values of the discount rate reflects the change in profitability and is depicted above. We see that solar collectors increase overall expenditures compared to the reference scenario, even with a discount rate of 2%.

NATURAL GAS PRICE

One of the largest moments of uncertainty in the analysis is the price of natural gas. The forecast assumes that no unexpected supply or demand shocks affect the natural gas market, which is unlikely over the lifespan of the project.

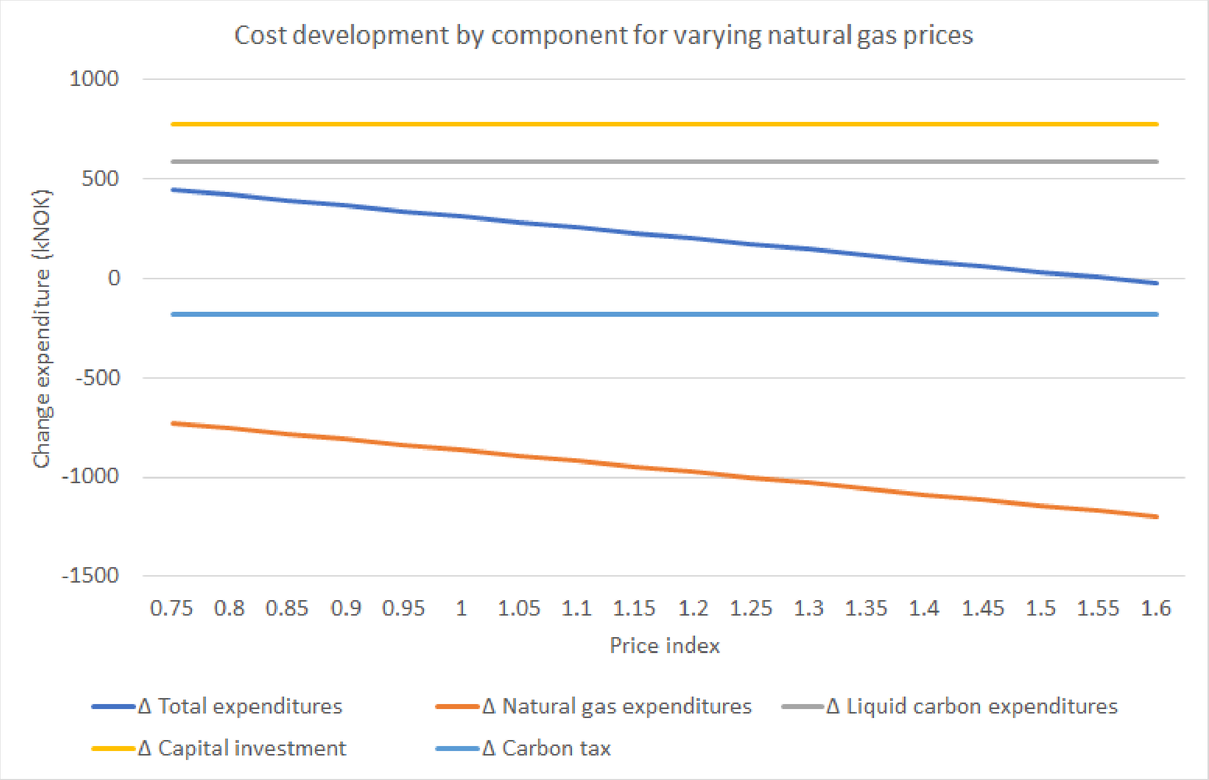


Figure 22: Sensitivity analysis natural gas price

The figure above shows profitability of collectors for different natural gas prices. The initial natural gas price is at indexed at 1 in the x-axis, where the x-axis displays price differential for all periods in the forecast natural gas price matrix, we generated in the data section. We read that a price 57% higher than the initial forecast makes the solar collectors break even.

CARBON INJECTION EFFICIENCY

The primary drawback of solar thermal collectors is the increased necessity for purchasing liquid carbon. In order to offset some of this effect the greenhouse can apply measures to improve injection efficiency. The injection rates for each month is shown in the data section. While quite high in the summer months, where more or less all of the carbon dioxide from natural gas combustion is injected, only a small share is injected during winter months.

The only months where carbon emissions from natural gas does not exceed the requirements for CO_2 is June, July and August. The theoretical potential for Wiig Gartneri through increased injection rate is therefore to eliminate carbon dioxide purchase in all months except these three. If achieved, only 96 tonnes of liquid CO_2 is required annually, which implies a net present value of cost decrease of 7.7 million over the next 25 years, where 35% of this is due to reduced carbon tax.

Improving injection efficiency slightly decreases the profitability of solar collectors initially, but when the efficiency approaches the full potential, solar collectors no longer have the offsetting effect in that additional carbon dioxide must be purchased. When the efficiency is increased, overall costs decrease for both the investment and non-invest scenario. However, for an increase in injection efficiency to synergize with solar collectors, one or more periods (in our case, months) must be completely depleted of its need for liquid carbon dioxide, and to such an extent that this is true also with solar collectors installed.

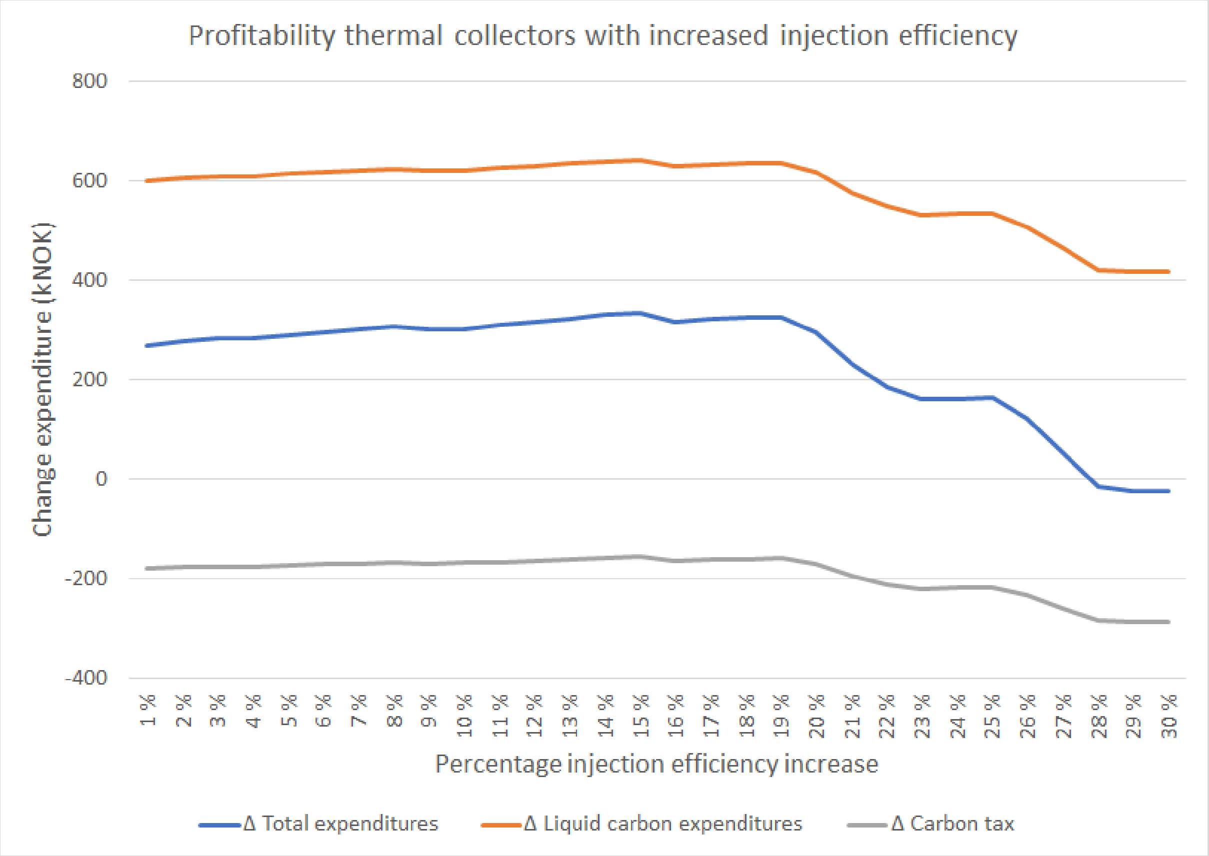


Figure 23: Sensitivity analysis carbon injection efficiency

We see that this effect comes into place at a 20% increase in the injection rate for each month, where the NPV of investing in solar with thermal collectors becoming profitable at 28% injection efficiency. Exactly how costly improvements in the injection efficiency are must be further examined by the greenhouse. If switching natural gas combustion to better match when carbon dioxide is required is not feasible, some technologies for short term carbon capture and storage might be an option, such as additional pipelines to increase the capacity of gas in circulation before injection.

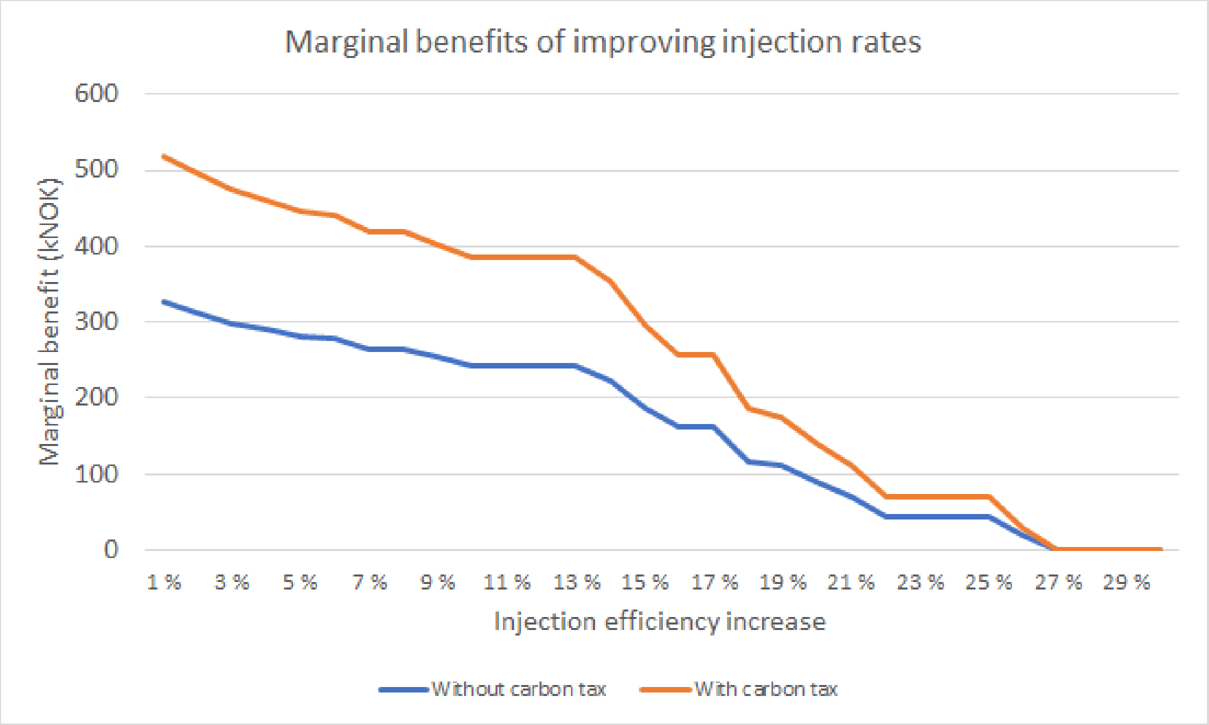


Figure 24: Marginal benefits of improving injection rates (kNOK)

The marginal benefits of increasing the injection rates showcase the potential cost savings of doing such adjustments in the reference scenario, and how the implementation of a carbon tax assists in incentivizing further. Such improvements should always be sought, as efficiency is improved. However, we see that the implementation of a carbon tax greatly increases the benefits of increased injection efficiency. If such improvements are implemented, solar thermal collectors might become profitable eventually as the offsetting effect they give is decrease.

5.4.5 SUMMARY SOLAR COLLECTORS

We have shown that, despite providing energy at a lower LCOE than natural gas, solar thermal collectors are not profitable with the current injection rates. This is primarily because of the seasonal production solar based technologies offer, combined with CO_2 being most scarce in the summer. We have also shown that while large improvements in the parameters are required to achieve profitability, improved injection efficiencies appear to be most promising. We also showed that the carbon tax further incentivizes such efficiency improvements, in that the marginal benefit of improving the injection increase substantially if the policy is implemented.

5.5 PROFITABILITY ANALYSIS WOODCHIPS

5.5.1 PROJECT DEFINITION

The final alternative we consider is the potential for implementing and investing in a boiler for woodchip combustion. The total benefits of the project are the present value of all energy related cost savings over the project's lifetime. This includes reduction in expenses for natural gas, liquid carbon and carbon tax. These benefits depend on two factors: the capacity of the woodchip boiler, and full load hours per month.

When analyzing this alternative, we assume that following the installation of a woodchip boiler, the capacity of the natural gas boiler must be unchanged. If periods emerge where woodchips are not available, the greenhouse will always have access to natural gas and thus meet its energy requirements. Moreover, we limit how much thermal energy woodchips can provide each year as woodchip supply may not cover demand in all periods for all years. This restriction is set at 20% of annual energy demand.

We also restrict that the woodchip boiler cannot exceed 480 full load hours per month or 16 hours per day on average. This is to control for heat demands being unevenly distributed within a month, and that the boiler cannot operate on max capacity for extended periods of time. In January 2019, the natural gas boiler at Wiig Gartneri operated 16 hours per day on average, the most intensive month. To simplify, we will assume that full load hours per month is equal for every year

5.5.2 ASSUMPTIONS WOODCHIP BOILER

Using woodchips comes with some distinct, interesting properties. While considered carbon neutral in the long run, wood-based biomass binds substantial amounts of CO_2. This is emitted when the chips are combusted and can be used as an input in production. Woodchips emit more CO_2 when combusted than natural gas, with 370 gram/kWh (Brænd & Hofstad, 2019). This is of course an attractive property, as it does not come with the same issues as renewable technologies, which increase the dependency on liquid CO_2, especially in scarce periods. To estimate CO_2 injection from woodchips, we will rely on the injection ratios we estimated in the data section.

The investment costs for the woodchip boiler are based on numbers from NIBIO (n.d.a) and are 8500 NOK/kw. Though they have not stated the moisture content of the woodchips used in these figures, we assume it is wet woodchips (moisture content >30%). This is because woodchips with higher moisture content are usually cheaper than dry woodchips, and the prices for woodchips usually range from 20-25 øre/kWh (Energigården, n.d.). NIBIO states the fuel price to be 21 øre/kWh, and we will adopt this price in this analysis. Based on data from Sidelnikova et al. (2015) we assume the economic lifetime of the woodchip boilers to be 20 years.

It could be argued that for such an immature technology it would be appropriate to increase the discount rate compared to solar collectors due to higher risks from uncertainty regarding supply, and how the fuel price of woodchips develops. Nevertheless, we will continue to use 4%, because, as aforementioned, the technologies should be evaluated at equal terms, and the discount rate should not be the cause of any differences.

The assumptions are summarized in the table below:

Assumptions woodchip boiler	
Lifetime	20 years
Investment cost (NOK/kW)	8500
Fuel cost (øre/kWh)	21
Operation- and maintenance costs (øre/kWh)	2
Carbon emissions (gram/kWh)	370
Discount rate	4 %

Table 13: Assumptions woodchip boiler (NIBIO, n.d.a; Sidelnikova et al., 2015; Brænd & Hofstad, 2019)

The model is set to minimize the sum of discounted costs over the lifetime of the project. The choice variables are how much capacity to invest in, measured in kW woodchip boiler, and the monthly full load hours. The restrictions are that woodchip technology can only supply

20% of annual energy demands, the boiler can only provide 480 full load hours monthly, and all energy and carbon dioxide demands must be met for all periods.

5.5.3 RESULTS

Under these assumptions, the optimal investment is 632 kW of woodchip boiler capacity. With the assumed price of 8500 NOK per kW, initial capital expenditures are 5 372 069 NOK. The average daily full load hours are distributed as follows:

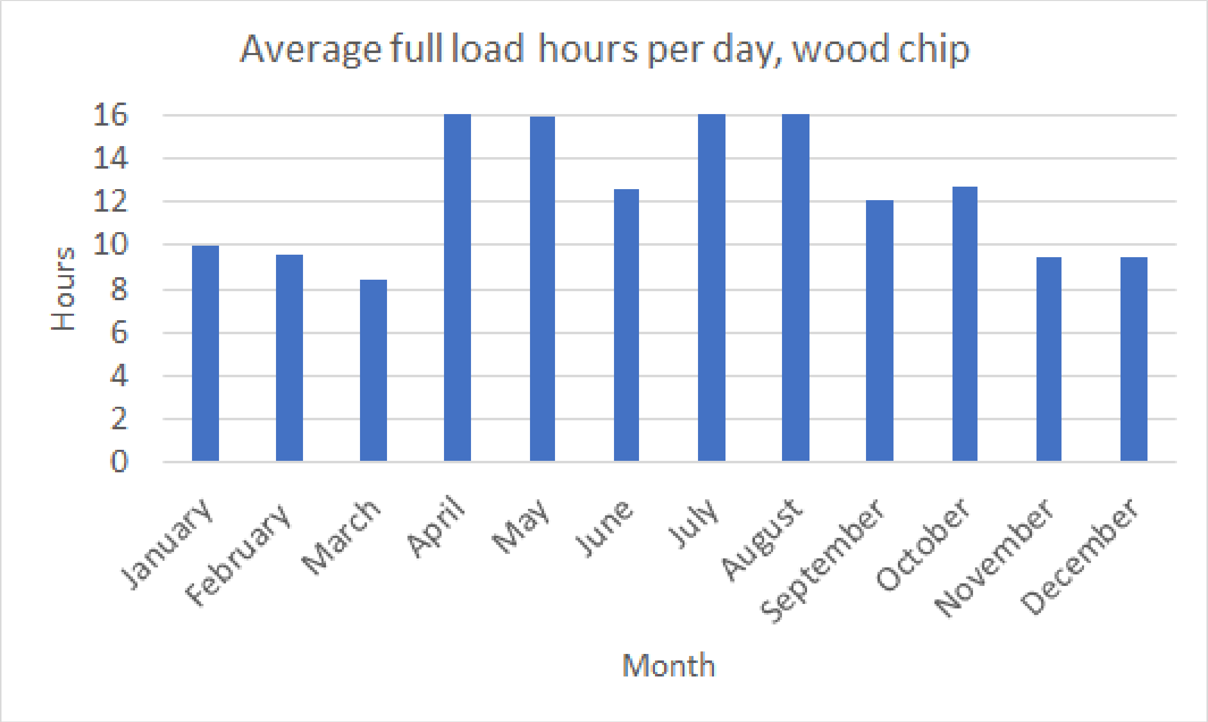


Figure 25: Average full load hours per day, woodchip (own calculations)

The restriction on maximum full load hours are binding for April, May, July and August. These are months where liquid CO_2 injections are high. This is intuitive, because woodchips provide the most benefit in periods where the greenhouse demand for CO_2 is high.

The net present value of expenses for the reference and investment scenario are summarized in the table below.

NPV of energy expenses (NOK)	Reference scenario	Invest	Change
Woodchip boiler investment	0	5 372 069	+ 5 372 069
Woodchip boiler fuel	0	9 428 883	+ 9 428 883
Natural gas	72 538 770	60 580 311	-11 958 459

Carbon tax	46 477 108	36 226 604	-10 250 504
Liquid carbon	7 475 483	1 479 494	-5 995 990
SUM	**126 491 361**	**113 087 360**	**+ 13 404 000**

Table 14: NPV of investment in 632 kW woodchip boiler (own calculations)

In this optimized solution, liquid carbon injections are reduced from 312 tonnes to 62 tonnes per year. Liquid injections are not needed six months per year, as the greenhouse gets enough carbon dioxide from combusting natural gas and woodchips.

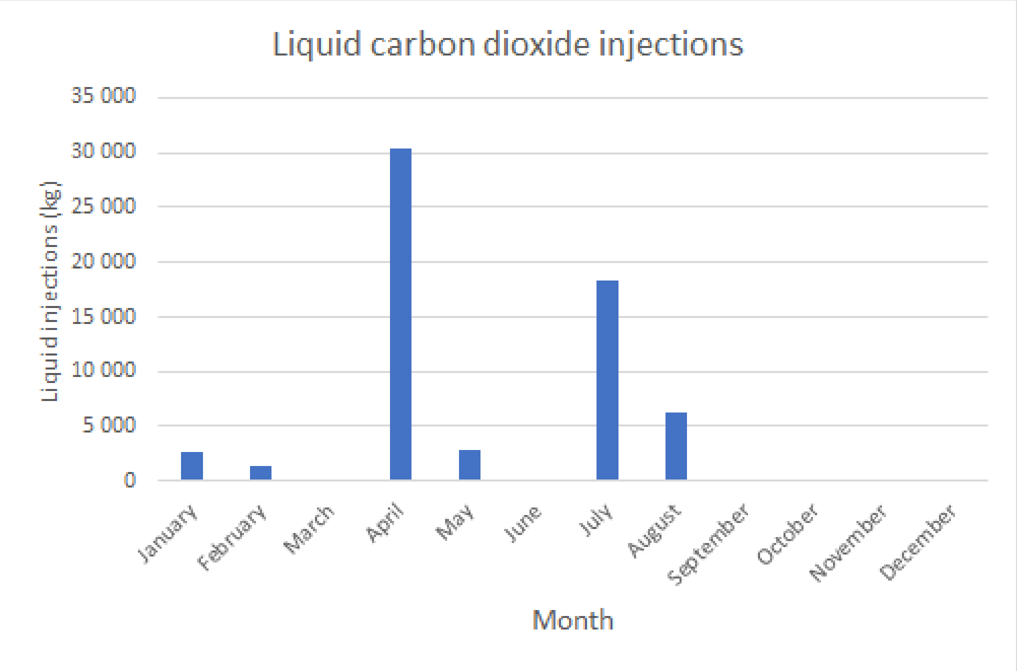


Figure 26: Liquid carbon dioxide injections

This results in almost 6 million NOK of saved liquid carbon expenses over the lifetime of the project. Carbon emissions from natural gas is reduced from 3372 tonnes to 2810 tonnes annually. Additional annual emissions from woodchip combustion amounts to 1096 tonnes, but these are considered carbon neutral. The LCOE from this technology is 33.7 øre per kWh, which is higher than both natural gas and solar thermal collectors. Woodchips are however profitable because it decreases expenses for liquid carbon substantially.

