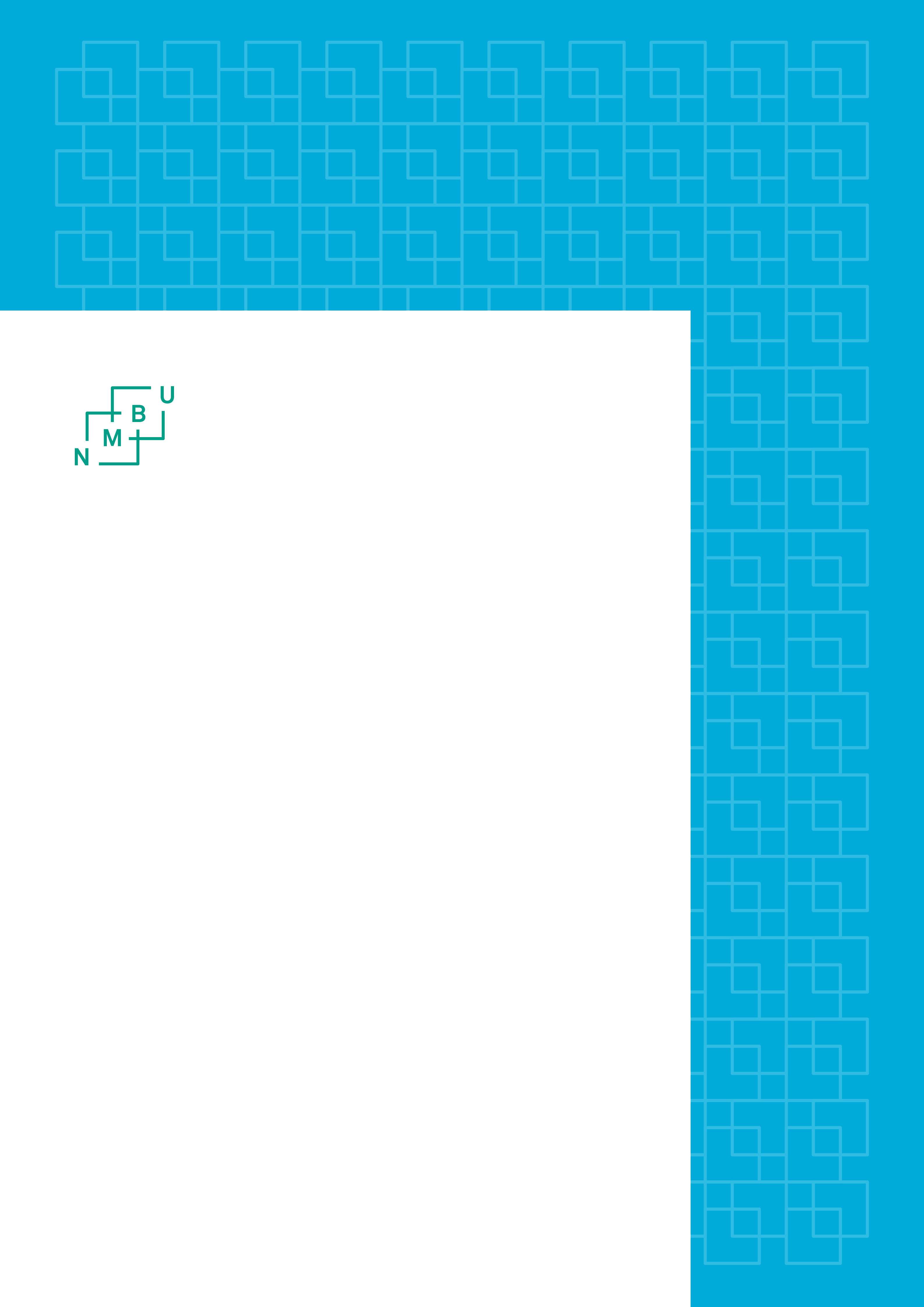
NMBU

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Finally, I would like to thank my family and friends who have supported me during my studies. I would especially like to thank my father for taking the time to read over my thesis, and my friends Martin Grimstad and Yun Walther-Zhang who have been my steadfast work and discussion partners for the past two years.