5.5.4 SENSITIVITIES

We perform sensitivity analysis of some variables to assess the importance of each. The sensitivities display how the total costs change, and also change in the cost components. Note that the graphs, like for solar thermal collectors, display the change in costs compared to not investing, so that a total cost curve below zero implies net profitability of the project, and a falling cost curve implies increasing profitability.

DISCOUNT RATE

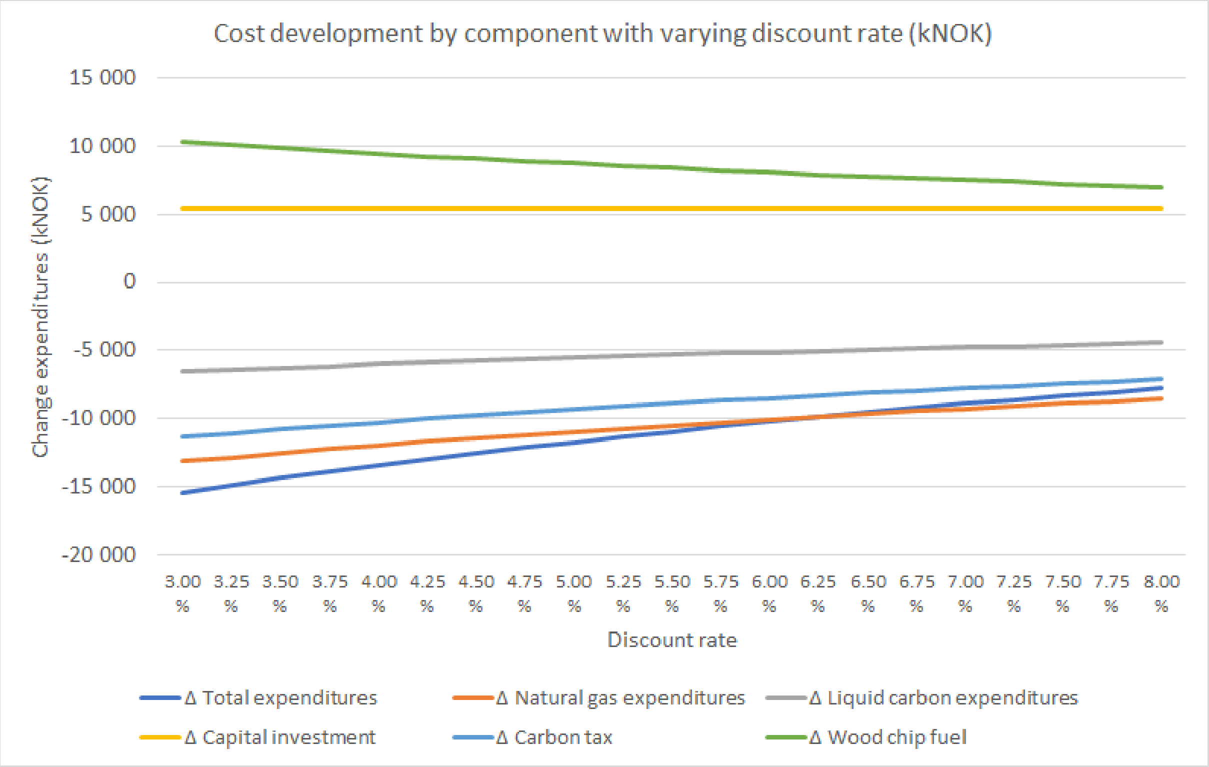


Figure 27: Cost development by component with varying discount rate (NOK)

Increased discount rate decreases the present value of all future costs and savings. Accordingly, all cost components trend toward zero, except for the initial capital investment which happens in the first period. The graph shows that investing in woodchip boiler is profitable for all discount rates up to 8%. This is a strong result, in the light that this type of investment is likely to have more risk than the other alternatives.

WOODCHIP PRICE

The future price of woodchips is difficult to forecast, consequently, the variable holds large uncertainty and is worth investigating.

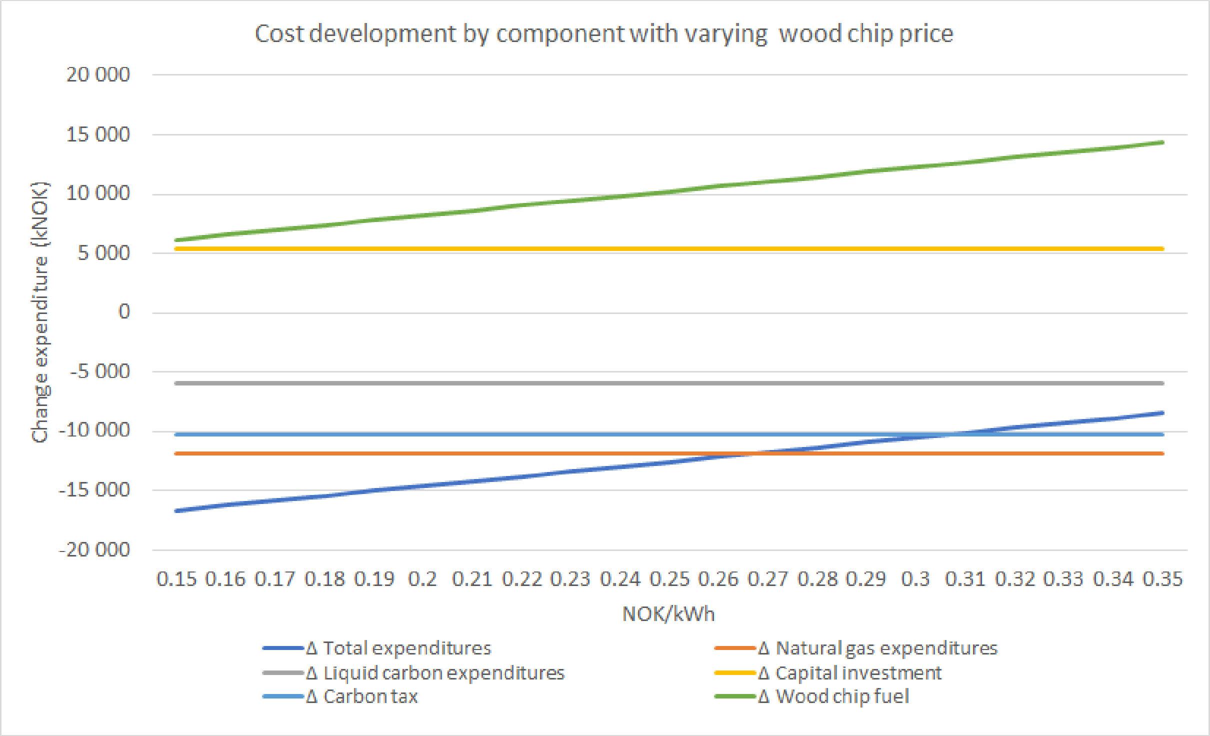


Figure 28: Cost development by component with varying woodchip (fuel) price

With a change in the price of woodchips, fuel expenses and total expenditures increase. While not depicted above, woodchips are still profitable until a price of 55.7 øre/kWh. We also read from the graph that total expenditures cross the carbon tax expenditure line at 31 øre/kWh, which implies that for prices above this a tax on carbon is required for woodchips to be profitable.

INITIAL CAPITAL COST

The per kilowatt (kW) cost of the initial investment only changes the initial investment, given that the optimal solution holds for varying capacity prices.

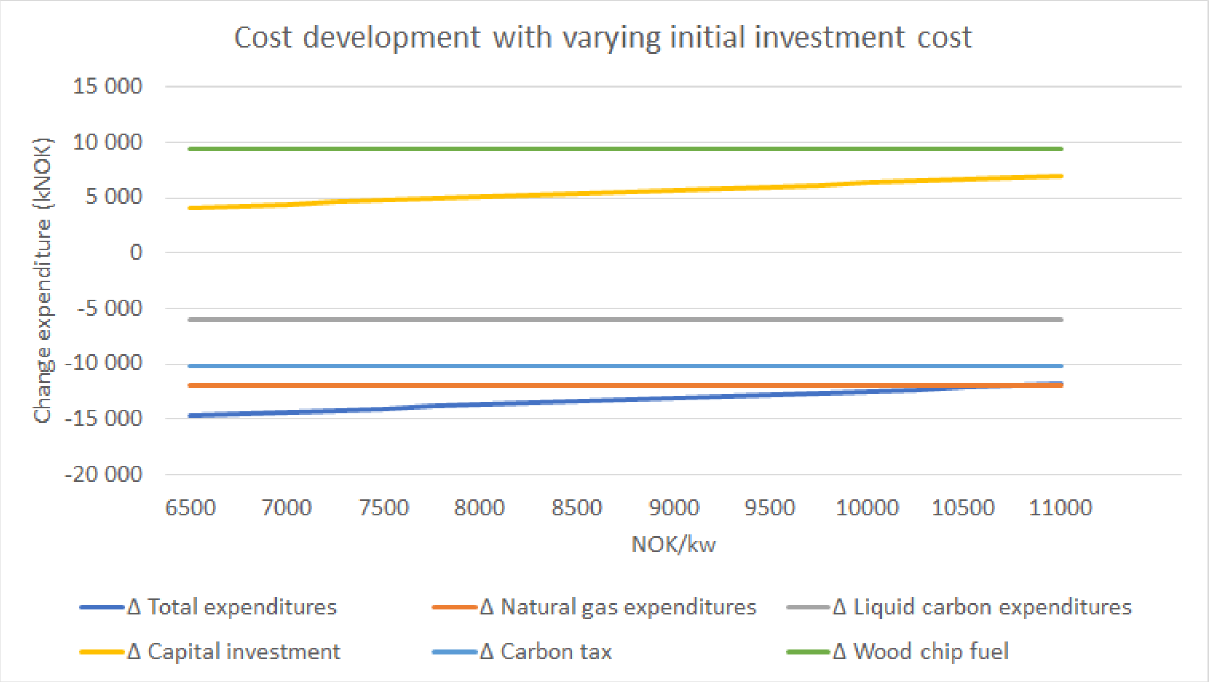


Figure 29: Cost development with varying initial investment cost

The graph shows that the project is until at least 11 000 NOK per kW, given by the change in total expenditure being below zero for all values of capital costs.

INJECTION EFFICIENCY

Increased injection efficiency reduces the benefits woodchip technology provides with respect to liquid carbon. This is because the benefits of increasing injection efficiency have the highest marginal benefit when liquid carbon dioxide is required for all months. Since woodchip technology makes liquid carbon dioxide obsolete for half of the months, the benefit of increasing efficiency is higher without woodchip technology.

The project is still profitable, with an NPV of cost savings of 8.8 million NOK with 30 % increase to injection efficiency, but increased injection efficiency decreases the net present value of the investment.

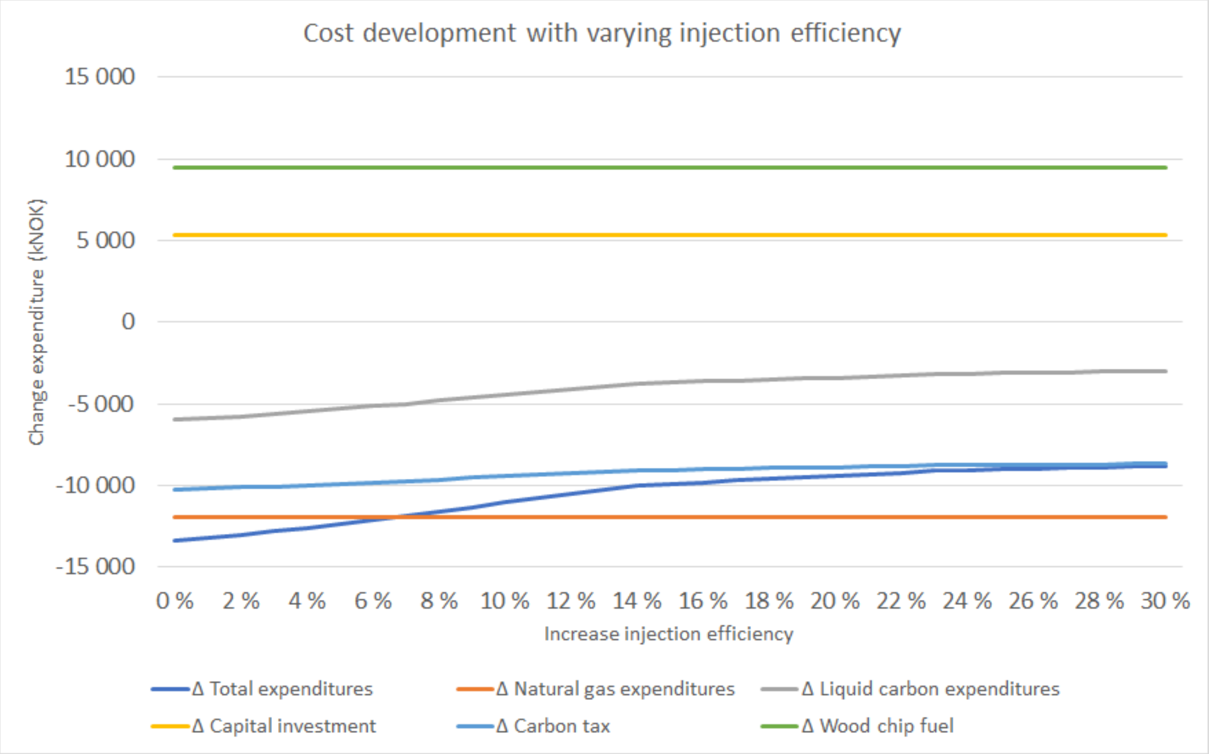


Figure 30: Cost development with varying injection efficiency

Interestingly, the table above shows that for higher injection efficiencies, the change in total expenditure curve almost crosses the change in carbon tax curve. This implies that even though the project is profitable, this is dependent on carbon tax being implemented. With an increase in injection efficiency increase of 30 %, the project is dependent on a carbon tax to be profitable. With a carbon tax however, the project has a high net present value.

5.5.5 SUMMARY WOODCHIPS

From the analysis, an investment in woodchips appears very profitable given the implementation of a carbon tax, independent on how much the different parameters are tweaked. The technology has a different respond to increased injection efficiency than solar thermal collectors, where such efficiency improvements decrease the net benefits of woodchips compared to the reference scenario.

While highly promoting this technology, it could be argued that a carbon tax does not necessarily achieves what it desires. While the CO_2 emissions that form the tax basis drop substantially, total emissions per year increase when woodchip technology is used. Although carbon neutral, it takes many years for the carbon to be sequestrated back into new biomass.

6. RESULTS AND DISCUSSION

The purpose of this thesis was to examine the effect of a carbon tax on the greenhouse sector, with the specific case of Wiig Gartneri. To do this, we established four research questions.

Our first research question was to examine how a carbon tax would affect energy demands if no other cost-effective alternatives exist. To achieve this, we did a regression on how the price fluctuations of natural gas affected natural gas consumption in 2019. The regression gave us an estimator of the short-term price elasticity of natural gas demands, which was not significantly different from zero. This implies that other factors than the price of natural gas is more important for explaining natural gas demands for Wiig Gartneri.

Moreover, if this result holds for all price fluctuations, natural gas demands will be largely unadjusted when faced with a carbon tax, and the tax will therefore only affect the profitability of the industry while carbon emissions are mostly unchanged. This result gives some support to the argument brought forth by Meberg whom we quoted in the introduction, claiming that the tax would be purely fiscal.

There is an issue with this method that should be considered. The regression only considers small day-to-day fluctuations in the price. A carbon tax of 545 NOK per ton implies a price increase of 10.9 øre per kWh. For small fluctuations in the price, there might be costs connected to switching from natural gas to electricity for heating, or costs from ramping up and down the natural gas boilers. With a large and constant price increase that comes with a carbon tax, switching fuel might become profitable, and it is therefore arguable whether our results hold for a tax implementation and not just daily fluctuations.
To further research this question, detailed data is required on how the electricity usage is divided between growth lights and heating.

Our remaining research questions considered the profitability of alternative technologies, under the pretext that a carbon tax is implemented. These technologies are solar thermal collectors, biogas, and woodchip combustion.

The results from the analysis suggests biogas is not a realistic alternative in Rogaland, at least yet, despite the introduction of a carbon tax. Our analysis show that unless a substantial cost decrease comes into fruition, a switch from natural gas to biogas will not be a reality for 17 years.

The net present value analysis shows that while solar collectors provide the cheapest energy in terms of LCOE, the technology is not profitable because it primarily provides energy in the summer. This is the period where carbon dioxide is most scarce, and annual liquid carbon purchase increase substantial. Two thirds of carbon emission decrease from reduced natural gas combustion is offset by increased liquid carbon dioxide requirements, and the net emission reduction is only 11 tonnes annually.

In addition, we show that the potential for solar thermal collectors to become profitable exists, if the greenhouse is able to increase its injection efficiency. To achieve this, options for short term carbon capture and storage should be investigated. Alternatively, carbon neutral CO_2 injections are becoming increasingly cost competitive, with actors such as Greencap Solutions developing new technologies for this. Test projects of closed greenhouses are also providing promising results, where ventilation is avoided to reduce loss of energy - increasing efficiency for both energy and carbon dioxide usage.

Finally, our analysis show that the most beneficial alternative for the greenhouse is to invest in woodchip combustor capacity. The proposed capacity gives a net present value of cost savings of 13.4 million NOK over the lifetime. This strong performance can be attributed to woodchip combustion providing double savings. In addition to decreasing emissions subject to carbon tax, the woodchips emit more carbon dioxide when combusted, decreasing liquid carbon dioxide expenses. Taxable emissions are reduced from 3684 tonnes per year to 2872. Emissions from combusting woodchips amounts to 1096 tonnes per year if this technology is implemented, but these emissions are not subject to taxation.

7. CONCLUSION AND CONCLUDING ASSESSMENTS

7.1 CONCLUSION

This paper presents the effects for a specific greenhouse in Rogaland, if a carbon tax is implemented. We have analyzed different technologies the greenhouse might utilize in response to a tax and compared them to a reference scenario where we assume business as usual. Because the climate problem is becoming more pressing, and appropriate action more urgent - we expect that the sector will have to face carbon taxes eventually, like most other sectors already have. The complicating factor is the role carbon dioxide serves in the greenhouse, as a growth enhancing input.

In establishing a reference scenario, we obtained an estimator for the short-term price elasticity of natural gas demands. This shows that demand is unresponsive in the short run for low fluctuations in the price. While we extend this result to also consider a large price increase which a carbon tax implies, the validity of this assumption should be further addressed.

Our analysis show that biogas is currently not a profitable alternative to natural gas, even when the latter faces a carbon tax. We also show that this is the case for a substantial period, unless a more mature, cost pressing market for biogas in the region emerge.
The policies required for this to happen should be further examined by policymakers if a carbon tax is implemented in the greenhouse sector. Facilitating biogas investments through government market interventions could ease the cost burden for greenhouses and decrease emissions. With such a technology, the important property of heat fuels to also supply CO_2 remains unchanged, if the biogas is similar quality as the natural gas with respect to methane density.

We then studied whether solar thermal collectors could be cost effective as a supplement to natural gas given a tax implementation. The thesis shows that, while providing energy at a lower cost than natural gas, solar thermal collectors are not profitable yet as they offset too much carbon dioxide. A substantial cost decreases is required for profitability. A more likely path to make solar power competitive for greenhouses are through improvements in the injection efficiency. We have shown a carbon tax substantially increase the benefits from such improvements.

The final technology we investigate is woodchips. This alternative gives high cost savings, despite having a higher LCOE than natural gas due to high capital costs. This is because the woodchips, despite being climate neutral, provide twice as much carbon emissions per energy output than natural gas.

7.2 CONCLUDING ASSESSMENTS

While currently too costly, the necessary conditions for a rapid cost decrease exist for biogas. The infrastructure is already in place in the form of natural gas pipelines, and more than half of the greenhouses are connected to these pipes. Furthermore, the biogas potential from livestock manure in Rogaland, Norway's most dense animal husbandry region, is large. Biogas could become a large industry if sufficient incentives provided by the government is in place. An approach for policymakers is to take away with one hand, and give with the other, by facilitating necessary investments for biogas to become cost competitive with natural gas.

While the by far most profitable alternative, the true climate neutrality of woodchip combustion warrants some discussion. While carbon neutral from a taxation point of view, actual carbon emissions increase if a switch is made towards woodchips. Carbon neutrality is only achieved when these emissions are fully sequestrated into the ecosystem, which may take 80-120 years. With urgency being of the essence in climate action, it is thus questionable whether such a scenario is desirable. In this thesis, we have not monetized this effect, but we believe this should be analyzed in further work on this subject. With the severity climate changes impose, any delay in climate gas emissions is desirable as from a damage perspective. It could therefore be argued that emissions from biomass sources should be taxed at the same rate as fossil fuels if increased deforestation is a direct consequence. These concerns do not however apply to wood debris, such as from logging or windfall.

As the analysis of different technologies is done on only one greenhouse, it is difficult to conclude whether the implementation of a carbon tax is a strong policy option. With Rogaland being the only region with access to natural gas, the results are likely to not hold beyond this region. Investigation is therefore required on how a carbon tax affects competitiveness amongst greenhouses in different regions. The carbon tax could have very different impacts on domestic greenhouses, depending on what is the primary fuel and accessibility to alternatives. Even within Rogaland, it is questionable if greenhouses are sufficiently homogenous for our results to be applicable for other greenhouses than Wiig Gartneri. For instance, Miljøgartneriet, the largest greenhouse in Norway, has a very different framework for operation with access to spillover heat from an adjacent Tine facility. It appears clear however that a carbon tax will give substantially higher costs for most greenhouses, increasing prices for consumers and decreasing domestic competitiveness. An import tariff might become necessary to address this issue.

An alternative approach to be considered for policymakers is to only tax emissions that do not provide the additional benefit of growth enhancement. This will incentivize injection efficiency improvements and may be considered a fair compromise. An issue with this scheme is that some mechanisms for control must be implemented, to keep the greenhouses from cheating on their required carbon dioxide injection requirements. We have previously mentioned that carbon dioxide can be injected beyond what is required for growth enhancement, without damaging the crops. Greenhouses will therefore have monetary gains by injecting carbon dioxide beyond what is required.

8. REFERENCES

Agri-e. (2018). Fornybar energi og karbonfangst. [Renewable energy and carbon capture]. Retrieved 28. Jan. 2020 from www.agri-e.no/forside/fornybar-energi-til-veksthus.

Alfredsen, G., Sandland, K. M., Gjølsø, S., Gobakken, L. R. & Bergseng, E. (2018). Sekundærråstoff fra trebaserte verdikjeder i Norge. [Secondary raw materials from wood-based value chains in Norway]. *NIBIO Rapport*, *4*(93). Retrieved from https://nibio.brage.unit.no/nibio-xmlui/bitstream/handle/11250/2504920/NIBIO_RAPPORT_2018_4_93.pdf?sequence=2&isAllowed=y.

Amundsen, B. (2019). For 25 år siden smakte tomater vondt. Det har forskere vært med på å endre. [25 years ago, tomatoes tasted bad. Scientists have helped to change that]. Retrieved 10. Mar. 2020 from forskning.no/mat/for-25-ar-siden-smakte-tomater-vondt-det-har-forskere-vaert-med-pa-a-endre/1323410.

Andersen, C. (2014). Flisfyring på flate Jæren. [Woodchip combustion in Jæren]. Retrieved 3. May 2020, from https://www.bondevennen.no/fagartiklar/flisfyring-pa-flate-jaeren/#.

Aurora Energy Research. (2020). European Gas Market Forecast - Annual Report 2019. Retrieved 3. Mar. 2020 from www.auroraer.com/insight/european-gas-market-forecast-2019/.

Blom, T. J., Straver, W. A., Ingratta, F. J., Khosla, S., & Brown, W. (2002). Carbon Dioxide in Greenhouses. Retrieved from http://www.omafra.gov.on.ca/english/crops/facts/00-077.htm

Boardman, A. E., Greenberg, D. H., Vining, A. R. & Weimer, D. L. (2018). *Cost-Benefit Analysis: Concepts and Practice*. 4th ed, Cambridge: Cambridge University Press.

Bondelaget. (2019). Intensjonsavtale mellom jordbruket og regjeringen om reduserte klimagassutslipp og økt opptak av karbon fra jordbruket for perioden 2021-2030. [Intent agreement between agriculture and the government on reduced greenhouse gas emissions and increased absorption of carbon from agriculture for the period 2021-2030]. Retrieved from www.bondelaget.no/getfile.php/13915420-1561096794/MMA/Bilder NB/Mat/Mat- og landbrukspolitikk/Miljø, energi og klima/Klimaforhandlinger/Forhandlingsdokument 6.2/avtale 210619.pdf.

Brænd, T. J. & Hofstad, K. (2019). Bioenergi. [Bioenergy]. In Store Norske Leksikon. Retrieved from https://snl.no.

Bævre, O. A., Bø, Ø. L., Jelsa, R., Randeberg, E. & Verheul, M. (2006). Energi til norsk veksthusnæring - bruk av naturgass som energibærer og CO2-kilde. [Energy for the Norwegian greenhouse industry - the use of natural gas as an energy carrier and CO2 source]. *Bioforsk Vest*, *1*(119), 1–36. Retrieved from https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2505510.

Correljé, Aa. (2016). The European Natural Gas Market. *Current Sustainable/Renewable Energy Reports*, *3* (1-2), 28–34., doi:10.1007/s40518-016-0048-y.

Danielsen, D.I. (2019). Norge har større avlinger av tomat og agurk enn Spania og Nederland. [Norway have larger crops of tomatoes and cucumber than Spain and Netherlands]. Retrieved from https://forskning.no/landbruk-mat-miljoteknologi/norge-har-storre-avlinger-av-tomat-og-agurk-enn-spania-og-nederland/1365313

Diaz, C. T., & Bertelsen, M. (2019). Lowest European gas prices in a decade. Retrieved from https://www.rystadenergy.com/newsevents/news/press-releases/Lowest-European-gas-prices-in-a-decade/

Diebold, F. X. (2019). Econometric Data Science: A Predictive Modeling Approach. Retrieved from https://www.sas.upenn.edu/~fdiebold/Teaching104/Econometrics.pdf

Ellingsen, J. G., & Filbakk, T. (2016). Håndbok i etablering og drift av gårdsbaserte biogassanlegg. [Manual in the establishment and operation of farm-based biogas plants]. Retrieved from https://www.fylkesmannen.no/globalassets/fm-troms-og-finnmark/landbruk-og-mat/skogbruk/biogasshandbok-norges-vel_2016.pdf.

Energifakta Norge. (2019). Varmeforsyning. [Heat Supply]. Retrieved from https://energifaktanorge.no/norsk-energiforsyning/varmeforsyning.

Energigården. (n.d.). Priskalkulator. [Price Calculator]. Retrieved 3. May 2020 from http://www.energigarden.no/om-bioenergi/priskalkulator/.

Energiverket. (2018). Solfangere lar deg bruke solenergi til varmtvann og oppvarming. [Solar panels allow you to use solar energy for hot water and heating]. Retrieved from https://www.energiverket.no/solfangere-mer-effektive-enn-solceller/.

Energi og Klima. (2020). Strømproduksjonen i Europa og USA nå: Kart i sanntid. [Power generation in Europe and the US now: Real-time maps]. Retrieved 26. Mar. 2020 from energiogklima.no/klimavakten/live-data-strom-og-co2/.

European Commission. (n.d.). Citizen support for climate action. Retrieved 1. Feb. 2020 from https://ec.europa.eu/clima/citizens/support_en

Gjessing, H. (2018). Livsløpsvurdering av tomatproduksjon i Norge. [Life cycle assessment of tomato production in Norway]. (Master thesis, NMBU). Retrieved from static02.nmbu.no/mina/studier/moppgaver/2018-Gjessing.pdf2.

Hagen, K. P. (2011). Verdsetting av fremtiden. Tidshorisont og diskonteringsrenter. [Appreciation of the future. Time horizon and discount rates]. *Concept*, NTNU. Retrieved from www.ntnu.edu/concept/concept-report-series.

Hansjürgens, B. (2004). Economic Valuation through Cost-Benefit Analysis - Possibilities and Limitations. *Toxicology*, *205* (3), 241–252. doi:10.1016/j.tox.2004.06.054.

Haugstad, T. (2020). Større avlinger I drivhus med CO_2 fangst. [Bigger crops in greenhouses with CO_2 capture]. Retrieved 24. May 2020 from https://www.tu.no/artikler/storre-avlinger-i-drivhus-med-co-fangst/483010.

Helm, D. (2005). Economic Instruments and Environmental Policy. *Oxford Review of Economic Policy*, *36*(3), 205–228. Retrieved from http://hdl.handle.net/2262/60159.

Knutsen, H., Haukås, T., Kårstad, S., Lerfald, M., & Kvamme, S. (2019). Verdiskaping i landbruk og landbruksbasert verksemd i Rogaland. [Value creation in agriculture and agricultural-based activities in Rogaland]. *NIBIO Rapport*, *5*(38). Retrieved from https://nibio.brage.unit.no/nibio-xmlui/handle/11250/2590275

Landbruksdirektoratet. (2019). Jordleieundersøkelsen 2019. [Ground Rent Survey 2019]. Retrieved from https://www.landbruksdirektoratet.no/no/eiendom-og-skog/eiendom/jordleiepriser/statistikk/jordleieundersøkelsen-2019

Landbruksdirektoratet. (2020). Husdyrgjødsel til biogass – gjennomgang av virkemidler for økt utnyttelse av husdyrgjødsel til biogassproduksjon. [Livestock manure for biogas - review of instruments for increased utilization of livestock manure for biogas production]. Retrieved from https://www.regjeringen.no/contentassets/6a5da53b1ba243eb86a4e2314abe96a4/husdyrgjodsel-til-biogass---gjennomgang-av-virkemidler-for-okt-utnyttelse-av-husdyrgjodsel-til-biogassproduksjon.pdf

Lansink, A. O., Verstegen, J., & Hengel, J. V. D. (2001). Investment decision making in Dutch greenhouse horticulture. *NJAS - Wageningen Journal of Life Sciences, 49*(4), 357–368. doi: 10.1016/s1573-5214(01)80023-3

Lie, Ø. (2012). Krafteksport Øker CO2-Utslippene. [Power exports Increases CO2 emissions]. Retrieved 26. Mar. 2020 from www.tu.no/artikler/krafteksport-oker-co2-utslippene/245113.

Lind, C. (2017). Biogass - verdifullt, effektivt og med dobbel klimanytte. [Biogas - valuable, efficient and with dual climate benefit]. Retrieved from https://www.avfallnorge.no/bransjen/nyheter/biogass-verdifullt-effektivt-og-klimanøytralt.

Lyse AS. (2017). Naturgassens Rolle i Rogaland. [The role of natural gas in Rogaland]. Retrieved 26. Mar. 2020 form www.lysekonsern.no/nyheter/naturgassens-rolle-i-rogaland-article2442-200.html.

Lyse AS. (2020). Priser på varme, kjøling og gass. [Prices for heating, cooling and gas]. Retrieved 18. May 2020 from https://www.lyse.no/varme/priser.

Mathisen, G. (2019). Nå er det gassbonanza i Rogaland. [Gaz bonanza in Rogaland]. Retrieved 26. Mar. 2020 from nemitek.no/biogass-eilif-dahle-energigass-norge/na-er-det-gassbonanza-i-rogaland/102741.

Ministry of Climate and Environment. (2019). Norge legger fram statusrapport på klima. [Norway Submits its National Plan on Climate]. Retrieved from www.regjeringen.no/en/aktuelt/norge-legger-fram-statusrapport-pa-klima/id2683975/.

Naturgass Nord. (n.d.). Litt Om Naturgass. [A little about natural gas]. Retrieved 26. Mar. 2020 from www.naturgassnord.no/litt-om-naturgass/.

NIBIO. (n.d.a). Flisfyring gir økt komfort og økt lønnsomhet. [Woodchip combustion gives increased comfort and increased profitability]. Retrieved from https://www.nibio.no/tema/skog/bruk-av-tre/bioenergi/brenselflis/_/attachment/inline/4ee83240-694a-4c15-9399-748be7c9cef1:9d9ecbe6c10fff104866bec807f92e665e640bdd/9%20-%20Flisfyring%20gir%20økt%20komfort%20og%20økt%20lønnsomhet.pdf

NIBIO. (n.d.b). Flisfyring - Miljøvennlig og lønnsomt. [Woodchip combustion – Environmentally friendy and profitable]. Retrieved from https://nibio.no/tema/skog/bruk-av-tre/bioenergi/Flisfyring/_/attachment/inline/a7fa6035-cfc3-416e-b9f1-fa9e0619add8:e974020aaf84c78d939b9ecddbdfc8dd097b7897/1 - Flisfyring - lønnsomt og miljøvennlig.pdf

NIBIO. (2020). Kilden. [The source]. Retrieved 28. Apr. from https://kilden.nibio.no/?lang=nb&topic=arealinformasjon&bgLayer=graatone_cache&X=7195706.12&Y=275054.87&zoom=0

NIBIO LMT. (2020). Weather data Særheim. Retrieved 28. Apr. from https://lmt.nibio.no/station/48/

Nordsletten, B. Å. (2018). Frustrasjon i Tomatmiljøet. [Frustration in the tomato environment]. Retrieved from www.bondevennen.no/aktuelt/frustrasjon-i-tomatmiljoet/#.

Norges Bank. (2020). Exchange rates. Retrieved 20. Apr. 2020 from https://www.norges-bank.no/en/topics/Statistics/exchange_rates/

NOU 2012:16. (2012). Cost-Benefit Analysis, *Ministry of Finance*. Retrieved from https://www.regjeringen.no/contentassets/5fce956d51364811b8547eebdbcde52c/en-gb/pdfs/nou201220120016000en_pdfs.pdf

NOU 2015: 15. (2015). Sett Pris På Miljøet. [Put a price on the environment]. Green Tax Commision. Retrieved from www.regjeringen.no/contentassets/38978c0304534ce6bd703c7c4cf32fc1/no/pdfs/nou201520150015000dddpdfs.pdf.

Norwegian Environment Agency. (2020). Klimakur 2030. [Cure for the climate 2030]. Retrieved from ww.miljodirektoratet.no/klimakur.

Norwegian Environment Agency. (2020). Virkemidler for Økt Bruk Og Produksjon Av Biogass. [Instruments for Increased Use and Production of Biogas]. Retrieved from https://www.miljodirektoratet.no/globalassets/publikasjoner/m1652/m1652.pdf.

Norwegian Environment Agency & Norwegian Water Resources and Energy Directorate. (2020). Bruk av gass til oppvarming. [The Use of Gas for Heating]. *Norwegian Environment Agency, M-1623,*1-35. Retrieved from https://www.miljodirektoratet.no/globalassets/publikasjoner/m1623/m1623.pdf.

NTB. (2019). Regjeringen øker CO2-avgiften med 5 prosent. [The government increases the carbon tax with 5 percent]. Retrieved 1 Jun. 2020 from https://www.aftenposten.no/verden/i/9vnPMd/solberg-beilet-til-fn-om-plass-i-sikkerhetsraadet

Pederstad, A., Vandenbussche, V., Rambech, E., Fiksen, K., Lossius, T., Halvorsen, F. & Isakova, I. (2018). Tilrettelegging for Bruk Av Biogass i Rogaland. [Facilitation for Use of Biogas in Rogaland]. Retrieved from www.miljokommune.no/Documents/Klima/Klima- og energitiltak i ulike sektorer/Energiproduksjon og -distribusjon/Utrede potensialet for produksjon av biogass/Rogaland Tilrettelegging for bruk av biogass i Rogaland.PDF.

Peterson, D. (2018). Managing Humidity in the Greenhouse. Retrieved from https://gpnmag.com/article/managing-humidity-in-the-greenhouse/

Rogaland Fylkeskommune. (2010). Regionalplan for Energi Og Klima i Rogaland. [Regional Plan for Energy and Climate in Rogaland]. Retrieved 28. Jan. 2020 from www.rogfk.no/_f/p1/id0ea6447-ed40-43cf-ad86-ba4a9b51fa74/regionalplan-for-energi-og-klima-i-rogaland.pdf.

Rosvold, K. (2019). Solfangere. [Solar collectors]. In *Store Norske Leksikon.* Retrieved from https://snl.no/.

Sidelnikova, M., Weir, D. E., Groth, L. H., Nybakke, K., Stensby, K. E., Langseth, B., ... Qureishy, T. H. (2015). Kostnader i energisektoren. [Costs in the energy sector]. NVE, rapport nr 2/2015 del 1. Retrieved from http://publikasjoner.nve.no/rapport/2015/rapport2015_02a.pdf.

Solenergiklyngen. (2019).

Statistics How To. (2018). Large Enough Sample Condition. Retrieved from https://www.statisticshowto.com/large-enough-sample-condition/

Statistics Norway. (2011).

Statistics Norway. (2019a). Forbruk Av Energi i Veksthus. [Consumption of energy in greenhouses]. Retrieved 3. Mar. 2020 from https://www.ssb.no/statbank/table/12834/.

Statistics Norway. (2019b). Jordbruksbedrifter Med Veksthus Og Veksthusareal, Etter Landsdel Og Størrelsen På Veksthusareal 1979 - 2018. [Farms with greenhouse and greenhouse area, by region and size of greenhouse area 1979 – 2018]. Retrieved 3. Mar. 2020 from www.ssb.no/statbank/table/12830/.

Steentjes, K., Pidgeon, N., Poortinga, W., Corner, A., Arnold, A., Böhm, G., … Tvinnereim, E. (2017). European Perceptions of Climate Change: Topline findings of a survey conducted in four European countries in 2016. Cardiff: Cardiff University.

Stryi-Hipp, G., Weiss, W., Mugnier, D. & Dias, P. (2012). Strategic Research Priorities for Solar Thermal Technology. Retrieved from https://www.rhc-platform.org/content/uploads/2019/05/Solar_thermal_SRP.pdf

The Norwegian Government. (2019). EØS-avtalen og handel med landbruksvarer mellom Norge og EU. [EEA Agreement and Trade in Agricultural Products Between Norway and the EU]. Retrieved from www.stortinget.no/globalassets/pdf/eu_open/handel_med_landbruksvarer_stortingets_utredningsseksjon.pdf.

Tvedt, R. K., Tengesdal, S. E., Stavnes, C. L., Håland, S., Ådland, K. L., Mjølhus, E. U., …, Egeland, C. (2012). Strategi med Handlingsplan for Skogsbasert Bioenergi i Rogaland. [Strategy with Action Plan for Forest-Based Bioenergy in Rogaland]. Retreived from https://www.fylkesmannen.no/globalassets/fm-rogaland/dokument-fmro/landbruk/regelverk-og-styringsdokument/bioenergistrategi.pdf.

U.S. Department of Energy. (n.d.). Levelized Cost of Energy (LCOE). Retrieved 3. May 2020, from https://www.energy.gov/sites/prod/files/2015/08/f25/LCOE.pdf

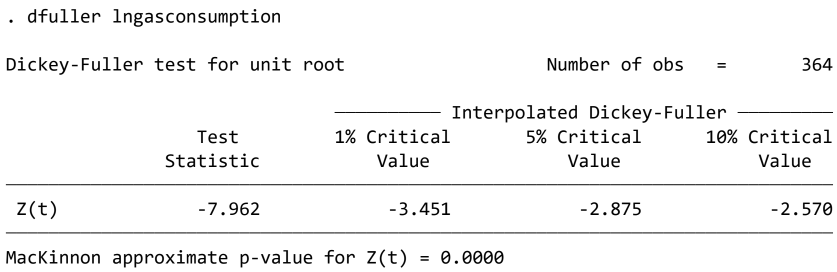
Verheul, M. J., & Thorsen, S. M. (2010). Klimagassregnskap for Norske Veksthusprodusenter. [Greenhouse gas accounts for Norwegian Greenhouse

Producers]. *Bioforsk Rapport, 5*(135). Retrieved from https://www.landbruksdirektoratet.no/no/dokumenter/publikasjoner/klimagassregnskap-for-norske-veksthusprodukter.

Volden, G. H. (2019). Assessing Public Projects' Value for Money: An Empirical Study of the Usefulness of Cost–Benefit Analyses in Decision-Making. International Journal of Project Management, Pergamon. https://doi.org/10.1016/j.ijproman.2019.02.007.

Wooldridge, J. M. (2012). Introductory Econometrics: a Modern Approach. 5th ed. Australia: South-Western Cengage Learning.

9. APPENDICES



```
. dfuller lngasconsumption

Dickey-Fuller test for unit root                   Number of obs   =       364

                               ---------- Interpolated Dickey-Fuller ---------
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
------------------------------------------------------------------------------
 Z(t)             -7.962            -3.451            -2.875            -2.570
------------------------------------------------------------------------------
MacKinnon approximate p-value for Z(t) = 0.0000
```

APPENDIX A: DICKEY-FULLER TEST NATURAL GAS CONSUMPTION

```
. dfuller lngasprice, regress lags(4)

Augmented Dickey-Fuller test for unit root         Number of obs   =       360

                               ────────── Interpolated Dickey-Fuller ─────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)             -2.239            -3.451            -2.876            -2.570
──────────────────────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.1923

──────────────────────────────────────────────────────────────────────────────
D.lngasprice │      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
  lngasprice │
         L1. │  -.0213606   .0095391    -2.24   0.026    -.0401209   -.0026002
         LD. │   -.078779   .0529433    -1.49   0.138    -.1829021     .025344
        L2D. │   .0915928   .0529845     1.73   0.085    -.0126111    .1957967
        L3D. │  -.0704521    .053007    -1.33   0.185    -.1747003    .0337962
        L4D. │  -.0480447   .0528132    -0.91   0.364    -.1519118    .0558224
             │
       _cons │   .0525696   .0244816     2.15   0.032     .0044219    .1007172
──────────────────────────────────────────────────────────────────────────────

. dfuller lnelprice, regress lags(4)

Augmented Dickey-Fuller test for unit root         Number of obs   =       360

                               ────────── Interpolated Dickey-Fuller ─────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)             -2.328            -3.451            -2.876            -2.570
──────────────────────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.1632

──────────────────────────────────────────────────────────────────────────────
 D.lnelprice │      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
   lnelprice │
         L1. │  -.0508557    .021849    -2.33   0.020    -.0938258   -.0078855
         LD. │  -.3120914   .0542008    -5.76   0.000    -.4186875   -.2054953
        L2D. │  -.2447908   .0558882    -4.38   0.000    -.3547053   -.1348762
        L3D. │  -.1243539   .0552722    -2.25   0.025     -.233057   -.0156507
        L4D. │  -.1307827   .0524092    -2.50   0.013    -.2338554   -.0277101
             │
       _cons │    .182651   .0795453     2.30   0.022     .0262103    .3390917
──────────────────────────────────────────────────────────────────────────────

. dfuller lnco2demand, regress lags(4)

Augmented Dickey-Fuller test for unit root         Number of obs   =       360

                               ────────── Interpolated Dickey-Fuller ─────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)             -2.097            -3.451            -2.876            -2.570
──────────────────────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.2456

──────────────────────────────────────────────────────────────────────────────
D.           │
 lnco2demand │      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
 lnco2demand │
         L1. │   -.046095   .0219789    -2.10   0.037    -.0893208   -.0028693
         LD. │  -.3573934   .0547824    -6.52   0.000    -.4651334   -.2496535
        L2D. │  -.2755107   .0558243    -4.94   0.000    -.3852996   -.1657217
        L3D. │  -.2384979   .0551639    -4.32   0.000     -.346988   -.1300077
        L4D. │  -.0583041   .0526388    -1.11   0.269    -.1618281    .0452199
             │
       _cons │   .3772201   .1796866     2.10   0.036     .0238326    .7306076
──────────────────────────────────────────────────────────────────────────────
```