May 2014

Borge Håmsø

Abstract

In this thesis I evaluate how the Norwegian Agriculture Authority's (SLF) subsidy to forest wood chip production has affected district heating facilities' profitability, and how the facilities will be affected by its removal in 2014. I evaluate the SLF subsidy by employing a theoretical investment model of a small and large district heating facility and model the removal of the subsidy through various scenarios. The analysis works under the assumption that district heating companies interpreted the subsidy as permanent and evaluates a worst-case and a best-case scenario for the removal of the subsidy. The small facility was particularly affected by the removal of the SLF subsidy with both scenarios yielding a negative net present value (NPV) on investment. For the large facility, only the worst-case scenario yielded a negative NPV. The analysis chapter demonstrates that the end of the SLF subsidy may have large impacts on district heating companies, particularly since many of the firms are still in a early stage of development and have thus far experienced relatively weak and variable financial results.

The thesis also demonstrates that the SLF subsidy's narrow focus on a particular type of wood chip may have favored specific technologies; thus creating a recipe for suboptimal investments in the sector. This prompts a discussion of what constitutes prudent policy design for the bio-energy and district heating sectors. In this context I make some observations on the design of the SLF subsidy and how it measures up to relevant literature on policy design. My results indicate that it is likely the SLF subsidy was designed without the foresight and necessary caution needed to stimulate appropriate investment in both bio-energy production and district heating.

Sammendrag

I denne oppgaven analyserer jeg hvordan energiflistilskuddet til Statens Landbruksforvaltning har påvirket lønnsomheten i fjernvarmebransjen og hva effekten vil bli av støtteordningens avvikling i 2014. Jeg bruker teoretiske investeringsmodeller for både et lite og et stort fjernvarmeanlegg, og gjennomfører scenarioanalyser av lønnsomhetsforandringer tilknyttet brenselprisøkning ved fjerning av energiflistilskuddet. Modellene forutsetter at fjernvarmeselskapene har tolket støtteordningen som permanent, og danner et best og verst tenkelig scenario for fjerning av tilskuddet. Resultatene viser at det lille fjernvarmeanlegget er spesielt sårbart for fjerning av tilskuddet, og modellen kommer fram til en negativ nåverdi i begge scenarioene. Det store anlegget får også en negativ nåverdi, men dette er kun i det verste scenarioet. Studien påpeker at fjerning av tilskuddet muligens kan ha en stor effekt på lønnsomheten i fjernvarmebransjen, spesielt for virksomheter med mange små anlegg. Dette er et viktig funn ettersom fjernvarme er en relativ ung bransje som har opplevd noe svak og variabel avkasting de siste årene.

I tillegg til å vise lønnsomhetseffekter ved fjerning av energiflistilskuddet, påpeker modellene at støtteordningen, ved å gi tilskudd til en bestemt type flis, kan ha favorisert spesifikke teknologier. Dette kan igjen ha støttet opp under feilinvesteringer i bransjen, noe som fører til en diskusjon rundt hvordan virkemidler for bioenergi og fjernvarmesektoren bør utformes. I dette kapittelet evalueres energiflistilskuddet ut i fra hva økonomisk litteratur skriver om hensiktsmessig design av virkemidler. Til slutt konkluderer jeg med at energiflistilskuddet sannsynligvis ikke var designet med den forutsigbarheten som er nødvendig for gode investeringer i bioenergi- og fjernvarmebransjen.

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1 Introduction

1.1 Short Background

Norway is a country with vast bio-energy resources, but these resources have historically been underutilized due to the presence of cheap hydropower. Therefore, unlike its immediate neighbors Sweden and Finland, Norway has relied heavily on electricity for heating. However, this is in the process of changing. Rhetoric supporting the increased use of bio-energy was present in policy documents already in the 1990s (Christiansen 2002). Support for bio-energy began in 2001 with the establishment of Enova, a state-owned organization designed to drive forward the change to more environmentally friendly energy systems. Bio-energy goals were then formalized in 2008 when the Norwegian authorities specified an objective of doubling the use of bio-energy from 14 TWh to 28 TWh by 2020 (Bioenergi strategi 2008). This goal has triggered financial support for bio-energy from various organizations and sources, resulting in a sector that is reliant on a complex array of support mechanisms. In this thesis I will analyze one of these support schemes: The Norwegian Agriculture Authority's (SLF) wood chip subsidy.