APPENDIX B: DICKEY-FULLER TESTS, PRICE OF NATURAL GAS, PRICE OF ELECTRICITY AND CO2 DEMANDS

```
. dfuller gasprice_d1, regress lags(4)

Augmented Dickey-Fuller test for unit root         Number of obs   =       359

                               ────────── Interpolated Dickey-Fuller ─────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)             -9.357            -3.451            -2.876            -2.570
──────────────────────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.0000

─────────────┬────────────────────────────────────────────────────────────────
D.           │
 gasprice_d1 │      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
 gasprice_d1 │
         L1. │  -1.179768   .1260835    -9.36   0.000    -1.427737   -.9317985
         LD. │   .0920774   .1112163     0.83   0.408    -.1266525    .3108074
        L2D. │   .1752349   .0953524     1.84   0.067    -.0122954    .3627651
        L3D. │   .1017428   .0793134     1.28   0.200    -.0542435     .257729
        L4D. │   .0434181    .053914     0.81   0.421    -.0626149    .1494511
             │
       _cons │  -.0020933   .0023726    -0.88   0.378    -.0067594    .0025729
─────────────┴────────────────────────────────────────────────────────────────

. dfuller elprice_d1, regress lags(4)

Augmented Dickey-Fuller test for unit root         Number of obs   =       359

                               ────────── Interpolated Dickey-Fuller ─────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)            -12.650            -3.451            -2.876            -2.570
──────────────────────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.0000

─────────────┬────────────────────────────────────────────────────────────────
D.elprice_d1 │      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
  elprice_d1 │
         L1. │   -2.20271   .1741292   -12.65   0.000    -2.545171   -1.860249
         LD. │   .8341618   .1500727     5.56   0.000     .5390127    1.129311
        L2D. │   .5400076   .1215519     4.44   0.000     .3009507    .7790645
        L3D. │    .353425   .0878251     4.02   0.000     .1806987    .5261513
        L4D. │   .1549971   .0524687     2.95   0.003     .0518066    .2581876
             │
       _cons │  -.0025404   .0038984    -0.65   0.515    -.0102074    .0051267
─────────────┴────────────────────────────────────────────────────────────────

. dfuller co2demand_d1, regress lags(4)

Augmented Dickey-Fuller test for unit root         Number of obs   =       359

                               ────────── Interpolated Dickey-Fuller ─────────
                  Test         1% Critical       5% Critical      10% Critical
               Statistic           Value             Value             Value
──────────────────────────────────────────────────────────────────────────────
 Z(t)            -11.142            -3.451            -2.876            -2.570
──────────────────────────────────────────────────────────────────────────────
MacKinnon approximate p-value for Z(t) = 0.0000

─────────────┬────────────────────────────────────────────────────────────────
D.           │
co2demand_d1 │      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
─────────────┼────────────────────────────────────────────────────────────────
co2demand_d1 │
         L1. │  -2.051308   .1841099   -11.14   0.000    -2.413398   -1.689218
         LD. │   .6558602   .1593134     4.12   0.000     .3425374     .969183
        L2D. │   .3452359   .1258092     2.74   0.006      .097806    .5926657
        L3D. │   .0829532   .0901442     0.92   0.358    -.0943341    .2602406
        L4D. │   .0131753   .0527665     0.25   0.803    -.0906009    .1169514
             │
       _cons │   .0009023   .0166806     0.05   0.957    -.0319035    .0337081
─────────────┴────────────────────────────────────────────────────────────────
```

APPENDIX C: DICKEY-FULLER TEST FIRST DIFFERENCE PRICE OF NATURAL GAS, PRICE OF ELECTRICITY AND CO2 DEMANDS

```
. bgodfrey, lags(4)

Breusch-Godfrey LM test for autocorrelation
---------------------------------------------------------------------------
    lags(p)  |          chi2               df                 Prob > chi2
-------------+-------------------------------------------------------------
       4     |         70.508               4                   0.0000
---------------------------------------------------------------------------
                        H0: no serial correlation

.
end of do-file

. do "C:\Users\Erlend\AppData\Local\Temp\STD1b20_000000.tmp"

. reg lngasconsumption l(1/10).lngasconsumption

      Source |       SS           df       MS      Number of obs   =       355
-------------+----------------------------------   F(10, 344)      =     42.42
       Model |  35.1163301        10  3.51163301   Prob > F        =    0.0000
    Residual |  28.4754756       344  .082777545   R-squared       =    0.5522
-------------+----------------------------------   Adj R-squared   =    0.5392
       Total |  63.5918057       354  .179637869   Root MSE        =    .28771

------------------------------------------------------------------------------
lngasconsumption |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-----------------+------------------------------------------------------------
lngasconsumption |
             L1. |   .5242947   .0535572     9.79   0.000     .4189539    .6296354
             L2. |   .0102747   .0602886     0.17   0.865    -.1083061    .1288554
             L3. |   .0619089   .0602808     1.03   0.305    -.0566565    .1804744
             L4. |   .0662157   .0604016     1.10   0.274    -.0525873    .1850186
             L5. |   .0688912   .0604711     1.14   0.255    -.0500485    .1878309
             L6. |   .0121174    .060477     0.20   0.841    -.1068338    .1310687
             L7. |   .0749325   .0603022     1.24   0.215    -.0436748    .1935398
             L8. |  -.0522068   .0603612    -0.86   0.388    -.1709302    .0665166
             L9. |    .015696   .0603547     0.26   0.795    -.1030148    .1344068
            L10. |   .1009752   .0534418     1.89   0.060    -.0041387    .2060891
                 |
           _cons |   1.248579   .4990747     2.50   0.013     .2669574    2.230201
------------------------------------------------------------------------------
```

APPENDIX D: BREUSCH-GODFREY TEST AND REGRESSION OF LAGGED VARIABLES

```
. reg lngasconsumption gasprice_d1 gasconsumption_l1 elprice_d1 co2demand_d1 temperature irradiance quarter1 quart
> er2 quarter3, robust

Linear regression                               Number of obs     =        364
                                                F(9, 354)         =      76.53
                                                Prob > F          =     0.0000
                                                R-squared         =     0.6351
                                                Root MSE          =     .25878

------------------------------------------------------------------------------
                  |               Robust
 lngasconsumption |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
------------------+-----------------------------------------------------------
      gasprice_d1 |   .3769409   .5388532     0.70   0.485    -.6828151    1.436697
gasconsumption_l1 |    .354162   .0766589     4.62   0.000     .2033979    .5049261
       elprice_d1 |   .1191487   .1232532     0.97   0.334    -.1232519    .3615492
     co2demand_d1 |   .0982087   .0952799     1.03   0.303    -.0891772    .2855945
      temperature |  -.0408087    .006943    -5.88   0.000    -.0544635    -.027154
       irradiance |   -.005664   .0026186    -2.16   0.031     -.010814    -.000514
         quarter1 |   .1462964   .0395279     3.70   0.000     .0685574    .2240355
         quarter2 |    .161712    .079405     2.04   0.042     .0055471     .317877
         quarter3 |    .169105   .0886525     1.91   0.057    -.0052467    .3434568
            _cons |   7.182241   .8526022     8.42   0.000     5.505438    8.859043
------------------------------------------------------------------------------
```

APPENDIX E: REGRESSION RESULT

```
. estat ovtest

Ramsey RESET test using powers of the fitted values of lngasconsumption
       Ho:  model has no omitted variables
                 F(3, 351) =      0.16
                  Prob > F =      0.9222
```

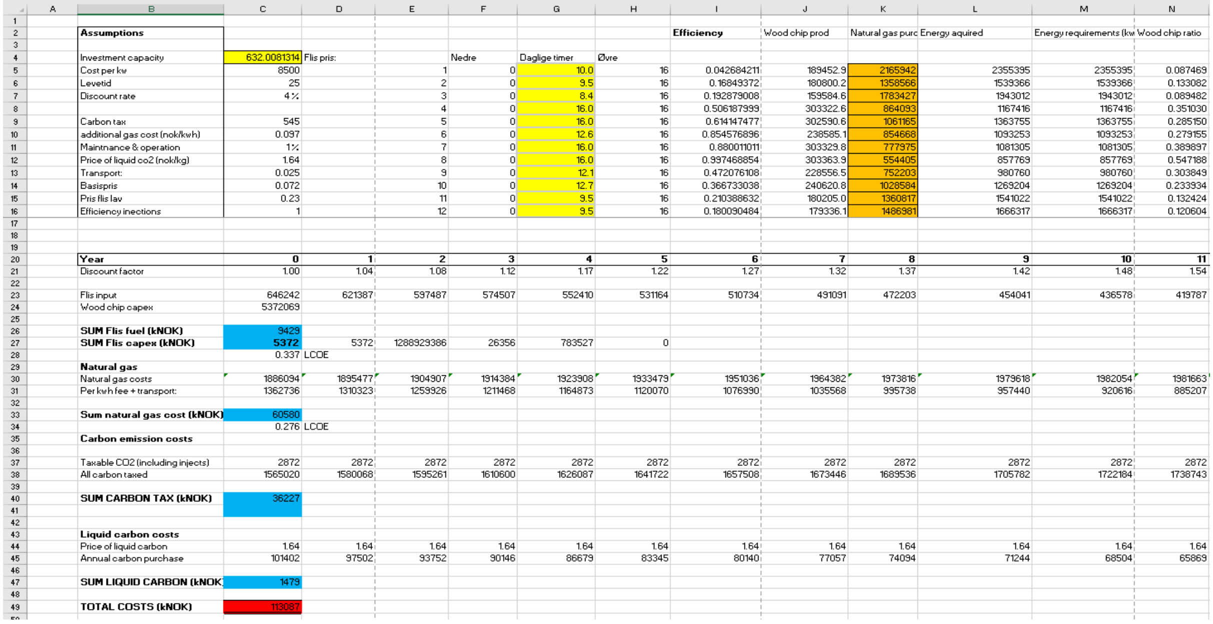
APPENDIX F: RAMSEY RESET TEST

DOFILE:

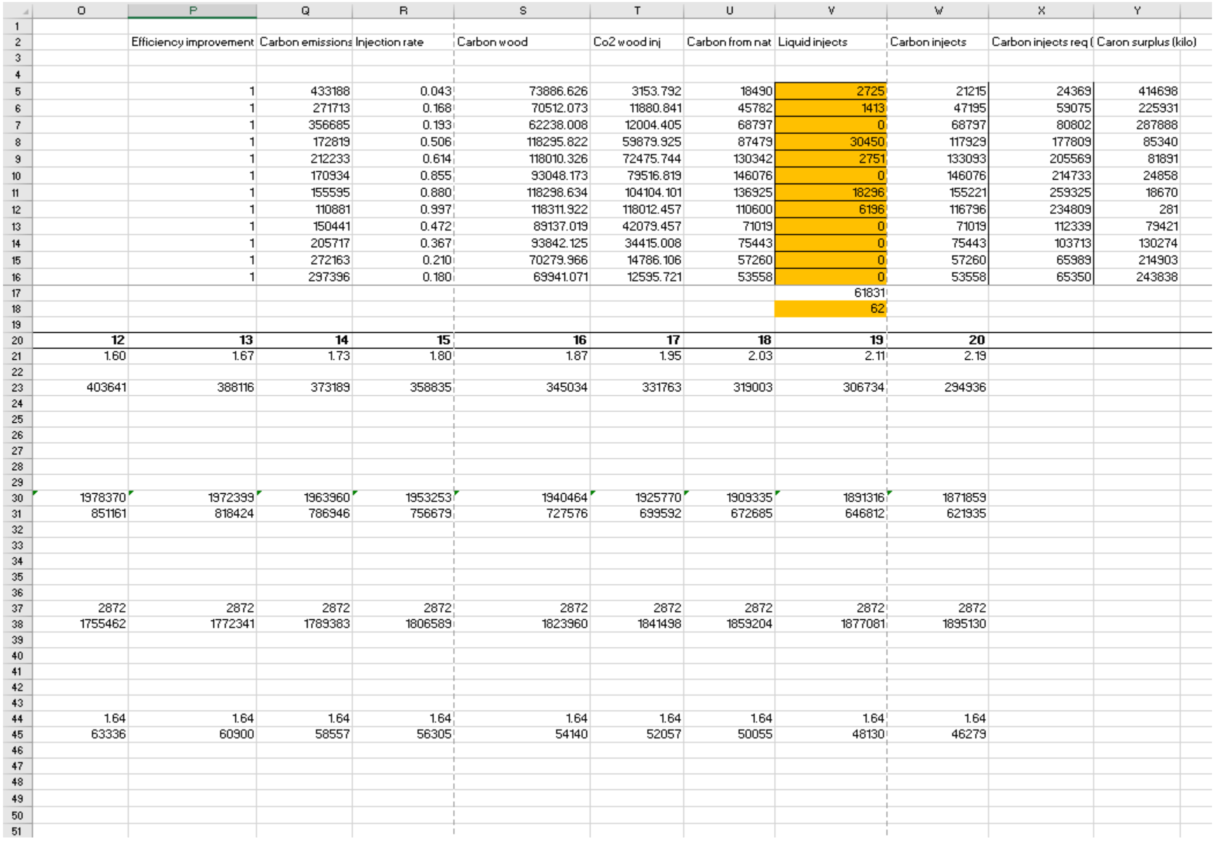
```
tsset DATO, daily

gen lngasconsumption = ln(KWHgass)

gen lngasprice = ln(ørekwhgass)

gen lnco2demand = ln(CO2behov)

gen lnelprice = ln(ørekwhel)

dfuller lngasconsumption, regress lags(4)

reg lngassforbruk lngasspris Temperatur Innstråling ørekwhel

estat ovtest

dfuller lngasprice, regress lags(4)

dfuller lnelprice, regress lags(4)

dfuller lnco2demand, regress lags(4)

generate gasprice_d1 = d1.lngasprice

generate elprice_d1 = d1.lnelprice

generate co2demand_d1 = d1.lnco2demand

dfuller gasprice_d1, regress lags(4)

dfuller elprice_d1, regress lags(4)

dfuller co2demand_d1, regress lags(4)

reg lngasconsumption gasprice_d1 temperature irradiance elprice_d1
co2demand_d1

bgodfrey, lags(4)

reg lngasconsumption l(1/10).lngasconsumption

gen gasconsumption_l1= l.lngasconsumption

reg lngasconsumption gasprice_d1 temperature irradiance elprice_d1
co2demand_d1 gasconsumption_l1

estat ovtest

gen month = month(DATO)

gen january = month==1

gen february = month==2
```

```
gen march = month==3

gen april = month==4

gen may = month==5

gen june = month==6

gen july = month==7

gen august = month==8

gen september = month==9

gen october = month==10

gen november = month==11

gen december = month==12

gen quarter1 = january+february+march

gen quarter2 = april+may+june

gen quarter3 = july+august+september

gen quarter4 = october+november+december

reg lngasconsumption gasprice_d1 temperature irradiance elprice_d1
co2demand_d1 gasconsumption_l1 quarter1 quarter2 quarter3

estat ovtest

estimate store m1, title(results)

estout m1, cells(b(star fmt(3)) se(par fmt(2))) legend label
varlabels(_cons constant) stats(F r2 df_r, fmt(2 3 0) label (F-statistic R-
sq dof))
```

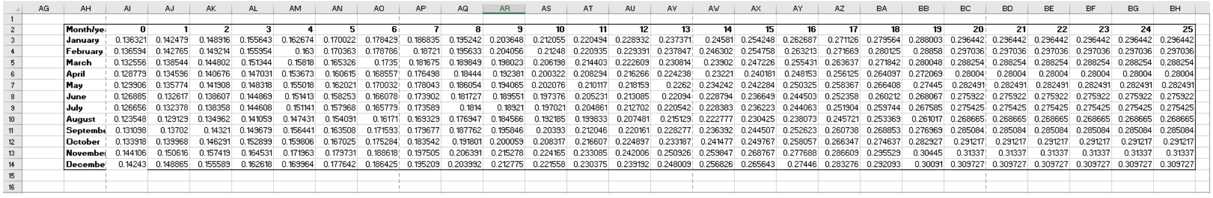
APPENDIX G: DO-FILE



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2		**Assumptions**							**Efficiency**	Wood chip prod	Natural gas purc	Energy aquired	Energy requirements (kw	Wood chip ratio
3														
4		Investment capacity	632.0081314	Flis pris:		Nedre	Daglige timer	Øvre						
5		Cost per kw	8500		1	0	10.0	16	0.042684211	189452.9	2165942	2355395	2355395	0.087469
6		Levetid	25		2	0	9.5	16	0.16849372	180800.2	1358566	1539366	1539366	0.133082
7		Discount rate	4%		3	0	8.4	16	0.192879008	159584.6	1783427	1943012	1943012	0.089482
8					4	0	16.0	16	0.506187999	303322.6	864093	1167416	1167416	0.351030
9		Carbon tax	545		5	0	16.0	16	0.614147477	302590.6	1061165	1363755	1363755	0.285150
10		additional gas cost (nok/kwh)	0.097		6	0	12.6	16	0.854576896	238585.1	854668	1093253	1093253	0.279155
11		Maintnance & operation	1%		7	0	16.0	16	0.880011011	303329.8	777975	1081305	1081305	0.389897
12		Price of liquid co2 (nok/kg)	1.64		8	0	16.0	16	0.997468854	303363.9	554405	857769	857769	0.547188
13		Transport:	0.025		9	0	12.1	16	0.472076108	228556.5	752203	980760	980760	0.303849
14		Basispris	0.072		10	0	12.7	16	0.366733038	240620.8	1028584	1269204	1269204	0.233934
15		Pris flis lav	0.23		11	0	9.5	16	0.210388632	180205.0	1360817	1541022	1541022	0.132424
16		Efficiency inections	1		12	0	9.5	16	0.180090484	179336.1	1486981	1666317	1666317	0.120604
17														
18														
19														
20		**Year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
21		Discount factor	1.00	1.04	1.08	1.12	1.17	1.22	1.27	1.32	1.37	1.42	1.48	1.54
22														
23		Flis input	646242	621387	597487	574507	552410	531164	510734	491091	472203	454041	436578	419787
24		Wood chip capex	5372069											
25														
26		**SUM Flis fuel (kNOK)**	9429											
27		**SUM Flis capex (kNOK)**	**5372**	5372	1288929386	26356	783527	0						
28			0.337	LCOE										
29		**Natural gas**												
30		Natural gas costs	1886094	1895477	1904907	1914384	1923908	1933479	1951036	1964382	1973816	1979618	1982054	1981663
31		Per kwh fee + transport:	1362736	1310323	1259926	1211468	1164873	1120070	1076990	1035568	995738	957440	920616	885207
32														
33		**Sum natural gas cost (kNOK)**	60580											
34			0.276	LCOE										
35		**Carbon emission costs**												
36														
37		Taxable CO2 (including injects)	2872	2872	2872	2872	2872	2872	2872	2872	2872	2872	2872	2872
38		All carbon taxed	1565020	1580068	1595261	1610600	1626087	1641722	1657508	1673446	1689536	1705782	1722184	1738743
39														
40		**SUM CARBON TAX (kNOK)**	36227											
41														
42														
43		**Liquid carbon costs**												
44		Price of liquid carbon	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
45		Annual carbon purchase	101402	97502	93752	90146	86679	83345	80140	77057	74094	71244	68504	65869
46														
47		**SUM LIQUID CARBON (kNOK**	1479											
48														
49		**TOTAL COSTS (kNOK)**	113087											

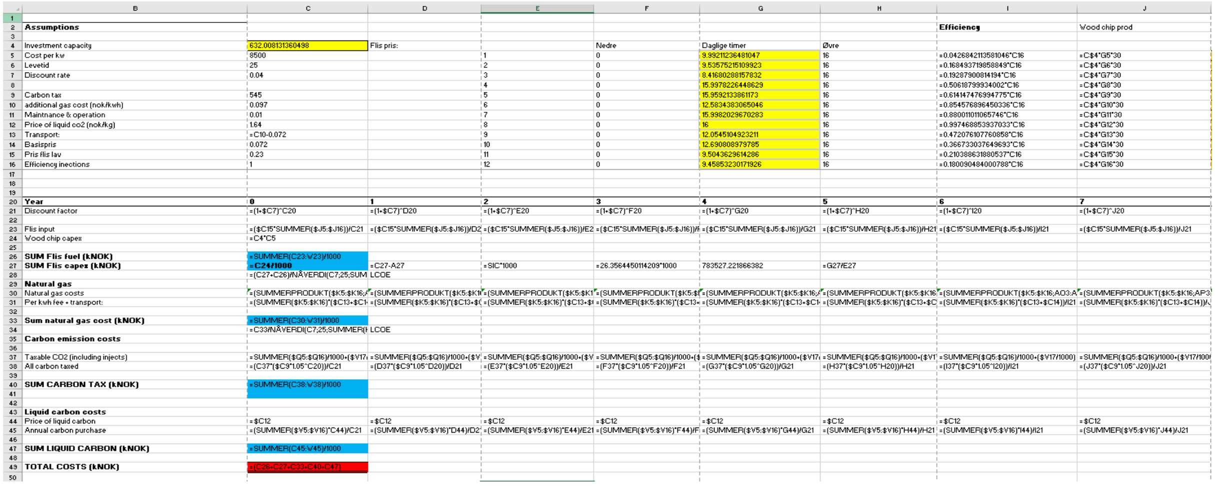


	O	P	Q	R	S	T	U	V	W	X	Y
1											
2		Efficiency improvement	Carbon emissions	Injection rate	Carbon wood	Co2 wood inj	Carbon from nat	Liquid injects	Carbon injects	Carbon injects req (	Caron surplus (kilo)
3											
4											
5		1	433188	0.043	73886.626	3153.792	18490	2725	21215	24369	414698
6		1	271713	0.168	70512.073	11880.841	45782	1413	47195	59075	225931
7		1	356685	0.193	62238.008	12004.405	68797	0	68797	80802	287888
8		1	172819	0.506	118295.822	59879.925	87479	30450	117929	177809	85340
9		1	212233	0.614	118010.326	72475.744	130342	2751	133093	205569	81891
10		1	170934	0.855	93048.173	79516.819	146076	0	146076	214733	24858
11		1	155595	0.880	118298.634	104104.101	136925	18296	155221	259325	18670
12		1	110881	0.997	118311.922	118012.457	110600	6196	116796	234809	281
13		1	150441	0.472	89137.019	42079.457	71019	0	71019	112339	79421
14		1	205717	0.367	93842.125	34415.008	75443	0	75443	103713	130274
15		1	272163	0.210	70279.966	14786.106	57260	0	57260	65989	214903
16		1	297396	0.180	69941.071	12595.721	53558	0	53558	65350	243838
17								61831			
18								62			
19											
20	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**		
21	1.60	1.67	1.73	1.80	1.87	1.95	2.03	2.11	2.19		
22											
23	403641	388116	373189	358835	345034	331763	319003	306734	294936		
24											
25											
26											
27											
28											
29											
30	1978370	1972399	1963960	1953253	1940464	1925770	1909335	1891316	1871859		
31	851161	818424	786946	756679	727576	699592	672685	646812	621935		
32											
33											
34											
35											
36											
37	2872	2872	2872	2872	2872	2872	2872	2872	2872		
38	1755462	1772341	1789383	1806589	1823960	1841498	1859204	1877081	1895130		
39											
40											
41											
42											
43											
44	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64		
45	63336	60900	58557	56305	54140	52057	50055	48130	46279		
46											
47											
48											
49											
50											
51											

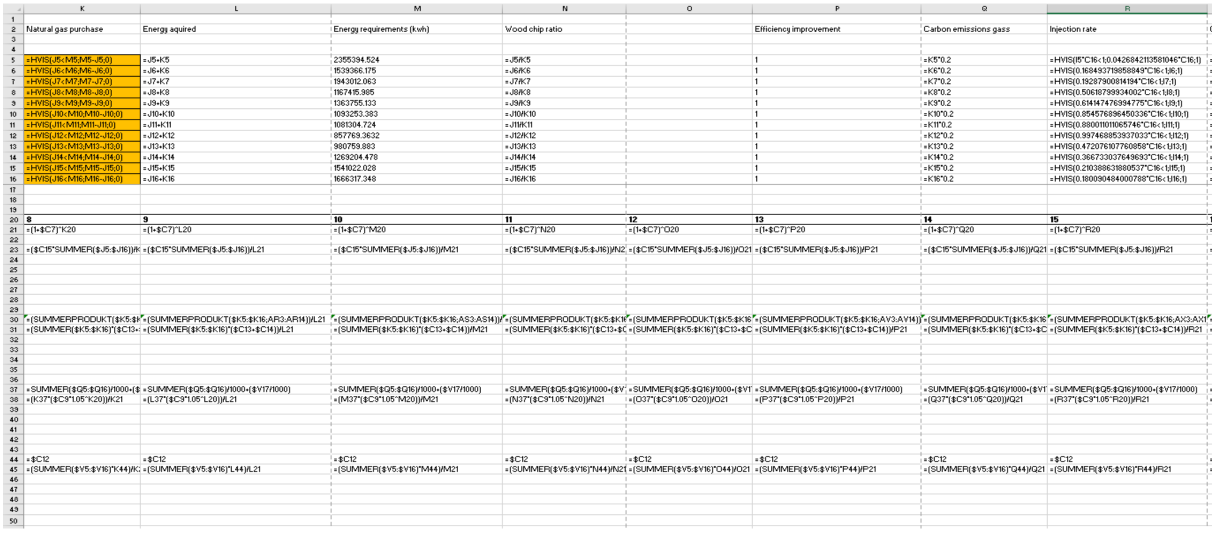


	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA	BB	BC	BD	BE	BF	BG	BH
1																												
2		**Month/ye**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**
3		**January**	0.136321	0.142479	0.148916	0.155643	0.162674	0.170022	0.178429	0.186835	0.195242	0.203648	0.212055	0.220494	0.228932	0.237371	0.24581	0.254248	0.262687	0.271126	0.279564	0.288003	0.296442	0.296442	0.296442	0.296442	0.296442	0.296442
4		**February**	0.136594	0.142765	0.149214	0.155954	0.163	0.170363	0.178786	0.18721	0.195633	0.204056	0.21248	0.220935	0.229391	0.237847	0.246302	0.254758	0.263213	0.271669	0.280125	0.28858	0.297036	0.297036	0.297036	0.297036	0.297036	0.297036
5		**March**	0.132556	0.138544	0.144802	0.151344	0.15818	0.165326	0.1735	0.181675	0.189849	0.198023	0.206198	0.214403	0.222609	0.230814	0.23902	0.247226	0.255431	0.263637	0.271842	0.280048	0.288254	0.288254	0.288254	0.288254	0.288254	0.288254
6		**April**	0.128779	0.134596	0.140676	0.147031	0.153673	0.160615	0.168557	0.176498	0.18444	0.192381	0.200322	0.208294	0.216266	0.224238	0.23221	0.240181	0.248153	0.256125	0.264097	0.272069	0.28004	0.28004	0.28004	0.28004	0.28004	0.28004
7		**May**	0.129906	0.135774	0.141908	0.148318	0.155018	0.162021	0.170032	0.178043	0.186054	0.194065	0.202076	0.210117	0.218159	0.2262	0.234242	0.242284	0.250325	0.258367	0.266408	0.27445	0.282491	0.282491	0.282491	0.282491	0.282491	0.282491
8		**June**	0.126885	0.132617	0.138607	0.144869	0.151413	0.158253	0.166078	0.173902	0.181727	0.189551	0.197376	0.205231	0.213085	0.22094	0.228794	0.236649	0.244503	0.252358	0.260212	0.268067	0.275922	0.275922	0.275922	0.275922	0.275922	0.275922
9		**July**	0.126656	0.132378	0.138358	0.144608	0.151141	0.157968	0.165779	0.173589	0.1814	0.18921	0.197021	0.204861	0.212702	0.220542	0.228383	0.236223	0.244063	0.251904	0.259744	0.267585	0.275425	0.275425	0.275425	0.275425	0.275425	0.275425
10		**August**	0.123548	0.129129	0.134962	0.141059	0.147431	0.154091	0.16171	0.169329	0.176947	0.184566	0.192185	0.199833	0.207481	0.215129	0.222777	0.230425	0.238073	0.245721	0.253369	0.261017	0.268665	0.268665	0.268665	0.268665	0.268665	0.268665
11		**Septembe**	0.131098	0.13702	0.14321	0.149679	0.156441	0.163508	0.171593	0.179677	0.187762	0.195846	0.20393	0.212046	0.220161	0.228277	0.236392	0.244507	0.252623	0.260738	0.268853	0.276969	0.285084	0.285084	0.285084	0.285084	0.285084	0.285084
12		**October**	0.133918	0.139968	0.146291	0.152899	0.159806	0.167025	0.175284	0.183542	0.191801	0.200059	0.208317	0.216607	0.224897	0.233187	0.241477	0.249767	0.258057	0.266347	0.274637	0.282927	0.291217	0.291217	0.291217	0.291217	0.291217	0.291217
13		**Novembe**	0.144106	0.150616	0.157419	0.164531	0.171963	0.179731	0.188618	0.197505	0.206391	0.215278	0.224165	0.233085	0.242006	0.250926	0.259847	0.268767	0.277688	0.286609	0.295529	0.30445	0.31337	0.31337	0.31337	0.31337	0.31337	0.31337
14		**Decembe**	0.14243	0.148865	0.155589	0.162618	0.169964	0.177642	0.186425	0.195209	0.203992	0.212775	0.221558	0.230375	0.239192	0.248009	0.256826	0.265643	0.27446	0.283276	0.292093	0.30091	0.309727	0.309727	0.309727	0.309727	0.309727	0.309727
15																												
16																												

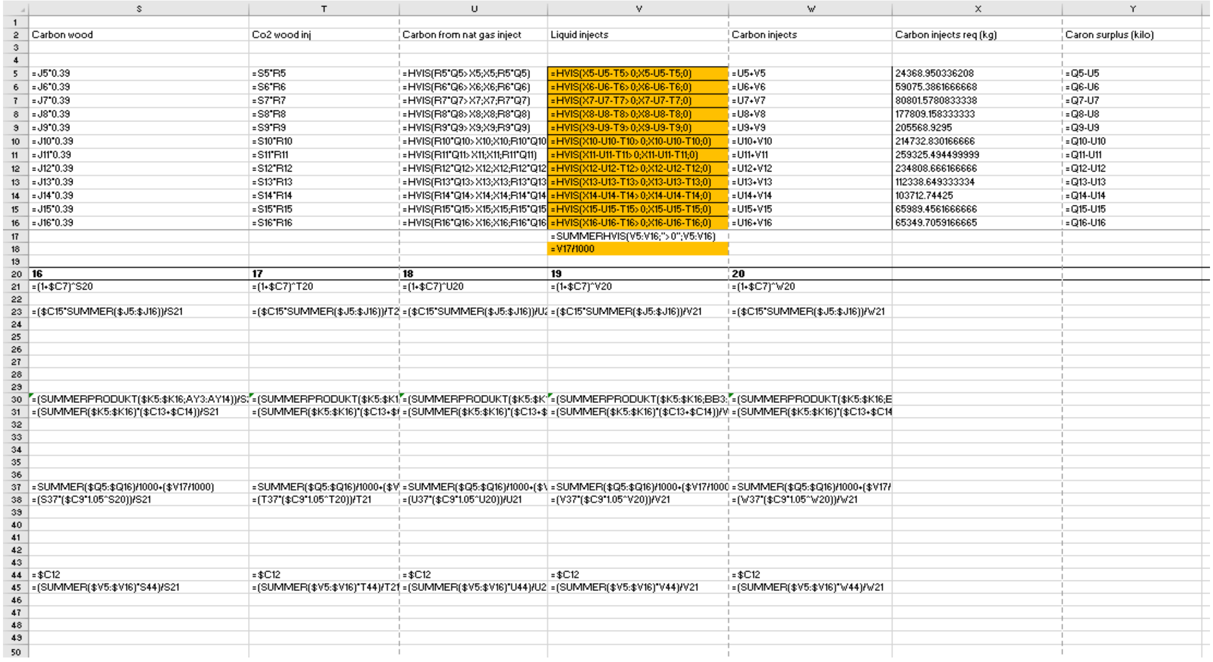
APPENDIX H: PROFITABILITY ANALYSIS WOODCHIPS (VALUES)



	B	C	D	E	F	G	H	I	J
2	**Assumptions**							**Efficiency**	Wood chip prod
4	Investment capacity	632.008131360498	Flis pris:		Nedre	Daglige timer	Øvre		
5	Cost per kw	8500		1	0	9.99211236481047	16	=0.0426842113581046*C16	=C$4*G5*30
6	Levetid	25		2	0	9.53575215109923	16	=0.168493719858849*C16	=C$4*G6*30
7	Discount rate	0.04		3	0	8.41680288157832	16	=0.19287900814194*C16	=C$4*G7*30
8				4	0	15.9978226448629	16	=0.50618799934002*C16	=C$4*G8*30
9	Carbon tax	545		5	0	15.9592133861173	16	=0.614147476994775*C16	=C$4*G9*30
10	additional gas cost (nok/kwh)	0.097		6	0	12.5834383065046	16	=0.854576896450336*C16	=C$4*G10*30
11	Maintnance & operation	0.01		7	0	15.9982029670283	16	=0.880011011065746*C16	=C$4*G11*30
12	Price of liquid co2 (nok/kg)	1.64		8	0	16	16	=0.997468853937033*C16	=C$4*G12*30
13	Transport:	=C10-0.072		9	0	12.0545104923211	16	=0.472076107760858*C16	=C$4*G13*30
14	Basispris	0.072		10	0	12.690808979785	16	=0.366733037649693*C16	=C$4*G14*30
15	Pris flis lav	0.23		11	0	9.5043629614286	16	=0.210388631880537*C16	=C$4*G15*30
16	Efficiency inections	1		12	0	9.45853230171926	16	=0.180090484000788*C16	=C$4*G16*30
20	**Year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
21	Discount factor	=(1+$C7)^C20	=(1+$C7)^D20	=(1+$C7)^E20	=(1+$C7)^F20	=(1+$C7)^G20	=(1+$C7)^H20	=(1+$C7)^I20	=(1+$C7)^J20
23	Flis input	=($C15*SUMMER($J5:$J16))/C21	=($C15*SUMMER($J5:$J16))/D2	=($C15*SUMMER($J5:$J16))/E2	=($C15*SUMMER($J5:$J16))/F	=($C15*SUMMER($J5:$J16))/G21	=($C15*SUMMER($J5:$J16))/H21	=($C15*SUMMER($J5:$J16))/I21	=($C15*SUMMER($J5:$J16))/J21
24	Wood chip capex	=C4*C5							
26	**SUM Flis fuel (kNOK)**	=SUMMER(C23:W23)/1000							
27	**SUM Flis capex (kNOK)**	**=C24/1000**	=C27-A27	=SIC*1000	=26.3564450114209*1000	783527.221866382	=G27/E27		
28		=(C27+C26)/NÅVERDI(C7;25;SUM	LCOE						
29	**Natural gas**								
30	Natural gas costs	=(SUMMERPRODUKT($K5:$K16;A	=(SUMMERPRODUKT($K5:$K1	=(SUMMERPRODUKT($K5:$K1	=(SUMMERPRODUKT($K5:$	=(SUMMERPRODUKT($K5:$K16;A	=(SUMMERPRODUKT($K5:$K16	=(SUMMERPRODUKT($K5:$K16;AO3:A	=(SUMMERPRODUKT($K5:$K16;AP3
31	Per kwh fee + transport:	=(SUMMER($K5:$K16)*($C13+$C1	=(SUMMER($K5:$K16)*($C13+$	=(SUMMER($K5:$K16)*($C13+$	=(SUMMER($K5:$K16)*($C13+	=(SUMMER($K5:$K16)*($C13+$C1	=(SUMMER($K5:$K16)*($C13+$C	=(SUMMER($K5:$K16)*($C13+$C14))/I21	=(SUMMER($K5:$K16)*($C13+$C14))/J
33	**Sum natural gas cost (kNOK)**	=SUMMER(C30:W31)/1000							
34		=C33/NÅVERDI(C7;25;SUMMER(	LCOE						
35	**Carbon emission costs**								
37	Taxable CO2 (including injects)	=SUMMER($Q5:$Q16)/1000+($V17/	=SUMMER($Q5:$Q16)/1000+($V	=SUMMER($Q5:$Q16)/1000+($V	=SUMMER($Q5:$Q16)/1000+($	=SUMMER($Q5:$Q16)/1000+($V17/	=SUMMER($Q5:$Q16)/1000+($V1	=SUMMER($Q5:$Q16)/1000+($V17/1000)	=SUMMER($Q5:$Q16)/1000+($V17/100
38	All carbon taxed	=(C37*($C9*1.05^C20))/C21	=(D37*($C9*1.05^D20))/D21	=(E37*($C9*1.05^E20))/E21	=(F37*($C9*1.05^F20))/F21	=(G37*($C9*1.05^G20))/G21	=(H37*($C9*1.05^H20))/H21	=(I37*($C9*1.05^I20))/I21	=(J37*($C9*1.05^J20))/J21
40	**SUM CARBON TAX (kNOK)**	=SUMMER(C38:W38)/1000							
43	**Liquid carbon costs**								
44	Price of liquid carbon	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12
45	Annual carbon purchase	=(SUMMER($V5:$V16)*C44)/C21	=(SUMMER($V5:$V16)*D44)/D2	=(SUMMER($V5:$V16)*E44)/E21	=(SUMMER($V5:$V16)*F44)/F	=(SUMMER($V5:$V16)*G44)/G21	=(SUMMER($V5:$V16)*H44)/H21	=(SUMMER($V5:$V16)*I44)/I21	=(SUMMER($V5:$V16)*J44)/J21
47	**SUM LIQUID CARBON (kNOK)**	=SUMMER(C45:W45)/1000							
49	**TOTAL COSTS (kNOK)**	=(C26+C27+C33+C40+C47)							

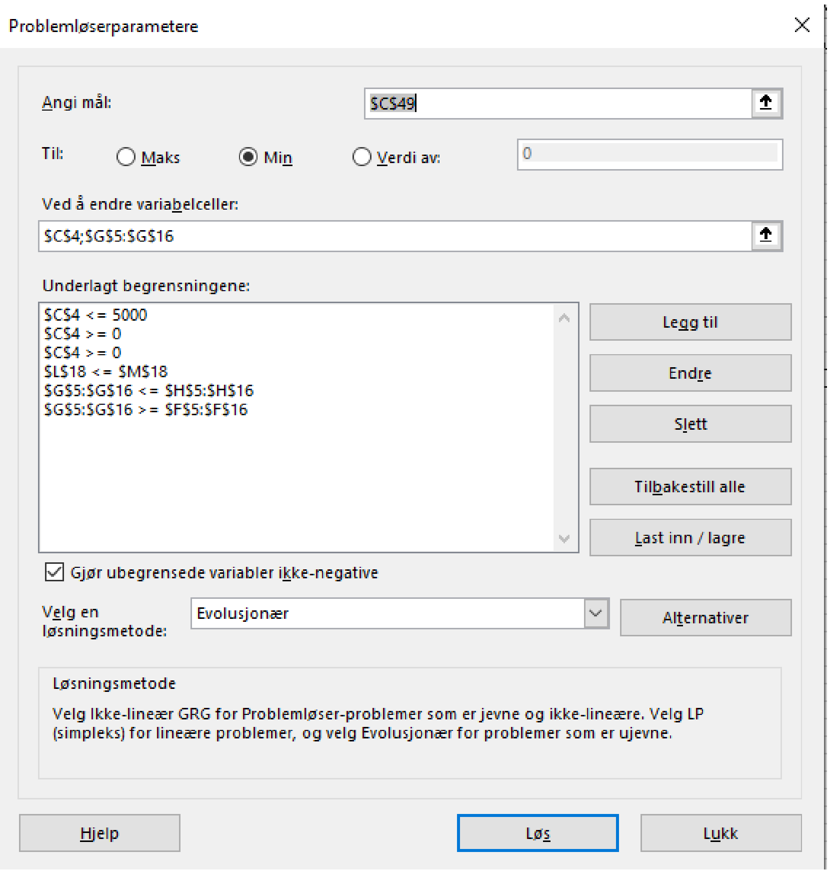


	K	L	M	N	O	P	Q	R
2	Natural gas purchase	Energy aquired	Energy requirements (kwh)	Wood chip ratio		Efficiency improvement	Carbon emissions gass	Injection rate
5	=HVIS(J5<M5;M5-J5;0)	=J5+K5	2355394.524	=J5/K5		1	=K5*0.2	=HVIS(I5*C16<1;0.0426842113581046*C16;1)
6	=HVIS(J6<M6;M6-J6;0)	=J6+K6	1539366.175	=J6/K6		1	=K6*0.2	=HVIS(0.168493719858849*C16<1;I6;1)
7	=HVIS(J7<M7;M7-J7;0)	=J7+K7	1943012.063	=J7/K7		1	=K7*0.2	=HVIS(0.19287900814194*C16<1;I7;1)
8	=HVIS(J8<M8;M8-J8;0)	=J8+K8	1167415.985	=J8/K8		1	=K8*0.2	=HVIS(0.50618799934002*C16<1;I8;1)
9	=HVIS(J9<M9;M9-J9;0)	=J9+K9	1363755.133	=J9/K9		1	=K9*0.2	=HVIS(0.614147476994775*C16<1;I9;1)
10	=HVIS(J10<M10;M10-J10;0)	=J10+K10	1093253.383	=J10/K10		1	=K10*0.2	=HVIS(0.854576896450336*C16<1;I10;1)
11	=HVIS(J11<M11;M11-J11;0)	=J11+K11	1081304.724	=J11/K11		1	=K11*0.2	=HVIS(0.880011011065746*C16<1;I11;1)
12	=HVIS(J12<M12;M12-J12;0)	=J12+K12	857769.3632	=J12/K12		1	=K12*0.2	=HVIS(0.997468853937033*C16<1;I12;1)
13	=HVIS(J13<M13;M13-J13;0)	=J13+K13	980759.883	=J13/K13		1	=K13*0.2	=HVIS(0.472076107760858*C16<1;I13;1)
14	=HVIS(J14<M14;M14-J14;0)	=J14+K14	1269204.478	=J14/K14		1	=K14*0.2	=HVIS(0.366733037649693*C16<1;I14;1)
15	=HVIS(J15<M15;M15-J15;0)	=J15+K15	1541022.028	=J15/K15		1	=K15*0.2	=HVIS(0.210388631880537*C16<1;I15;1)
16	=HVIS(J16<M16;M16-J16;0)	=J16+K16	1666317.348	=J16/K16		1	=K16*0.2	=HVIS(0.180090484000788*C16<1;I16;1)
20	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
21	=(1+$C7)^K20	=(1+$C7)^L20	=(1+$C7)^M20	=(1+$C7)^N20	=(1+$C7)^O20	=(1+$C7)^P20	=(1+$C7)^Q20	=(1+$C7)^R20
23	=($C15*SUMMER($J5:$J16))/K	=($C15*SUMMER($J5:$J16))/L21	=($C15*SUMMER($J5:$J16))/M21	=($C15*SUMMER($J5:$J16))/N2	=($C15*SUMMER($J5:$J16))/O21	=($C15*SUMMER($J5:$J16))/P21	=($C15*SUMMER($J5:$J16))/Q21	=($C15*SUMMER($J5:$J16))/R21
30	=(SUMMERPRODUKT($K5:$K	=(SUMMERPRODUKT($K5:$K16;AR3:AR14))/L21	=(SUMMERPRODUKT($K5:$K16;AS3:AS14))/	=(SUMMERPRODUKT($K5:$K16	=(SUMMERPRODUKT($K5:$K16	=(SUMMERPRODUKT($K5:$K16;AV3:AV14))	=(SUMMERPRODUKT($K5:$K16	=(SUMMERPRODUKT($K5:$K16;AX3:AX1
31	=(SUMMER($K5:$K16)*($C13+	=(SUMMER($K5:$K16)*($C13+$C14))/L21	=(SUMMER($K5:$K16)*($C13+$C14))/M21	=(SUMMER($K5:$K16)*($C13+$C	=(SUMMER($K5:$K16)*($C13+$C	=(SUMMER($K5:$K16)*($C13+$C14))/P21	=(SUMMER($K5:$K16)*($C13+$C	=(SUMMER($K5:$K16)*($C13+$C14))/R21
37	=SUMMER($Q5:$Q16)/1000+($	=SUMMER($Q5:$Q16)/1000+($V17/1000)	=SUMMER($Q5:$Q16)/1000+($V17/1000)	=SUMMER($Q5:$Q16)/1000+($V	=SUMMER($Q5:$Q16)/1000+($V1	=SUMMER($Q5:$Q16)/1000+($V17/1000)	=SUMMER($Q5:$Q16)/1000+($V1	=SUMMER($Q5:$Q16)/1000+($V17/1000)
38	=(K37*($C9*1.05^K20))/K21	=(L37*($C9*1.05^L20))/L21	=(M37*($C9*1.05^M20))/M21	=(N37*($C9*1.05^N20))/N21	=(O37*($C9*1.05^O20))/O21	=(P37*($C9*1.05^P20))/P21	=(Q37*($C9*1.05^Q20))/Q21	=(R37*($C9*1.05^R20))/R21
44	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12
45	=(SUMMER($V5:$V16)*K44)/K	=(SUMMER($V5:$V16)*L44)/L21	=(SUMMER($V5:$V16)*M44)/M21	=(SUMMER($V5:$V16)*N44)/N21	=(SUMMER($V5:$V16)*O44)/O21	=(SUMMER($V5:$V16)*P44)/P21	=(SUMMER($V5:$V16)*Q44)/Q21	=(SUMMER($V5:$V16)*R44)/R21