The SLF wood chip subsidy was designed to: increase bio-energy use; promote job creation in the forest sector; and make it profitable to extract bio-energy resources that would otherwise not be utilized. It was instituted in 2009, partially in response to the 2008 financial crisis, and was framed as a temporary support mechanism. With the establishment of the new government the subsidy has now ended in 2014. The subsidy supported primarily the production of whole-tree wood chips (heltreflis) and chips from forest residues (grotflis) (Norwegian Agriculture Authority 2013).

When it was established, its proponents touted the subsidy as a method for establishing supply chains for utilizing forest resources such as forest residues and cleaning up the cultural landscape and roadways. Forest residues are a resource that have historically been considered waste at lumber sites and yield a lower quality wood chip with a relatively high moisture-content. Meanwhile, cleaning up the cultural landscape and roadways results in the chipping of entire trees, which yields wood chips that are of slightly higher quality. Information on types of wood chips and their relevant translations from Norwegian to English can be seen in appendix 2. With the recent establishment of the new government in the autumn of 2013, the SLF subsidy was removed with the justification that it created unfair competition with the use of sawdust (Prop. 1 S Tillegg 1 2013-2014).

The decision to remove the wood chip subsidy prompted an outcry from many actors in the bio-energy and district heating sectors. It resulted in newspaper articles with stirring headlines such as: “May have invested 175 million to no use” and “Could be the end of production of forest wood chips” (Fredriksen 2013; Müller 2013). These newspaper articles emphasize the importance of continued production of forest wood chips and stress that many businesses have relied on this support scheme. Meanwhile, various companies made statements stressing the significance of the subsidy, and Nobio, the Norwegian bio-energy association, organized a seminar about the policy’s removal (Nobio 2013). These company statements, the newspaper articles, and the seminar bring up several important issues: that sawdust does not directly compete with forest wood chips; that many companies are likely to stop producing whole-tree chips and forest residue chips after the subsidy has been removed; that many district heating facilities rely directly on SLF supported wood chips; and that the sector may be poorly understood due to complexity and lack of consolidated information.

1.2 Problem Statement

In this thesis I will evaluate how the Norwegian Agriculture Authority’s (SLF) subsidy has affected district heating facilities’ profitability and what effects its removal in 2014 may have on the sector. In addition to assessing how the SLF subsidy has affected a district heating facility’s financial results, I will also explore the above-mentioned issues raised by firms, newspaper articles, and Nobio.

1.3 Progression of the Thesis

I will consolidate information on bio-boiler technologies and wood chip prices and qualities to examine how whole-tree chips and chips from forest residues are used in district heating facilities. This data is then used in a theoretical financial model of a small and a large district heating facility to simulate the financial implications of the SLF subsidy's removal. Thereafter, I evaluate the SLF subsidy based on its design and how it may have been interpreted in the district-heating sector. It should be noted that my thesis does not include a discussion of what is the best use of forest resources or evaluate the societal value of cleaning up roadsides and harvesting forest residues. Nor does it discuss the value of creating supply chains for future development of bio-energy. The thesis focuses on evaluating how the SLF subsidy has affected district-heating companies.