	S	T	U	V	W	X	Y
2	Carbon wood	Co2 wood inj	Carbon from nat gas inject	Liquid injects	Carbon injects	Carbon injects req (kg)	Caron surplus (kilo)
5	=J5*0.39	=S5*R5	=HVIS(R5*Q5>X5;X5;R5*Q5)	=HVIS(X5-U5-T5>0;X5-U5-T5;0)	=U5+V5	24368.950336208	=Q5-U5
6	=J6*0.39	=S6*R6	=HVIS(R6*Q6>X6;X6;R6*Q6)	=HVIS(X6-U6-T6>0;X6-U6-T6;0)	=U6+V6	59075.3861666668	=Q6-U6
7	=J7*0.39	=S7*R7	=HVIS(R7*Q7>X7;X7;R7*Q7)	=HVIS(X7-U7-T7>0;X7-U7-T7;0)	=U7+V7	80801.5780833338	=Q7-U7
8	=J8*0.39	=S8*R8	=HVIS(R8*Q8>X8;X8;R8*Q8)	=HVIS(X8-U8-T8>0;X8-U8-T8;0)	=U8+V8	177809.158333333	=Q8-U8
9	=J9*0.39	=S9*R9	=HVIS(R9*Q9>X9;X9;R9*Q9)	=HVIS(X9-U9-T9>0;X9-U9-T9;0)	=U9+V9	205568.9295	=Q9-U9
10	=J10*0.39	=S10*R10	=HVIS(R10*Q10>X10;X10;R10*Q10	=HVIS(X10-U10-T10>0;X10-U10-T10;0)	=U10+V10	214732.830166666	=Q10-U10
11	=J11*0.39	=S11*R11	=HVIS(R11*Q11>X11;X11;R11*Q11)	=HVIS(X11-U11-T11>0;X11-U11-T11;0)	=U11+V11	259325.494499999	=Q11-U11
12	=J12*0.39	=S12*R12	=HVIS(R12*Q12>X12;X12;R12*Q12	=HVIS(X12-U12-T12>0;X12-U12-T12;0)	=U12+V12	234808.666166666	=Q12-U12
13	=J13*0.39	=S13*R13	=HVIS(R13*Q13>X13;X13;R13*Q13	=HVIS(X13-U13-T13>0;X13-U13-T13;0)	=U13+V13	112338.649333334	=Q13-U13
14	=J14*0.39	=S14*R14	=HVIS(R14*Q14>X14;X14;R14*Q14	=HVIS(X14-U14-T14>0;X14-U14-T14;0)	=U14+V14	103712.74425	=Q14-U14
15	=J15*0.39	=S15*R15	=HVIS(R15*Q15>X15;X15;R15*Q15	=HVIS(X15-U15-T15>0;X15-U15-T15;0)	=U15+V15	65989.4561666666	=Q15-U15
16	=J16*0.39	=S16*R16	=HVIS(R16*Q16>X16;X16;R16*Q16	=HVIS(X16-U16-T16>0;X16-U16-T16;0)	=U16+V16	65349.7059166665	=Q16-U16
17				=SUMMERHVIS(V5:V16;">0";V5:V16)			
18				=V17/1000			
20	**16**	**17**	**18**	**19**	**20**		
21	=(1+$C7)^S20	=(1+$C7)^T20	=(1+$C7)^U20	=(1+$C7)^V20	=(1+$C7)^W20		
23	=($C15*SUMMER($J5:$J16))/S21	=($C15*SUMMER($J5:$J16))/T2	=($C15*SUMMER($J5:$J16))/U2	=($C15*SUMMER($J5:$J16))/V21	=($C15*SUMMER($J5:$J16))/W21		
30	=(SUMMERPRODUKT($K5:$K16;AY3:AY14))/S	=(SUMMERPRODUKT($K5:$K1	=(SUMMERPRODUKT($K5:$K	=(SUMMERPRODUKT($K5:$K16;BB3:	=(SUMMERPRODUKT($K5:$K16;E		
31	=(SUMMER($K5:$K16)*($C13+$C14))/S21	=(SUMMER($K5:$K16)*($C13+$	=(SUMMER($K5:$K16)*($C13+$	=(SUMMER($K5:$K16)*($C13+$C14))/V	=(SUMMER($K5:$K16)*($C13+$C14		
37	=SUMMER($Q5:$Q16)/1000+($V17/1000)	=SUMMER($Q5:$Q16)/1000+($V	=SUMMER($Q5:$Q16)/1000+($V	=SUMMER($Q5:$Q16)/1000+($V17/1000	=SUMMER($Q5:$Q16)/1000+($V17/		
38	=(S37*($C9*1.05^S20))/S21	=(T37*($C9*1.05^T20))/T21	=(U37*($C9*1.05^U20))/U21	=(V37*($C9*1.05^V20))/V21	=(W37*($C9*1.05^W20))/W21		
44	=$C12	=$C12	=$C12	=$C12	=$C12		
45	=(SUMMER($V5:$V16)*S44)/S21	=(SUMMER($V5:$V16)*T44)/T21	=(SUMMER($V5:$V16)*U44)/U2	=(SUMMER($V5:$V16)*V44)/V21	=(SUMMER($V5:$V16)*W44)/W21		

APPENDIX I: PROFITABILITY ANALYSIS WOODCHIPS (FORMULAS)



Problemløserparametere

Angi mål: $C$49

Til: ○ Maks ● Min ○ Verdi av: 0

Ved å endre variabelceller: $C$4;$G$5:$G$16

Underlagt begrensningene:

$C$4 <= 5000
$C$4 >= 0
$C$4 >= 0
$L$18 <= $M$18
$G$5:$G$16 <= $H$5:$H$16
$G$5:$G$16 >= $F$5:$F$16

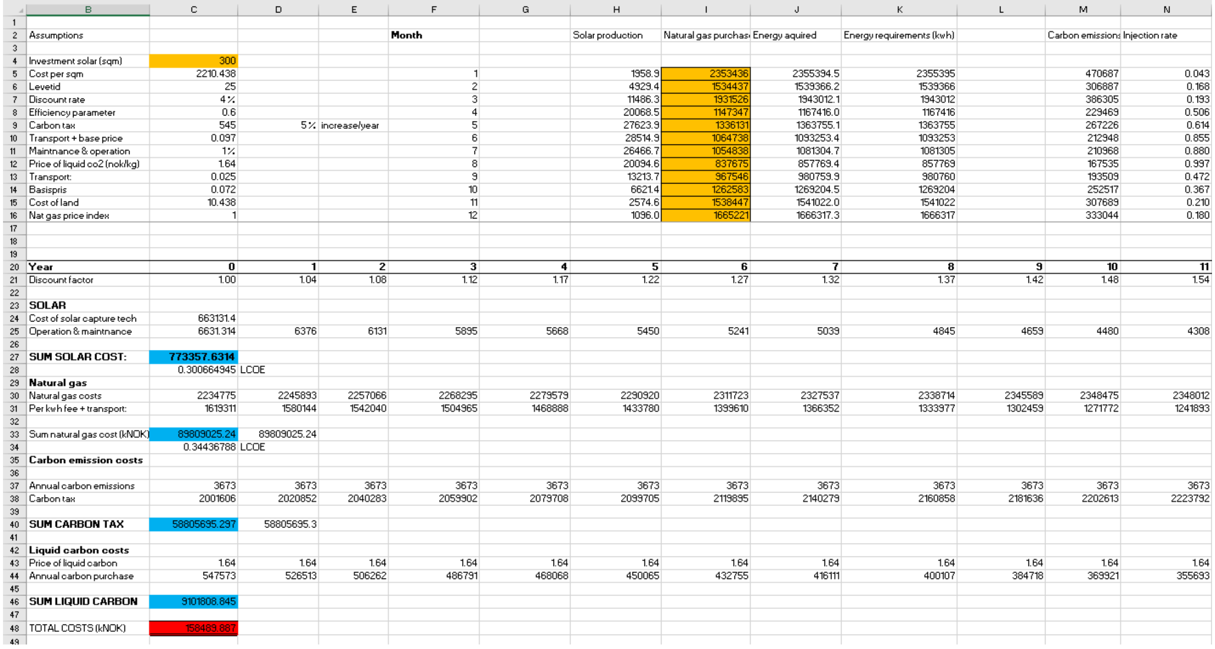
☑ Gjør ubegrensede variabler ikke-negative

Velg en løsningsmetode: Evolusjonær

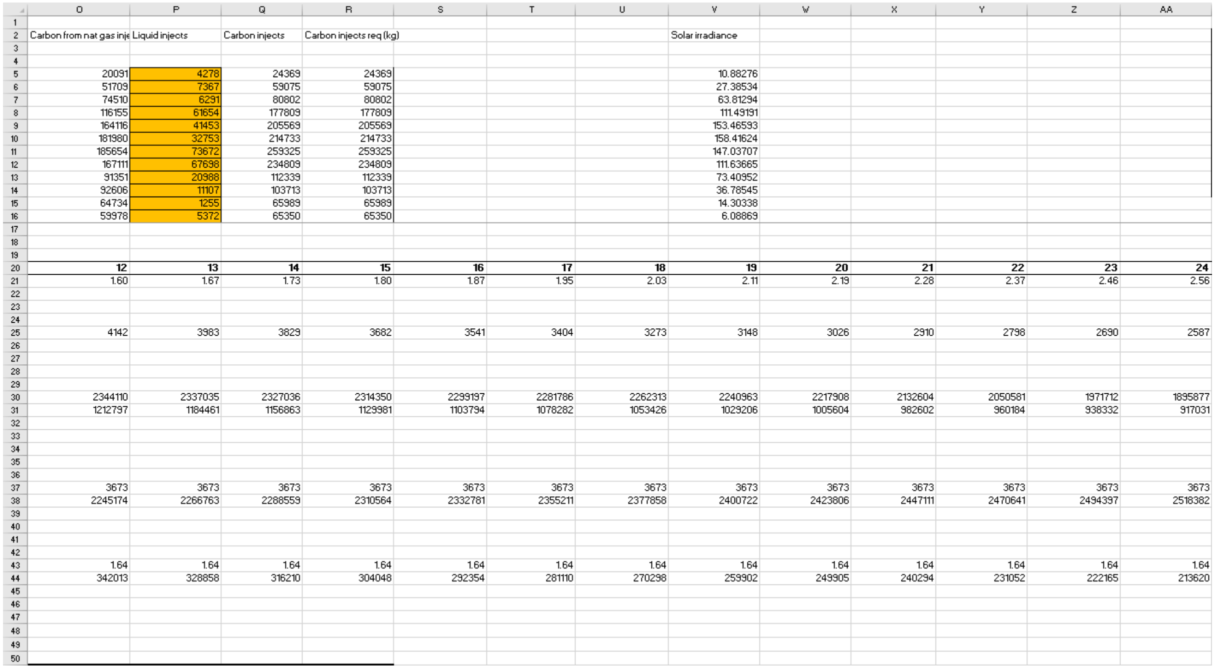
Løsningsmetode

Velg Ikke-lineær GRG for Problemløser-problemer som er jevne og ikke-lineære. Velg LP (simpleks) for lineære problemer, og velg Evolusjonær for problemer som er ujevne.

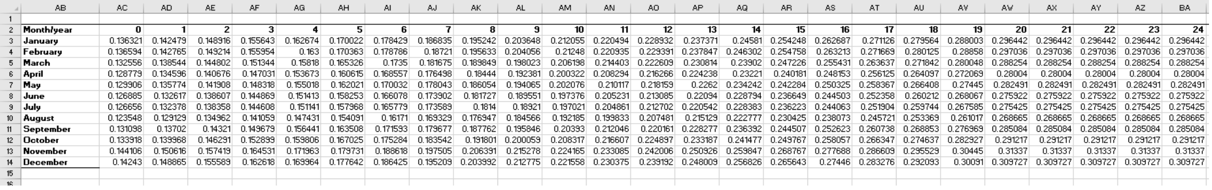
APPENDIX J: PROFITABILITY ANALYSIS WOODCHIPS (SOLVER)



	B	C	D	E	F	G	H	I	J	K	L	M	N
1													
2	Assumptions				**Month**		Solar production	Natural gas purchas	Energy aquired	Energy requirements (kwh)		Carbon emissions	Injection rate
3													
4	Investment solar (sqm)	300											
5	Cost per sqm	2210.438			1		1958.9	2353436	2355394.5	2355395		470687	0.043
6	Levetid	25			2		4929.4	1534437	1539366.2	1539366		306887	0.168
7	Discount rate	4%			3		11486.3	1931526	1943012.1	1943012		386305	0.193
8	Efficiency parameter	0.6			4		20068.5	1147347	1167416.0	1167416		229469	0.506
9	Carbon tax	545	5%	increase/year	5		27623.9	1336131	1363755.1	1363755		267226	0.614
10	Transport + base price	0.097			6		28514.9	1064738	1093253.4	1093253		212948	0.855
11	Maintnance & operation	1%			7		26466.7	1054838	1081304.7	1081305		210968	0.880
12	Price of liquid co2 (nok/kg)	1.64			8		20094.6	837675	857769.4	857769		167535	0.997
13	Transport:	0.025			9		13213.7	967546	980759.9	980760		193509	0.472
14	Basispris	0.072			10		6621.4	1262583	1269204.5	1269204		252517	0.367
15	Cost of land	10.438			11		2574.6	1538447	1541022.0	1541022		307689	0.210
16	Nat gas price index	1			12		1096.0	1665221	1666317.3	1666317		333044	0.180
17													
18													
19													
20	**Year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
21	Discount factor	1.00	1.04	1.08	1.12	1.17	1.22	1.27	1.32	1.37	1.42	1.48	1.54
22													
23	**SOLAR**												
24	Cost of solar capture tech	663131.4											
25	Operation & maintnance	6631.314	6376	6131	5895	5668	5450	5241	5039	4845	4659	4480	4308
26													
27	**SUM SOLAR COST:**	**773357.6314**											
28		0.300664945	LCOE										
29	**Natural gas**												
30	Natural gas costs	2234775	2245893	2257066	2268295	2279579	2290920	2311723	2327537	2338714	2345589	2348475	2348012
31	Per kwh fee + transport:	1619311	1580144	1542040	1504965	1468888	1433780	1399610	1366352	1333977	1302459	1271772	1241893
32													
33	Sum natural gas cost (kNOK)	89809025.24	89809025.24										
34		0.34436788	LCOE										
35	**Carbon emission costs**												
36													
37	Annual carbon emissions	3673	3673	3673	3673	3673	3673	3673	3673	3673	3673	3673	3673
38	Carbon tax	2001606	2020852	2040283	2059902	2079708	2099705	2119895	2140279	2160858	2181636	2202613	2223792
39													
40	**SUM CARBON TAX**	58805695.297	58805695.3										
41													
42	**Liquid carbon costs**												
43	Price of liquid carbon	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
44	Annual carbon purchase	547573	526513	506262	486791	468068	450065	432755	416111	400107	384718	369921	355693
45													
46	**SUM LIQUID CARBON**	9101808.845											
47													
48	TOTAL COSTS (kNOK)	158489.887											

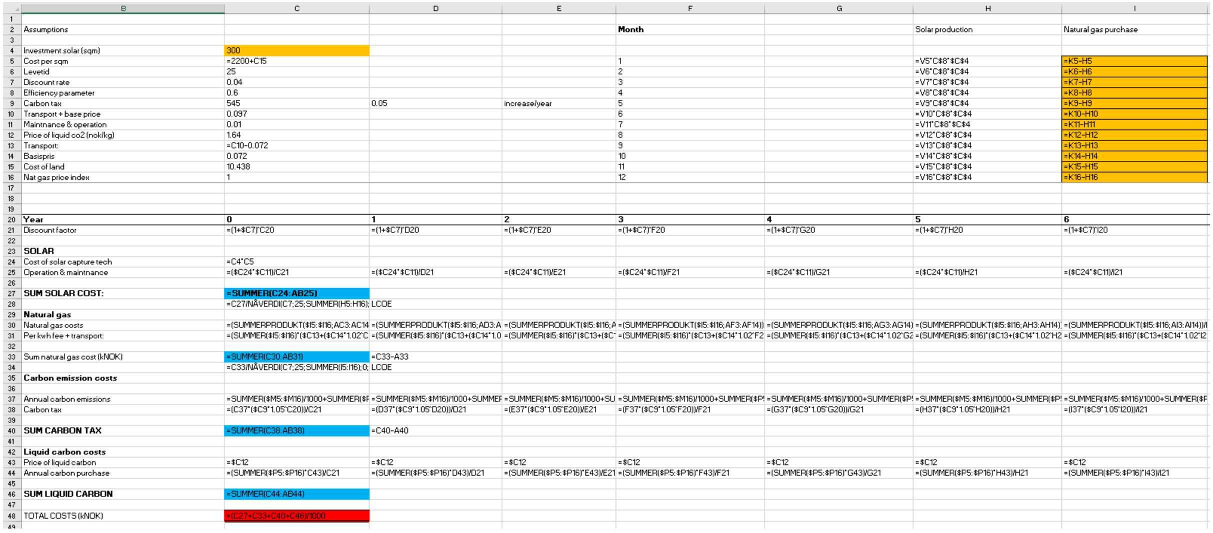


	O	P	Q	R	S	T	U	V	W	X	Y	Z	AA
1													
2	Carbon from nat gas inje	Liquid injects	Carbon injects	Carbon injects req (kg)				Solar irradiance					
3													
4													
5	20091	4278	24369	24369				10.88276					
6	51709	7367	59075	59075				27.38534					
7	74510	6291	80802	80802				63.81294					
8	116155	61654	177809	177809				111.49191					
9	164116	41453	205569	205569				153.46593					
10	181980	32753	214733	214733				158.41624					
11	185654	73672	259325	259325				147.03707					
12	167111	67698	234809	234809				111.63665					
13	91351	20988	112339	112339				73.40952					
14	92606	11107	103713	103713				36.78545					
15	64734	1255	65989	65989				14.30338					
16	59978	5372	65350	65350				6.08869					
17													
18													
19													
20	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
21	1.60	1.67	1.73	1.80	1.87	1.95	2.03	2.11	2.19	2.28	2.37	2.46	2.56
22													
23													
24													
25	4142	3983	3829	3682	3541	3404	3273	3148	3026	2910	2798	2690	2587
26													
27													
28													
29													
30	2344110	2337035	2327036	2314350	2299197	2281786	2262313	2240963	2217908	2132604	2050581	1971712	1895877
31	1212797	1184461	1156863	1129981	1103794	1078282	1053426	1029206	1005604	982602	960184	938332	917031
32													
33													
34													
35													
36													
37	3673	3673	3673	3673	3673	3673	3673	3673	3673	3673	3673	3673	3673
38	2245174	2266763	2288559	2310564	2332781	2355211	2377858	2400722	2423806	2447111	2470641	2494397	2518382
39													
40													
41													
42													
43	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64	1.64
44	342013	328858	316210	304048	292354	281110	270298	259902	249905	240294	231052	222165	213620
45													
46													
47													
48													
49													
50													

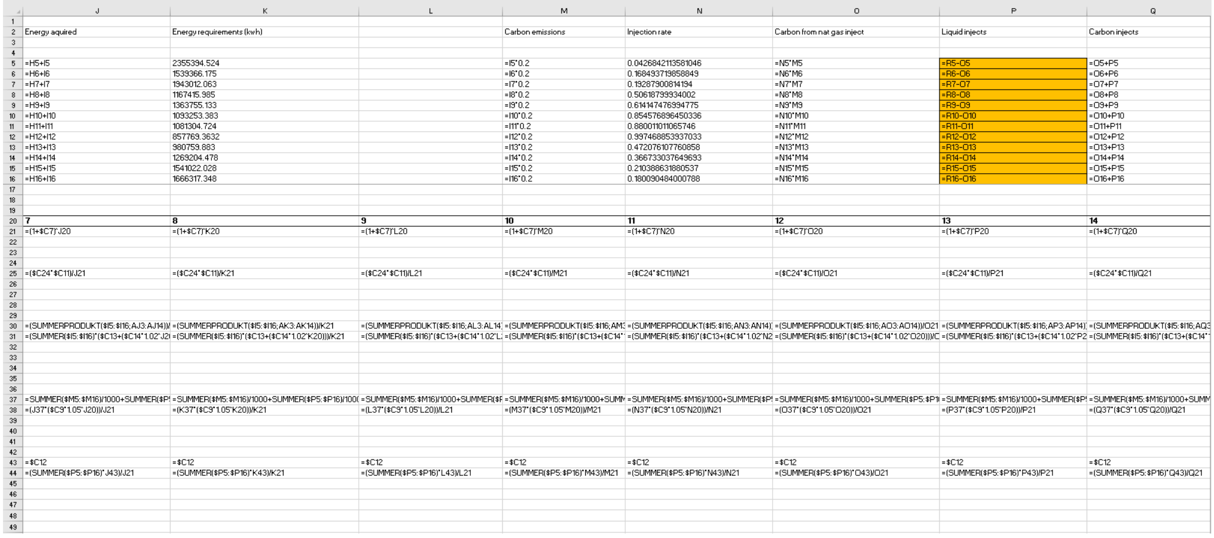


	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN	AO	AP	AQ	AR	AS	AT	AU	AV	AW	AX	AY	AZ	BA
1																										
2	**Month/year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
3	**January**	0.136321	0.142479	0.148916	0.155643	0.162674	0.170022	0.178429	0.186835	0.195242	0.203648	0.212055	0.220494	0.228932	0.237371	0.24581	0.254248	0.262687	0.271126	0.279564	0.288003	0.296442	0.296442	0.296442	0.296442	0.296442
4	**February**	0.136594	0.142765	0.149214	0.155954	0.163	0.170363	0.178786	0.18721	0.195633	0.204056	0.21248	0.220935	0.229391	0.237847	0.246302	0.254758	0.263213	0.271669	0.280125	0.28858	0.297036	0.297036	0.297036	0.297036	0.297036
5	**March**	0.132556	0.138544	0.144802	0.151344	0.15818	0.165326	0.1735	0.181675	0.189849	0.198023	0.206198	0.214403	0.222609	0.230814	0.23902	0.247226	0.255431	0.263637	0.271842	0.280048	0.288254	0.288254	0.288254	0.288254	0.288254
6	**April**	0.128779	0.134596	0.140676	0.147031	0.153673	0.160615	0.168557	0.176498	0.18444	0.192381	0.200322	0.208294	0.216266	0.224238	0.23221	0.240181	0.248153	0.256125	0.264097	0.272069	0.28004	0.28004	0.28004	0.28004	0.28004
7	**May**	0.129906	0.135774	0.141908	0.148318	0.155018	0.162021	0.170032	0.178043	0.186054	0.194065	0.202076	0.210117	0.218159	0.2262	0.234242	0.242284	0.250325	0.258367	0.266408	0.27445	0.282491	0.282491	0.282491	0.282491	0.282491
8	**June**	0.126885	0.132617	0.138607	0.144869	0.151413	0.158253	0.166078	0.173902	0.181727	0.189551	0.197376	0.205231	0.213085	0.22094	0.228794	0.236649	0.244503	0.252358	0.260212	0.268067	0.275922	0.275922	0.275922	0.275922	0.275922
9	**July**	0.126656	0.132378	0.138358	0.144608	0.151141	0.157968	0.165779	0.173589	0.1814	0.18921	0.197021	0.204861	0.212702	0.220542	0.228383	0.236223	0.244063	0.251904	0.259744	0.267585	0.275425	0.275425	0.275425	0.275425	0.275425
10	**August**	0.123548	0.129129	0.134962	0.141059	0.147431	0.154091	0.16171	0.169329	0.176947	0.184566	0.192185	0.199833	0.207481	0.215129	0.222777	0.230425	0.238073	0.245721	0.253369	0.261017	0.268665	0.268665	0.268665	0.268665	0.268665
11	**September**	0.131098	0.13702	0.14321	0.149679	0.156441	0.163508	0.171593	0.179677	0.187762	0.195846	0.20393	0.212046	0.220161	0.228277	0.236392	0.244507	0.252623	0.260738	0.268853	0.276969	0.285084	0.285084	0.285084	0.285084	0.285084
12	**October**	0.133918	0.139968	0.146291	0.152899	0.159806	0.167025	0.175284	0.183542	0.191801	0.200059	0.208317	0.216607	0.224897	0.233187	0.241477	0.249767	0.258057	0.266347	0.274637	0.282927	0.291217	0.291217	0.291217	0.291217	0.291217
13	**November**	0.144106	0.150616	0.157419	0.164531	0.171963	0.179731	0.188618	0.197505	0.206391	0.215278	0.224165	0.233085	0.242006	0.250926	0.259847	0.268767	0.277688	0.286609	0.295529	0.30445	0.31337	0.31337	0.31337	0.31337	0.31337
14	**December**	0.14243	0.148865	0.155589	0.162618	0.169964	0.177642	0.186425	0.195209	0.203992	0.212775	0.221558	0.230375	0.239192	0.248009	0.256826	0.265643	0.27446	0.283276	0.292093	0.30091	0.309727	0.309727	0.309727	0.309727	0.309727
15																										

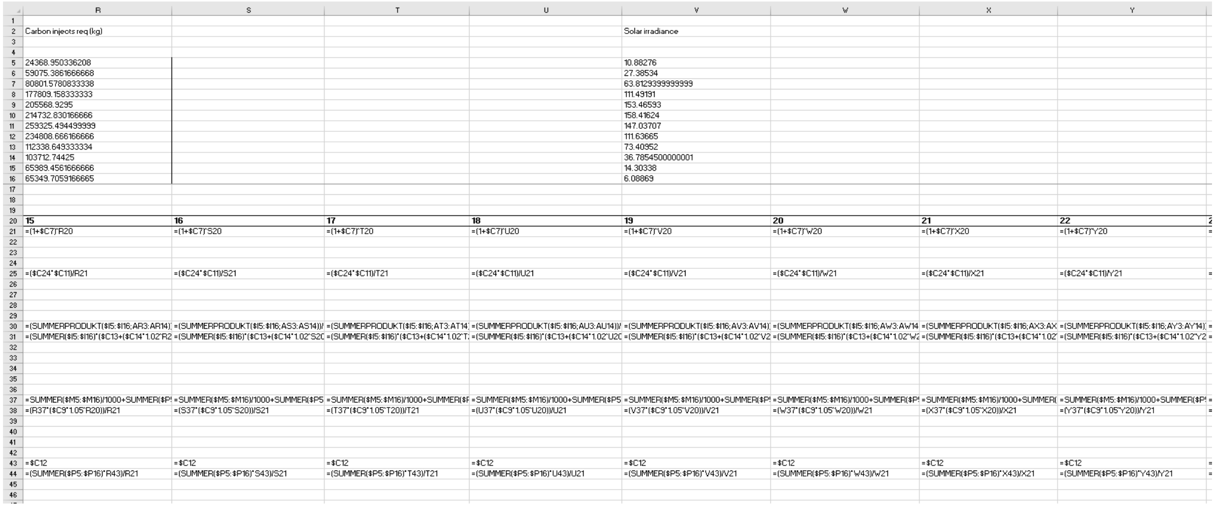
APPENDIX K: PROFITABILITY ANALYSIS SOLAR COLLECTORS (VALUES)



	B	C	D	E	F	G	H	I
1								
2	Assumptions				**Month**		Solar production	Natural gas purchase
3								
4	Investment solar (sqm)	300						
5	Cost per sqm	=2200+C15			1		=V5*C$8*$C$4	=K5-H5
6	Levetid	25			2		=V6*C$8*$C$4	=K6-H6
7	Discount rate	0.04			3		=V7*C$8*$C$4	=K7-H7
8	Efficiency parameter	0.6			4		=V8*C$8*$C$4	=K8-H8
9	Carbon tax	545	0.05	increase/year	5		=V9*C$8*$C$4	=K9-H9
10	Transport + base price	0.097			6		=V10*C$8*$C$4	=K10-H10
11	Maintnance & operation	0.01			7		=V11*C$8*$C$4	=K11-H11
12	Price of liquid co2 (nok/kg)	1.64			8		=V12*C$8*$C$4	=K12-H12
13	Transport:	=C10-0.072			9		=V13*C$8*$C$4	=K13-H13
14	Basispris	0.072			10		=V14*C$8*$C$4	=K14-H14
15	Cost of land	10.438			11		=V15*C$8*$C$4	=K15-H15
16	Nat gas price index	1			12		=V16*C$8*$C$4	=K16-H16
17								
18								
19								
20	**Year**	**0**	**1**	**2**	**3**	**4**	**5**	**6**
21	Discount factor	=(1+$C7)^C20	=(1+$C7)^D20	=(1+$C7)^E20	=(1+$C7)^F20	=(1+$C7)^G20	=(1+$C7)^H20	=(1+$C7)^I20
22								
23	**SOLAR**							
24	Cost of solar capture tech	=C4*C5						
25	Operation & maintnance	=($C24*$C11)/C21	=($C24*$C11)/D21	=($C24*$C11)/E21	=($C24*$C11)/F21	=($C24*$C11)/G21	=($C24*$C11)/H21	=($C24*$C11)/I21
26								
27	**SUM SOLAR COST:**	**=SUMMER(C24:AB25)**						
28		=C27/NÅVERDI(C7;25;SUMMER(H5:H16);	LCOE					
29	**Natural gas**							
30	Natural gas costs	=(SUMMERPRODUKT($I5:$I16;AC3:AC14	=(SUMMERPRODUKT($I5:$I16;AD3:A	=(SUMMERPRODUKT($I5:$I16;A	=(SUMMERPRODUKT($I5:$I16;AF3:AF14))	=(SUMMERPRODUKT($I5:$I16;AG3:AG14)	=(SUMMERPRODUKT($I5:$I16;AH3:AH14)	=(SUMMERPRODUKT($I5:$I16;AI3:AI14))/I
31	Per kwh fee + transport:	=(SUMMER($I5:$I16)*($C13+($C14*1.02^C	=(SUMMER($I5:$I16)*($C13+($C14*1.0	=(SUMMER($I5:$I16)*($C13+($C	=(SUMMER($I5:$I16)*($C13+($C14*1.02^F2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^G2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^H2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^I2
32								
33	Sum natural gas cost (kNOK)	=SUMMER(C30:AB31)	=C33-A33					
34		=C33/NÅVERDI(C7;25;SUMMER(I5:I16);0;	LCOE					
35	**Carbon emission costs**							
36								
37	Annual carbon emissions	=SUMMER($M5:$M16)/1000+SUMMER($F	=SUMMER($M5:$M16)/1000+SUMMEF	=SUMMER($M5:$M16)/1000+SU	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER($F
38	Carbon tax	=(C37*($C9*1.05^C20))/C21	=(D37*($C9*1.05^D20))/D21	=(E37*($C9*1.05^E20))/E21	=(F37*($C9*1.05^F20))/F21	=(G37*($C9*1.05^G20))/G21	=(H37*($C9*1.05^H20))/H21	=(I37*($C9*1.05^I20))/I21
39								
40	**SUM CARBON TAX**	=SUMMER(C38:AB38)	=C40-A40					
41								
42	**Liquid carbon costs**							
43	Price of liquid carbon	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12
44	Annual carbon purchase	=(SUMMER($P5:$P16)*C43)/C21	=(SUMMER($P5:$P16)*D43)/D21	=(SUMMER($P5:$P16)*E43)/E21	=(SUMMER($P5:$P16)*F43)/F21	=(SUMMER($P5:$P16)*G43)/G21	=(SUMMER($P5:$P16)*H43)/H21	=(SUMMER($P5:$P16)*I43)/I21
45								
46	**SUM LIQUID CARBON**	=SUMMER(C44:AB44)						
47								
48	TOTAL COSTS (kNOK)	=(C27+C33+C40+C46)/1000						



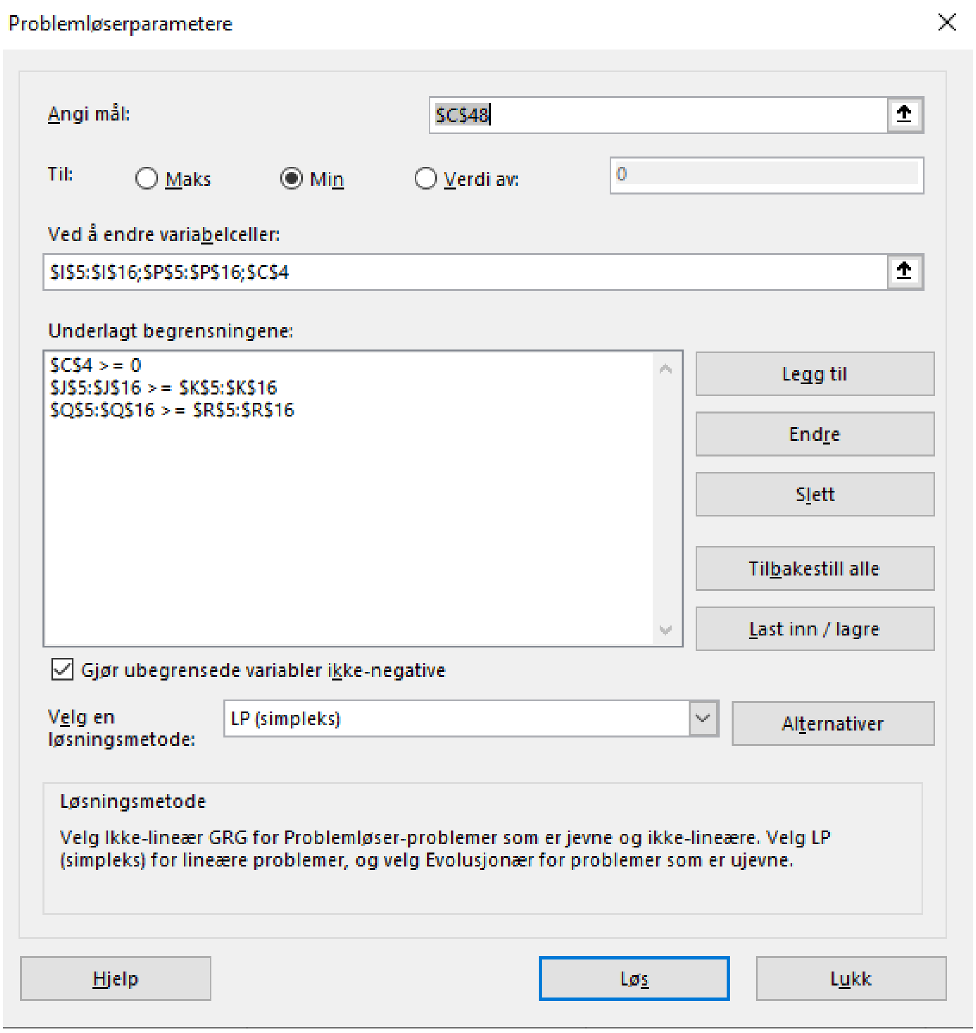
	J	K	L	M	N	O	P	Q
1								
2	Energy aquired	Energy requirements (kwh)		Carbon emissions	Injection rate	Carbon from nat gas inject	Liquid injects	Carbon injects
3								
4								
5	=H5+I5	2355394.524		=I5*0.2	0.0426842113581046	=N5*M5	=R5-O5	=O5+P5
6	=H6+I6	1539366.175		=I6*0.2	0.168493719858849	=N6*M6	=R6-O6	=O6+P6
7	=H7+I7	1943012.063		=I7*0.2	0.19287900814194	=N7*M7	=R7-O7	=O7+P7
8	=H8+I8	1167415.985		=I8*0.2	0.50618799934002	=N8*M8	=R8-O8	=O8+P8
9	=H9+I9	1363755.133		=I9*0.2	0.614147476994775	=N9*M9	=R9-O9	=O9+P9
10	=H10+I10	1093253.383		=I10*0.2	0.854576896450336	=N10*M10	=R10-O10	=O10+P10
11	=H11+I11	1081304.724		=I11*0.2	0.880011011065746	=N11*M11	=R11-O11	=O11+P11
12	=H12+I12	857769.3632		=I12*0.2	0.997468853937033	=N12*M12	=R12-O12	=O12+P12
13	=H13+I13	980759.883		=I13*0.2	0.472076107760858	=N13*M13	=R13-O13	=O13+P13
14	=H14+I14	1269204.478		=I14*0.2	0.366733037649693	=N14*M14	=R14-O14	=O14+P14
15	=H15+I15	1541022.028		=I15*0.2	0.210388631880537	=N15*M15	=R15-O15	=O15+P15
16	=H16+I16	1666317.348		=I16*0.2	0.180090484000788	=N16*M16	=R16-O16	=O16+P16
17								
18								
19								
20	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
21	=(1+$C7)^J20	=(1+$C7)^K20	=(1+$C7)^L20	=(1+$C7)^M20	=(1+$C7)^N20	=(1+$C7)^O20	=(1+$C7)^P20	=(1+$C7)^Q20
22								
23								
24								
25	=($C24*$C11)/J21	=($C24*$C11)/K21	=($C24*$C11)/L21	=($C24*$C11)/M21	=($C24*$C11)/N21	=($C24*$C11)/O21	=($C24*$C11)/P21	=($C24*$C11)/Q21
26								
27								
28								
29								
30	=(SUMMERPRODUKT($I5:$I16;AJ3:AJ14))/	=(SUMMERPRODUKT($I5:$I16;AK3:AK14))/K21	=(SUMMERPRODUKT($I5:$I16;AL3:AL14)	=(SUMMERPRODUKT($I5:$I16;AM	=(SUMMERPRODUKT($I5:$I16;AN3:AN14)	=(SUMMERPRODUKT($I5:$I16;AO3:AO14))/O21	=(SUMMERPRODUKT($I5:$I16;AP3:AP14)	=(SUMMERPRODUKT($I5:$I16;AQ
31	=(SUMMER($I5:$I16)*($C13+($C14*1.02^J2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^K20)))/K21	=(SUMMER($I5:$I16)*($C13+($C14*1.02^L	=(SUMMER($I5:$I16)*($C13+($C14*	=(SUMMER($I5:$I16)*($C13+($C14*1.02^N2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^O20)))/C	=(SUMMER($I5:$I16)*($C13+($C14*1.02^P2	=(SUMMER($I5:$I16)*($C13+($C14*
32								
33								
34								
35								
36								
37	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER($P5:$P16)/100	=SUMMER($M5:$M16)/1000+SUMMER($F	=SUMMER($M5:$M16)/1000+SUMM	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER($P5:$P1	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMM
38	=(J37*($C9*1.05^J20))/J21	=(K37*($C9*1.05^K20))/K21	=(L37*($C9*1.05^L20))/L21	=(M37*($C9*1.05^M20))/M21	=(N37*($C9*1.05^N20))/N21	=(O37*($C9*1.05^O20))/O21	=(P37*($C9*1.05^P20))/P21	=(Q37*($C9*1.05^Q20))/Q21
39								
40								
41								
42								
43	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12
44	=(SUMMER($P5:$P16)*J43)/J21	=(SUMMER($P5:$P16)*K43)/K21	=(SUMMER($P5:$P16)*L43)/L21	=(SUMMER($P5:$P16)*M43)/M21	=(SUMMER($P5:$P16)*N43)/N21	=(SUMMER($P5:$P16)*O43)/O21	=(SUMMER($P5:$P16)*P43)/P21	=(SUMMER($P5:$P16)*Q43)/Q21
45								
46								
47								
48								
49								



	R	S	T	U	V	W	X	Y	
1									
2	Carbon injects req (kg)				Solar irradiance				
3									
4									
5	24368.950336208				10.88276				
6	59075.3861666668				27.38534				
7	80801.5780833338				63.8129399999999				
8	177809.158333333				111.49191				
9	205568.9295				153.46593				
10	214732.830166666				158.41624				
11	259325.494499999				147.03707				
12	234808.666166666				111.63665				
13	112338.649333334				73.40952				
14	103712.74425				36.7854500000001				
15	65989.4561666666				14.30338				
16	65349.7059166665				6.08869				
17									
18									
19									
20	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**2**
21	=(1+$C7)^R20	=(1+$C7)^S20	=(1+$C7)^T20	=(1+$C7)^U20	=(1+$C7)^V20	=(1+$C7)^W20	=(1+$C7)^X20	=(1+$C7)^Y20	=
22									
23									
24									
25	=($C24*$C11)/R21	=($C24*$C11)/S21	=($C24*$C11)/T21	=($C24*$C11)/U21	=($C24*$C11)/V21	=($C24*$C11)/W21	=($C24*$C11)/X21	=($C24*$C11)/Y21	=
26									
27									
28									
29									
30	=(SUMMERPRODUKT($I5:$I16;AR3:AR14)	=(SUMMERPRODUKT($I5:$I16;AS3:AS14))/	=(SUMMERPRODUKT($I5:$I16;AT3:AT14)	=(SUMMERPRODUKT($I5:$I16;AU3:AU14))/	=(SUMMERPRODUKT($I5:$I16;AV3:AV14)	=(SUMMERPRODUKT($I5:$I16;AW3:AW14	=(SUMMERPRODUKT($I5:$I16;AX3:AX	=(SUMMERPRODUKT($I5:$I16;AY3:AY14)	=
31	=(SUMMER($I5:$I16)*($C13+($C14*1.02^R2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^S2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^T	=(SUMMER($I5:$I16)*($C13+($C14*1.02^U2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^V2	=(SUMMER($I5:$I16)*($C13+($C14*1.02^W2	=(SUMMER($I5:$I16)*($C13+($C14*1.02	=(SUMMER($I5:$I16)*($C13+($C14*1.02^Y2	=
32									
33									
34									
35									
36									
37	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER($P5	=SUMMER($M5:$M16)/1000+SUMMER($F	=SUMMER($M5:$M16)/1000+SUMMER($P5	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER($P	=SUMMER($M5:$M16)/1000+SUMMER(	=SUMMER($M5:$M16)/1000+SUMMER($P	=
38	=(R37*($C9*1.05^R20))/R21	=(S37*($C9*1.05^S20))/S21	=(T37*($C9*1.05^T20))/T21	=(U37*($C9*1.05^U20))/U21	=(V37*($C9*1.05^V20))/V21	=(W37*($C9*1.05^W20))/W21	=(X37*($C9*1.05^X20))/X21	=(Y37*($C9*1.05^Y20))/Y21	=
39									
40									
41									
42									
43	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=$C12	=
44	=(SUMMER($P5:$P16)*R43)/R21	=(SUMMER($P5:$P16)*S43)/S21	=(SUMMER($P5:$P16)*T43)/T21	=(SUMMER($P5:$P16)*U43)/U21	=(SUMMER($P5:$P16)*V43)/V21	=(SUMMER($P5:$P16)*W43)/W21	=(SUMMER($P5:$P16)*X43)/X21	=(SUMMER($P5:$P16)*Y43)/Y21	=
45									
46									

	Z	AA
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		
16		
17		
18		
19		
20	**23**	**24**
21	=(1+$C7)^Z20	=(1+$C7)^AA20
22		
23		
24		
25	=($C24*$C11)/Z21	=($C24*$C11)/AA21
26		
27		
28		
29		
30	=(SUMMERPRODUKT($I5:$I16;AZ3:AZ14))/	=(SUMMERPRODUKT($I5:$I16;BA3:BA14)
31	=(SUMMER($I5:$I16)*($C13+($C14*1.02^Z20	=(SUMMER($I5:$I16)*($C13+($C14*1.02^AA
32		
33		
34		
35		
36		
37	=SUMMER($M5:$M16)/1000+SUMMER($P5	=SUMMER($M5:$M16)/1000+SUMMER($P
38	=(Z37*($C9*1.05^Z20))/Z21	=(AA37*($C9*1.05^AA20))/AA21
39		
40		
41		
42		
43	=$C12	=$C12
44	=(SUMMER($P5:$P16)*Z43)/Z21	=(SUMMER($P5:$P16)*AA43)/AA21
45		
46		

APPENDIX L: PROFITABILITY ANALYSIS SOLAR COLLECTORS(FORMULAS)



Problemløserparametere

Angi mål: $C$48

Til: ○ Maks ● Min ○ Verdi av: 0

Ved å endre variabelceller:
$I$5:$I$16;$P$5:$P$16;$C$4

Underlagt begrensningene:
$C$4 > = 0
$J$5:$J$16 > = $K$5:$K$16
$Q$5:$Q$16 > = $R$5:$R$16

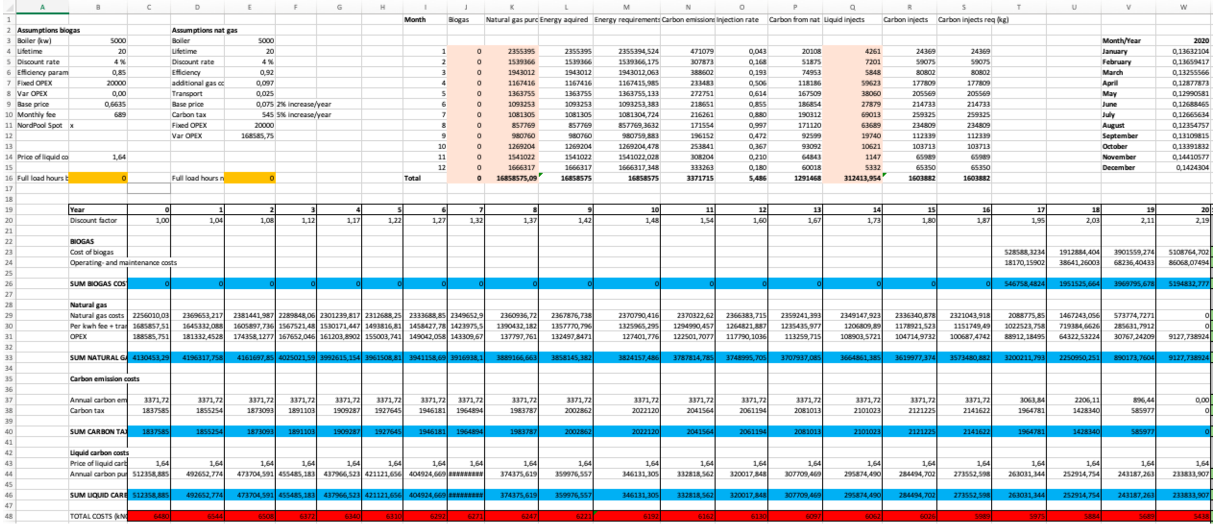
☑ Gjør ubegrensede variabler ikke-negative

Velg en løsningsmetode: LP (simpleks)

Løsningsmetode

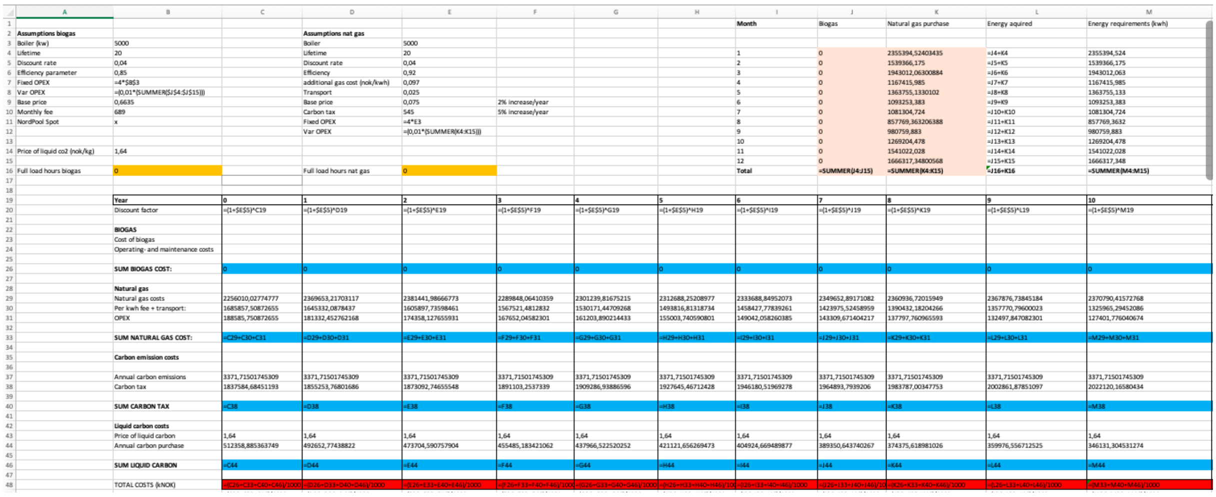
Velg Ikke-lineær GRG for Problemløser-problemer som er jevne og ikke-lineære. Velg LP (simpleks) for lineære problemer, og velg Evolusjonær for problemer som er ujevne.