2 Background

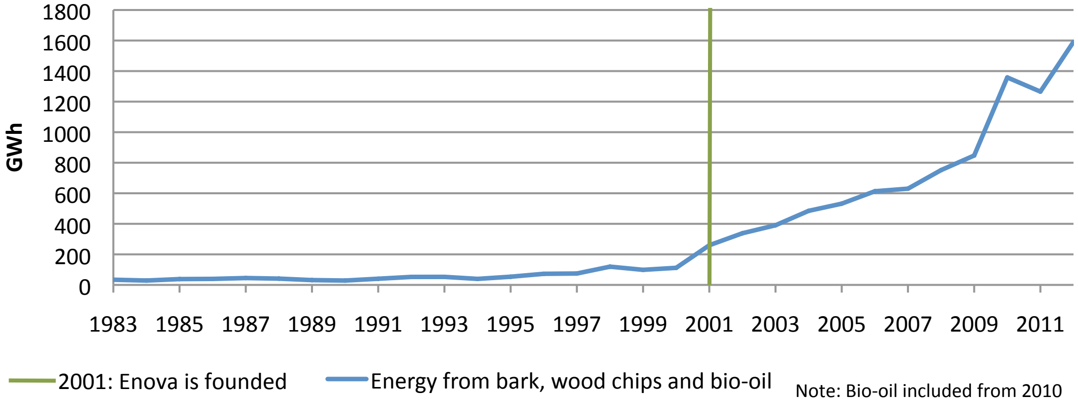
In Norway there exist several programs that directly support both the infrastructure and the use of bio-energy. Moreover, there exist many forms of indirect support via financial assistance to building of forest roads, regional development, etc. As mentioned in the introduction, my thesis focuses on the Norwegian Agriculture Authority's (SLF) wood chip subsidy. However, in order to understand the true effect of this policy, it is important to examine it within the proper setting. Norway has supported the development of bio-energy both on the demand side, via expansion of bio-based heating, and the supply side, via support of wood chip production. This background chapter will introduce relevant regulation of the district heating sector and provide an overview of subsidies to wood chip heating facilities and wood chip production by the three main actors: Enova, Innovation Norway, and SLF. It will then review some of the attributes of the wood chips supported by the SLF subsidy and go through relevant bio-boiler technology.

2.1 Current District Heating Regulations

Similar to electricity distribution companies, district heating companies are natural monopolies. Hence, there would not be economic rationale for more than one heating distribution system within an area. Theoretically, it would be possible to have companies compete in heat production; however, this is not currently practiced. District heating companies in Norway today sell a product that encompasses both production and distribution (Pöyri 2010). In addition, there is also often a mandate for new buildings to connect to a pre-existing district heating system. In order to combat excessive use of market power, Norway regulates district heating under section 5.5 of the energy law (Energiloven 1990). Section 5.5 states that the price of district heating should not exceed the cost of electric heating in the area. This regulation means that the only way for companies to increase profits and expand is to reduce costs. Therefore, investment support and fuel subsidies have been essential to ensure the profitability and expansion of the sector.

2.2 Financial Support to District Heating

Norway began providing incentives for the expansion of bio-based district heating in the early 2000s. Since then, investment in district heating and bio-energy production has increased dramatically. Figure 2.1 shows how energy delivered from bio-based district heating has evolved since the start of data collection in 1983.



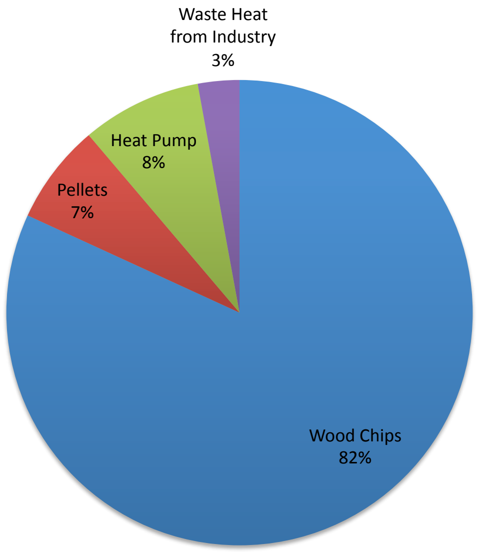
(Statistics Norway 2013)

Figure 2.1: Energy Delivered from Bio-based District Heating

2.2.1 Enova

Enova was established in 2001. It is an organization funded by the Norwegian Government to promote energy efficiency, sustainable energy production, and the development of climate-friendly technology (Enova). Enova provides investment support for renewable energy based heating facilities. Its specific program for district heating is divided into two parts: "infrastructure" and "new establishment". The infrastructure program encompasses expansion of heat distribution while the new-establishment program involves the construction of new district heating facilities. Support to the different types of bio-based heating, including all of Enova's programs, is summarized in Figure 2.3.

Figure 2.3 shows that the vast majority of Enova's support in the five years through 2012 has gone to *investment* in wood chip projects. Enova also supports some *production* of biofuels, but this has in the five-year period been almost entirely focused on biogas.



(Multiconsult 2014a)

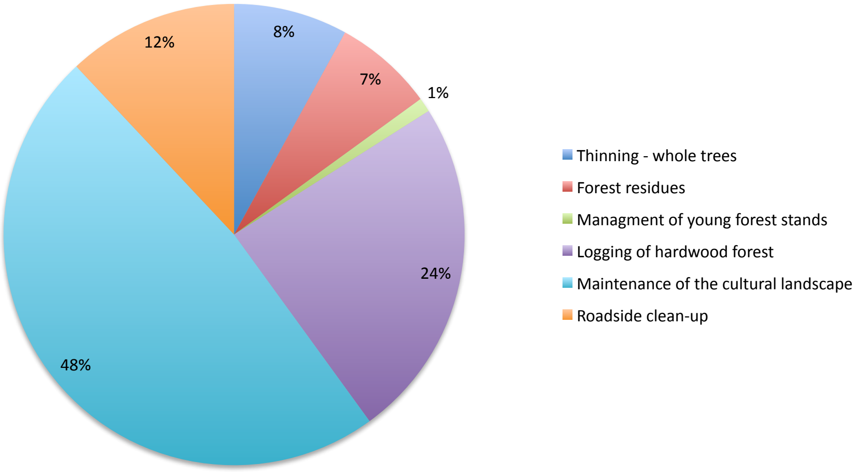
Figure 2.2: Enova Investment Support 2008-2012

2.2.2 Innovation Norway

Innovation Norway is the Norwegian Government's instrument to promote the development of Norwegian enterprise and industry. They help new companies with financing, consulting, and networking. Through their underlying goal of promoting Norwegian innovation, they also support a variety of bio-energy start-ups (Innovation Norway 2014b). Unlike Enova most of Innovation Norway's support goes to small entrepreneurs who are using bio-energy to heat small farms or small-scale industry. Additionally, they support the purchase of wood chipping machinery, which serves as an indirect subsidy to fuel supply (Innovation Norway 2014a). Their documentation of support for bio-based heat and fuel production is unfortunately not divided by fuel type. However, it is likely that a large portion of the support goes to small wood chip-based heating systems and various-sized wood chippers. Innovation Norway's bio-energy support is mainly focused on smaller heating facilities and wood chip producers, which is not the main focus of this thesis. This support will therefore be excluded from the analysis.

2.2.3 The Norwegian Agriculture Authority

For the five years 2009-2013, the Norwegian Agriculture Authority (SLF) provided around NOK 30 million annually to support the production of wood chips from a variety of different sources. The main sources for the produced wood chips are shown in Figure 2.3.



(Multiconsult 2014b)

Figure 2.3: SLF Wood Chip Subsidy: Financial Support 2009-2013

The SLF subsidy was aimed at landowners in possession of forests not producing a large enough fraction of quality timber for lumber or paper/pulp. The purpose of the subsidy, as described on SLF's web pages, was to aid in the goal of increasing bio-energy use by 14 TWh by 2020, promote job creation in the forest sector, and make it profitable to produce bio-based fuel that would otherwise not be utilized.

Table 2.1 shows the subsidy rates for the different types of wood chips for 2013, though it should be noted that these rates have been adjusted within the 2009-2013 subsidy period. As mentioned earlier, this study will focus primarily on whole-tree wood chips and chips from forest residues since they receive the highest subsidy per kWh and are expected to be the most affected by the removal of the support scheme.

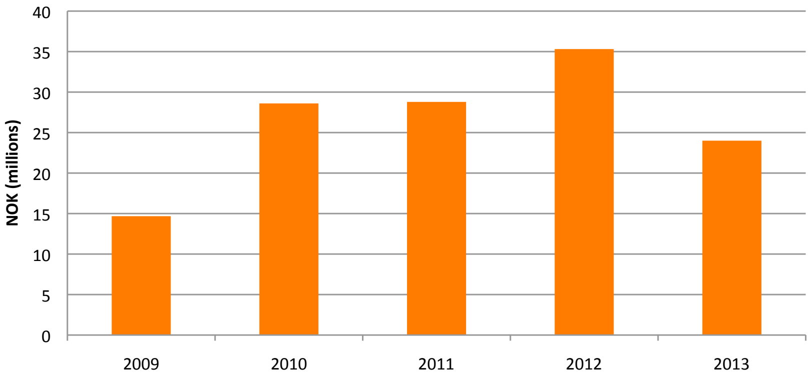
Table 2.1: Financial Support to Different Types of Wood Chips

Type of material	Activity	Financial Support
Round wood	First thinning	15 NOK/sm³ round wood ≈ 0.7 øre/kWh[1]
Whole trees	First thinning Management of young forest stands Logging of Hardwood forest Maintenance of the cultural landscape Roadside clean-up	43 NOK/ lm³ wood chips ≈ 5 øre/kWh
Forest residues	Removal after logging operations Clean-up after natural disasters and storms	27 NOK/ lm³ wood chips ≈ 3.2 øre/kWh

(Norwegian Agriculture Authority 2013)

(Multiconsult 2014b)

Figure 2.4 and 2.5 reveals NOK used per year and the GWh of contracted energy associated with the subsidy. It should be noted that calculating energy produced from volumes of wood chips involves many uncertainties, exacerbated by the wood chips' large variations in moisture content.



2009: Support began in july
2013: Includes support through 12.11.14

(Multiconsult 2014b)

Figure 2.4: SLF Support to Wood Chip Production (MNOK/yr)

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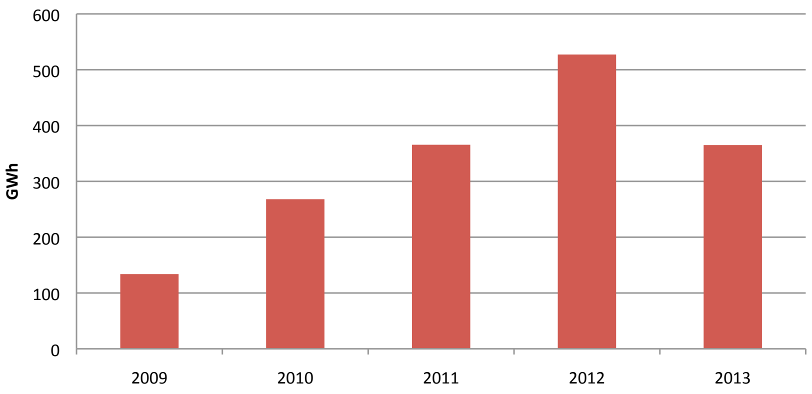
[1] lm³ = cubic meters loose chips, sm³ = cubic meters solid stems

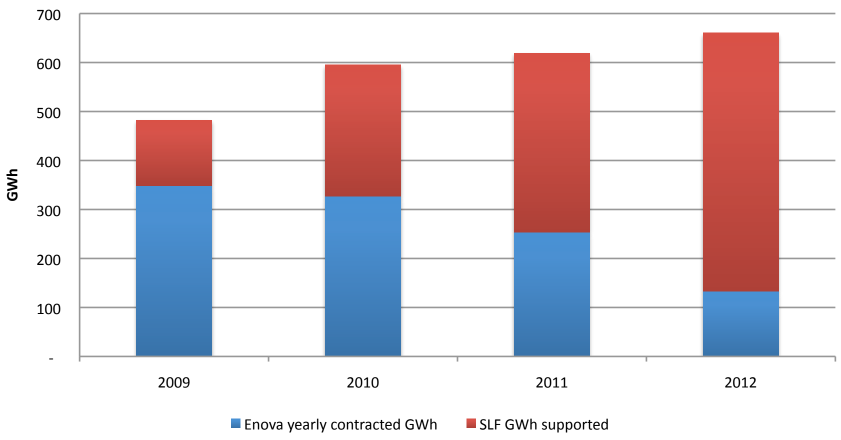


2009: Support began in july
2013: Includes support through 12.11.14

(Multiconsult 2014b)

Figure 2.5: SLF Contracted Wood Chip Production

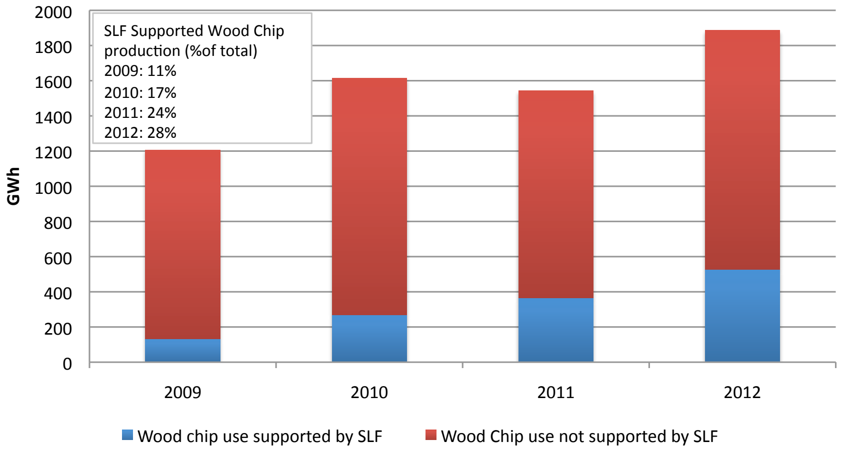
It is also useful to put the SLF subsidy in the proper perspective with support provided by the other organizations. Figure 2.6 compares Enova's yearly contracted GWh with GWh supported wood chips from the SLF subsidy and demonstrates that although SLF support has been short lived, it has represented a major source of financial support in the past five years. It should be noted that Figure 2.6 is somewhat misleading because these two support schemes cannot be directly compared. Enova supports investment in new district heating facilities or in many cases the installation of new bio-boilers. Through this investment support Enova and a district heating company contract a certain amount of renewable energy that will be delivered per year throughout the lifetime of the facility. Therefore, to get a true comparison of the two support schemes, the Enova result should technically be multiplied by twenty or twenty-five years depending on the projected lifespan of the facility. However, Figure 2.6 provides an appropriate backdrop for how important the wood chip subsidy has been in the past few years.



(Multiconsult 2014a)

Figure 2.6: Enova and SLF Contracted GWh

While the previous graph compares the SLF policy to Enova's investment support, it is also important to examine how large a proportion of wood chips used in the past 5 years have received financial support from SLF.



(Statistics Norway 2013)

Figure 2.7: Proportion of Total Norwegian Wood Chips Supported by SLF Subsidy

Figure 2.7 demonstrates both how use of wood chips has dramatically increased in the years 2009 to 2012 and that the SLF-supported wood chips have represented a significant and growing portion of this use. It should be noted that data for use of wood chips in Norway is limited and that the above chart represents an approximation based on aggregate numbers from Statistics Norway. [2]

2.3 Types of Wood Chips and Bio-Boiler Technology

To understand how district heating companies have responded to the SLF wood chip subsidy, it is imperative to examine both the type of wood chips produced by the SLF subsidy and how they are used by district heating companies. The SLF subsidy mainly supports the production of two types of wood chips: wood chips from forest residues and whole-tree wood chips. Forest residues are usually branches and tree crowns left at logging sites, and whole-tree chips are, as the name implies, chips created from entire trees. An overview of relevant types of wood chips that can be used in bio-boilers is provided in Appendix 2. Whole-tree chips and chips from forest residues generally have a higher moisture-content and may contain more impurities and fine particles than other higher-quality wood chips or more processed fuels. Consequently, utilizing these types of wood chips generally requires investment in more costly bio-boiler technology and wood chip feeding and mixing systems. Due to the larger initial investment cost, there is a facility size threshold for this type of investment to be financially viable. However, this threshold has been steadily decreasing (Multiconsult 2012).

This chapter has served to provide the appropriate context for examining the SLF wood chip subsidy. The past five years have seen a massive growth in bio-based district heating as a result of various policies. Untangling the specific effects of the wood chip subsidy involves comprehensive knowledge of relevant regulation and financial support in the sector. Understanding the regulated nature of the district heating sector, the size and scope of the subsidy, and attaining a basic

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[2] Total wood chip use = SSB aggregate wood chip, bark, and bio-oil use in district heating + SSB aggregate wood and waste use in the manufacturing sector (assumed 60% wood chips) – Hafslund use of bio-oil.

understanding of relevant fuel types and technologies is essential when evaluating how the SLF subsidy has affected district heating companies.

3 Methodology and Scope

Analyzing how the Norwegian Agriculture Authority's (SLF) subsidy has affected district-heating companies involves addressing several inherent difficulties. The challenges include: a lack of detailed statistics on bio-energy use in Norway; lack of sufficient data on firms' fuel mixes; an immature market for wood chips; and the relatively short time span since the end of the subsidy. Therefore, this analysis will use a combination of a theoretical model for investment in a wood chip-based district heating facility and various conversations and exchanges with experts in the sector as a basis for evaluation. These experts include employees in several district-heating companies; wood chip producers; representatives from nobio, the bio-energy association, and representatives from SLF and Enova. These conversations have been combined with an email survey of bio-based district heating firms in Norway. This email survey is available in Appendix 3, and provides insight into how many companies use whole-tree chips, their boiler size, and how they rank the possibility of switching to other types of chips. After evaluating the effect of the policy on district heating companies, the discussion will be expanded to the design of sensible bio-energy policy. This portion of the study will take the form of a literature review.

3.1 Scope

This thesis focuses on the design of the SLF subsidy and how it has affected district heating. It does not discuss the merits of different types of biofuels or the best way of utilizing Norway's large bio-energy resources. These topics are of course greatly related to the design of the policy, but the answer to these questions fall outside of the scope of the thesis.

3.2 Data and Model Challenges

Statistics on both bio-energy use and production in Norway are inadequate. Statistics Norway (SSB) only has limited aggregate statistics that describe the use of bio-energy both in industry and district heating. The SSB data neither adequately distinguishes between fuel types, nor are the time series particularly long. This lack of desired data is due to the fact that, unlike Sweden and Finland, Norway has an abundance of hydropower and has therefore only recently begun to take advantage of its bio-energy resources. Sweden and Finland have a longer history of bio-energy use. However, one cannot make direct comparisons with Norway because these countries have historically used district heating, and population densities are much greater than in Norway.

Another important issue is the complexity associated with bio-boiler technology and the wood chip market. Even if one only examines wood chip boilers, there exists a wide variety of bio-boiler and feeding mechanism solutions. District heating companies have access to a wide range of wood chip qualities, and companies have their own optimal mixes. Another issue is the fact that the wood chip market is relatively new and immature in Norway. Volumes of wood chips produced are relatively modest; availability of different types of wood chips can vary between regions; and the price is greatly affected by transport costs.

The survey I conducted was designed to be simple so as to achieve a high response rate (approximately 70 percent of companies responded), but this came at the expense of the quantity of data collected per respondent. Responses were generally of good quality, although in cases when elaborate but indirect answers were given, I needed to make some assumptions and interpretations to fill in responses in a prudent manner. Some responses I kept out of the numerical analysis when no reasonable conclusions could be drawn from them. Phone conversations and email exchanges with industry representatives were helpful to set the scene and bring perspective and insight into particular matters. It should be noted that there might be an incentive for companies to exaggerate their reliance on SLF-supported wood chips.

3.3 The Model

The lack of sufficient historical data meant that using econometric techniques to analyze the problem would not suffice. Therefore, rather than analyzing the wood chip and district-heating sector using statistical tools, I chose to create investment models for two theoretical district-heating facilities and run scenario analysis that under various assumptions will demonstrate a facility's sensitivity to the availability and price of wood chips.

4 Theory

Norway regulates district heating under energy law 5.5, which states that the price of district heating cannot exceed the cost of electric heating in a specific region (Energiloven 1990). This means that the only factor district-heating companies have control over is cost. Figure 4.1 demonstrates this visually. District heating companies would invest in those facilities that can supply heat at a price that is lower than the cost of electric heating i.e. the portion of the supply curve below the horizontal line. A subsidy such as Enova's support scheme or the SLF subsidy would shift the supply curve to the right from S_0 to S_1, thus making additional district-heating facilities financially attractive. It should be noted that electricity prices are highly variable, and the flat line in Figure 4.1 is merely a simplification to demonstrate the concept more clearly.