APPENDIX M: PROFITABILITY ANALYSIS SOLAR COLLECTORS (SOLVER)

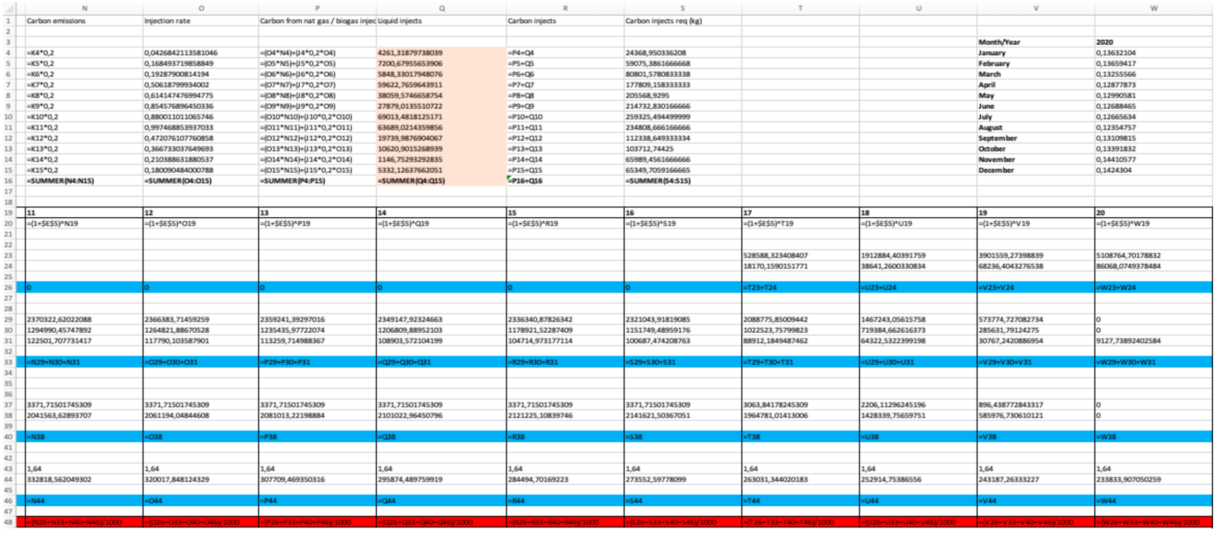


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
1									Month	Biogas	Natural gas purc	Energy aquired	Energy requirements	Carbon emissions	Injection rate	Carbon from nat	Liquid injects	Carbon injects	Carbon injects req (kg)				
2	Assumptions biogas			Assumptions nat gas																			
3	Boiler (kw)	5000		Boiler	5000																	Month/Year	2020
4	Lifetime	20		Lifetime	20				1	0	2355395	2355395	2355394,524	471079	0,043	20108	4261	24369	24369			January	0,13632104
5	Discount rate	4 %		Discount rate	4 %				2	0	1539366	1539366	1539366,175	307873	0,168	51875	7201	59075	59075			February	0,13659417
6	Efficiency param	0,85		Efficiency	0,92				3	0	1943012	1943012	1943012,063	388602	0,193	74953	5848	80802	80802			March	0,13255566
7	Fixed OPEX	20000		additional gas cc	0,097				4	0	1167416	1167416	1167415,985	233483	0,506	118186	59623	177809	177809			April	0,12877873
8	Var OPEX	0,00		Transport	0,025				5	0	1363755	1363755	1363755,133	272751	0,614	167509	38060	205569	205569			May	0,12990581
9	Base price	0,6635		Base price	0,075	2% increase/year			6	0	1093253	1093253	1093253,383	218651	0,855	186854	27879	214733	214733			June	0,12688465
10	Monthly fee	689		Carbon tax	545	5% increase/year			7	0	1081305	1081305	1081304,724	216261	0,880	190312	69013	259325	259325			July	0,12665634
11	NordPool Spot	x		Fixed OPEX	20000				8	0	857769	857769	857769,3632	171554	0,997	171120	63689	234809	234809			August	0,12354757
12				Var OPEX	168585,75				9	0	980760	980760	980759,883	196152	0,472	92599	19740	112339	112339			September	0,13109815
13									10	0	1269204	1269204	1269204,478	253841	0,367	93092	10621	103713	103713			October	0,13391832
14	Price of liquid co	1,64							11	0	1541022	1541022	1541022,028	308204	0,210	64843	1147	65989	65989			November	0,14410577
15									12	0	1666317	1666317	1666317,348	333263	0,180	60018	5332	65350	65350			December	0,1424304
16	Full load hours b	0		Full load hours n	0				Total	0	16858575,09	16858575	16858575	3371715	5,486	1291468	312413,954	1603882	1603882				
17																							
18																							
19		Year	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
20		Discount factor	1,00	1,04	1,08	1,12	1,17	1,22	1,27	1,32	1,37	1,42	1,48	1,54	1,60	1,67	1,73	1,80	1,87	1,95	2,03	2,11	2,19
21																							
22		BIOGAS																					
23		Cost of biogas																		528588,3234	1912884,404	3901559,274	5108764,702
24		Operating- and maintenance costs																		18170,15902	38641,26003	68236,40433	86068,07494
25																							
26		SUM BIOGAS COS	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	546758,4824	1951525,664	3969795,678	5194832,777
27																							
28		Natural gas																					
29		Natural gas costs	2256010,03	2369653,217	2381441,987	2289848,06	2301239,817	2312688,25	2333688,85	2349652,9	2360936,72	2367876,738	2370790,416	2370322,62	2366383,715	2359241,393	2349147,923	2336340,878	2321043,918	2088775,85	1467243,056	573774,7271	0
30		Per kwh fee + trai	1685857,51	1645332,088	1605897,736	1567521,48	1530171,447	1493816,81	1458427,78	1423975,5	1390432,182	1357770,796	1325965,295	1294990,457	1264821,887	1235435,977	1206809,89	1178921,523	1151749,49	1022523,758	719384,6626	285631,7912	0
31		OPEX	188585,751	181332,4528	174358,1277	167652,046	161203,8902	155003,741	149042,058	143309,67	137797,761	132497,8471	127401,776	122501,7077	117790,1036	113259,715	108903,5721	104714,9732	100687,4742	88912,18495	64322,53224	30767,24209	9127,738924
32																							
33		SUM NATURAL GA	4130453,29	4196317,758	4161697,85	4025021,59	3992615,154	3961508,81	3941158,69	3916938,1	3889166,663	3858145,382	3824157,486	3787814,785	3748995,705	3707937,085	3664861,385	3619977,374	3573480,882	3200211,793	2250950,251	890173,7604	9127,738924
34																							
35		Carbon emission costs																					
36																							
37		Annual carbon em	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3371,72	3063,84	2206,11	896,44	0,00
38		Carbon tax	1837585	1855254	1873093	1891103	1909287	1927645	1946181	1964894	1983787	2002862	2022120	2041564	2061194	2081013	2101023	2121225	2141622	1964781	1428340	585977	0
39																							
40		SUM CARBON TA	1837585	1855254	1873093	1891103	1909287	1927645	1946181	1964894	1983787	2002862	2022120	2041564	2061194	2081013	2101023	2121225	2141622	1964781	1428340	585977	0
41																							
42		Liquid carbon costs																					
43		Price of liquid carb	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
44		Annual carbon pur	512358,885	492652,774	473704,591	455485,183	437966,523	421121,656	404924,669	#########	374375,619	359976,557	346131,305	332818,562	320017,848	307709,469	295874,490	284494,702	273552,598	263031,344	252914,754	243187,263	233833,907
45																							
46		SUM LIQUID CARB	512358,885	492652,774	473704,591	455485,183	437966,523	421121,656	404924,669	#########	374375,619	359976,557	346131,305	332818,562	320017,848	307709,469	295874,490	284494,702	273552,598	263031,344	252914,754	243187,263	233833,907
47																							
48		TOTAL COSTS (kNO	6480	6544	6508	6372	6340	6310	6292	6271	6247	6221	6192	6162	6130	6097	6062	6026	5989	5975	5884	5689	5438

APPENDIX N: PROFITABILITY ANALYSIS BIOGAS (VALUES)

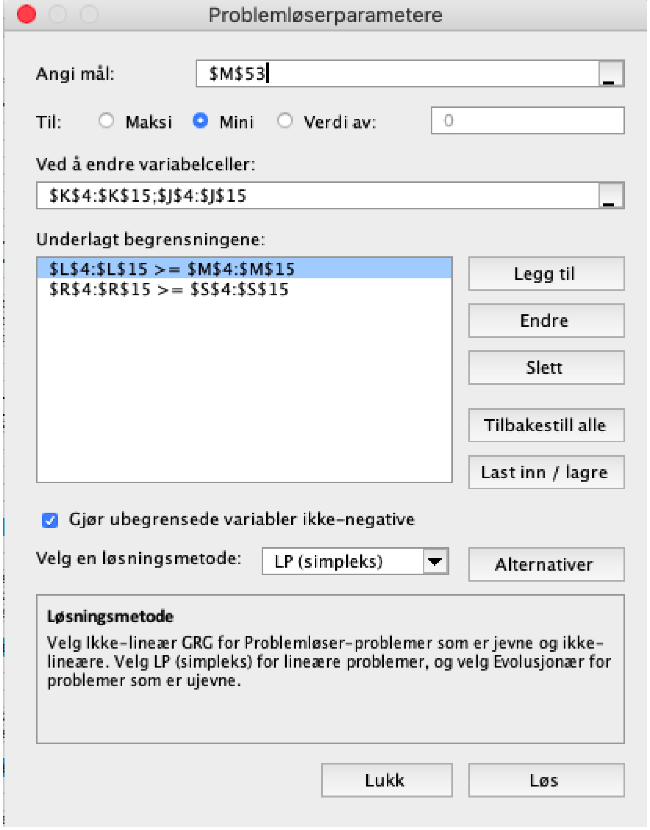


	A	B	C	D	E	F	G	H	I	J	K	L	M
1									Month	Biogas	Natural gas purchase	Energy aquired	Energy requirements (kwh)
2	Assumptions biogas			Assumptions nat gas									
3	Boiler (kw)	5000		Boiler	5000								
4	Lifetime	20		Lifetime	20				1	0	2355394,52403435	=J4+K4	2355394,524
5	Discount rate	0,04		Discount rate	0,04				2	0	1539366,175	=J5+K5	1539366,175
6	Efficiency parameter	0,85		Efficiency	0,92				3	0	1943012,06300884	=J6+K6	1943012,063
7	Fixed OPEX	=4*$B$3		additional gas cost (nok/kwh)	0,097				4	0	1167415,985	=J7+K7	1167415,985
8	Var OPEX	=(0,01*(SUMMER($J$4:$J$15)))		Transport	0,025				5	0	1363755,1330102	=J8+K8	1363755,133
9	Base price	0,6635		Base price	0,075	2% increase/year			6	0	1093253,383	=J9+K9	1093253,383
10	Monthly fee	689		Carbon tax	545	5% increase/year			7	0	1081304,724	=J10+K10	1081304,724
11	NordPool Spot	x		Fixed OPEX	=4*E3				8	0	857769,363206388	=J11+K11	857769,3632
12				Var OPEX	=(0,01*(SUMMER(K4:K15)))				9	0	980759,883	=J12+K12	980759,883
13									10	0	1269204,478	=J13+K13	1269204,478
14	Price of liquid co2 (nok/kg)	1,64							11	0	1541022,028	=J14+K14	1541022,028
15									12	0	1666317,34800568	=J15+K15	1666317,348
16	Full load hours biogas	0		Full load hours nat gas	0				Total	=SUMMER(J4:J15)	=SUMMER(K4:K15)	=J16+K16	=SUMMER(M4:M15)
17													
18													
19		Year	0	1	2	3	4	5	6	7	8	9	10
20		Discount factor	=(1+$E$5)^C19	=(1+$E$5)^D19	=(1+$E$5)^E19	=(1+$E$5)^F19	=(1+$E$5)^G19	=(1+$E$5)^H19	=(1+$E$5)^I19	=(1+$E$5)^J19	=(1+$E$5)^K19	=(1+$E$5)^L19	=(1+$E$5)^M19
21													
22		BIOGAS											
23		Cost of biogas											
24		Operating- and maintenance costs											
25													
26		SUM BIOGAS COST:	0	0	0	0	0	0	0	0	0	0	0
27													
28		Natural gas											
29		Natural gas costs	2256010,02774777	2369653,21703117	2381441,98666773	2289848,06410359	2301239,81675215	2312688,25208977	2333688,84952073	2349652,89171082	2360936,72015949	2367876,73845184	2370790,41572768
30		Per kwh fee + transport:	1685857,50872655	1645332,0878437	1605897,73598461	1567521,4812832	1530171,44709268	1493816,81318734	1458427,77839261	1423975,52458959	1390432,18204266	1357770,79600023	1325965,29452086
31		OPEX	188585,750872655	181332,452762168	174358,127655931	167652,04582301	161203,890214433	155003,740590801	149042,058260385	143309,671404217	137797,760965593	132497,847082301	127401,776040674
32													
33		SUM NATURAL GAS COST:	=C29+C30+C31	=D29+D30+D31	=E29+E30+E31	=F29+F30+F31	=G29+G30+G31	=H29+H30+H31	=I29+I30+I31	=J29+J30+J31	=K29+K30+K31	=L29+L30+L31	=M29+M30+M31
34													
35		Carbon emission costs											
36													
37		Annual carbon emissions	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309
38		Carbon tax	1837584,68451193	1855253,76801686	1873092,74655548	1891103,2537339	1909286,93886596	1927645,46712428	1946180,51969278	1964893,7939206	1983787,00347753	2002861,87851097	2022120,16580434
39													
40		SUM CARBON TAX	=C38	=D38	=E38	=F38	=G38	=H38	=I38	=J38	=K38	=L38	=M38
41													
42		Liquid carbon costs											
43		Price of liquid carbon	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
44		Annual carbon purchase	512358,885363749	492652,77438822	473704,590757904	455485,183421062	437966,522520252	421121,656269473	404924,669489877	389350,643740267	374375,618981026	359976,556712525	346131,304531274
45													
46		SUM LIQUID CARBON	=C44	=D44	=E44	=F44	=G44	=H44	=I44	=J44	=K44	=L44	=M44
47													
48		TOTAL COSTS (kNOK)	=(C26+C33+C40+C46)/1000	=(D26+D33+D40+D46)/1000	=(E26+E33+E40+E46)/1000	=(F26+F33+F40+F46)/1000	=(G26+G33+G40+G46)/1000	=(H26+H33+H40+H46)/10	=(I26+I33+I40+I46)/1000	=(J26+J33+J40+J46)/10	=(K26+K33+K40+K46)/1000	=(L26+L33+L40+L46)/1000	=(M33+M40+M46)/1000



	N	O	P	Q	R	S	T	U	V	W
1	Carbon emissions	Injection rate	Carbon from nat gas / biogas injec	Liquid injects	Carbon injects	Carbon injects req (kg)				
2										
3									Month/Year	2020
4	=K4*0,2	0,0426842113581046	=(O4*N4)+(J4*0,2*O4)	4261,31879738039	=P4+Q4	24368,950336208			January	0,13632104
5	=K5*0,2	0,168493719858849	=(O5*N5)+(J5*0,2*O5)	7200,67955653906	=P5+Q5	59075,3861666668			February	0,13659417
6	=K6*0,2	0,19287900814194	=(O6*N6)+(J6*0,2*O6)	5848,33017948076	=P6+Q6	80801,5780833338			March	0,13255566
7	=K7*0,2	0,50618799934002	=(O7*N7)+(J7*0,2*O7)	59622,7659643911	=P7+Q7	177809,158333333			April	0,12877873
8	=K8*0,2	0,614147476994775	=(O8*N8)+(J8*0,2*O8)	38059,5746658754	=P8+Q8	205568,9295			May	0,12990581
9	=K9*0,2	0,854576896450336	=(O9*N9)+(J9*0,2*O9)	27879,0135510722	=P9+Q9	214732,830166666			June	0,12688465
10	=K10*0,2	0,880011011065746	=(O10*N10)+(J10*0,2*O10)	69013,4818125171	=P10+Q10	259325,494499999			July	0,12665634
11	=K11*0,2	0,997468853937033	=(O11*N11)+(J11*0,2*O11)	63689,0214359856	=P11+Q11	234808,666166666			August	0,12354757
12	=K12*0,2	0,472076107760858	=(O12*N12)+(J12*0,2*O12)	19739,9876904067	=P12+Q12	112338,649333334			September	0,13109815
13	=K13*0,2	0,366733037649693	=(O13*N13)+(J13*0,2*O13)	10620,9015268939	=P13+Q13	103712,74425			October	0,13391832
14	=K14*0,2	0,210388631880537	=(O14*N14)+(J14*0,2*O14)	1146,75293292835	=P14+Q14	65989,4561666666			November	0,14410577
15	=K15*0,2	0,180090484000788	=(O15*N15)+(J15*0,2*O15)	5332,12637662051	=P15+Q15	65349,7059166665			December	0,1424304
16	=SUMMER(N4:N15)	=SUMMER(O4:O15)	=SUMMER(P4:P15)	=SUMMER(Q4:Q15)	=P16+Q16	=SUMMER(S4:S15)				
17										
18										
19	11	12	13	14	15	16	17	18	19	20
20	=(1+$E$5)^N19	=(1+$E$5)^O19	=(1+$E$5)^P19	=(1+$E$5)^Q19	=(1+$E$5)^R19	=(1+$E$5)^S19	=(1+$E$5)^T19	=(1+$E$5)^U19	=(1+$E$5)^V19	=(1+$E$5)^W19
21										
22										
23							528588,323408407	1912884,40391759	3901559,27398839	5108764,70178832
24							18170,1590151771	38641,2600330834	68236,4043276538	86068,0749378484
25										
26	0	0	0	0	0	0	=T23+T24	=U23+U24	=V23+V24	=W23+W24
27										
28										
29	2370322,62022088	2366383,71459259	2359241,39297016	2349147,92324663	2336340,87826342	2321043,91819085	2088775,85009442	1467243,05615758	573774,727082734	0
30	1294990,45747892	1264821,88670528	1235435,97722074	1206809,88952103	1178921,52287409	1151749,48959176	1022523,75799823	719384,662616373	285631,79124275	0
31	122501,707731417	117790,103587901	113259,714988367	108903,572104199	104714,973177114	100687,474208763	88912,1849487462	64322,5322399198	30767,2420886954	9127,73892402584
32										
33	=N29+N30+N31	=O29+O30+O31	=P29+P30+P31	=Q29+Q30+Q31	=R29+R30+R31	=S29+S30+S31	=T29+T30+T31	=U29+U30+U31	=V29+V30+V31	=W29+W30+W31
34										
35										
36										
37	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3371,71501745309	3063,84178245309	2206,11296245196	896,438772843317	0
38	2041563,62893707	2061194,04844608	2081013,22198884	2101022,96450796	2121225,10839746	2141621,50367051	1964781,01413006	1428339,75659751	585976,730610121	0
39										
40	=N38	=O38	=P38	=Q38	=R38	=S38	=T38	=U38	=V38	=W38
41										
42										
43	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64	1,64
44	332818,562049302	320017,848124329	307709,469350316	295874,489759919	284494,70169223	273552,59778099	263031,344020183	252914,75386556	243187,26333227	233833,907050259
45										
46	=N44	=O44	=P44	=Q44	=R44	=S44	=T44	=U44	=V44	=W44
47										
48	=(N26+N33+N40+N46)/1000	=(O26+O33+O40+O46)/1000	=(P26+P33+P40+P46)/1000	=(Q26+Q33+Q40+Q46)/1000	=(R26+R33+R40+R46)/1000	=(S26+S33+S40+S46)/1000	=(T26+T33+T40+T46)/1000	=(U26+U33+U40+U46)/1000	=(V26+V33+V40+V46)/1000	=(W26+W33+W40+W46)/1000

APPENDIX O: PROFITABILITY ANALYSIS BIOGAS (FORMULA)



Angi mål: $M$53

Til: ○ Maksi ● Mini ○ Verdi av: 0

Ved å endre variabelceller:
$K$4:$K$15;$J$4:$J$15

Underlagt begrensningene:
$L$4:$L$15 >= $M$4:$M$15
$R$4:$R$15 >= $S$4:$S$15

☑ Gjør ubegrensede variabler ikke-negative

Velg en løsningsmetode: LP (simpleks)

Løsningsmetode
Velg Ikke-lineær GRG for Problemløser-problemer som er jevne og ikke-lineære. Velg LP (simpleks) for lineære problemer, og velg Evolusjonær for problemer som er ujevne.

APPENDIX P: PROFITABILITY ANALYSIS BIOGAS (SOLVER)

Norges miljø- og biovitenskapelige universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway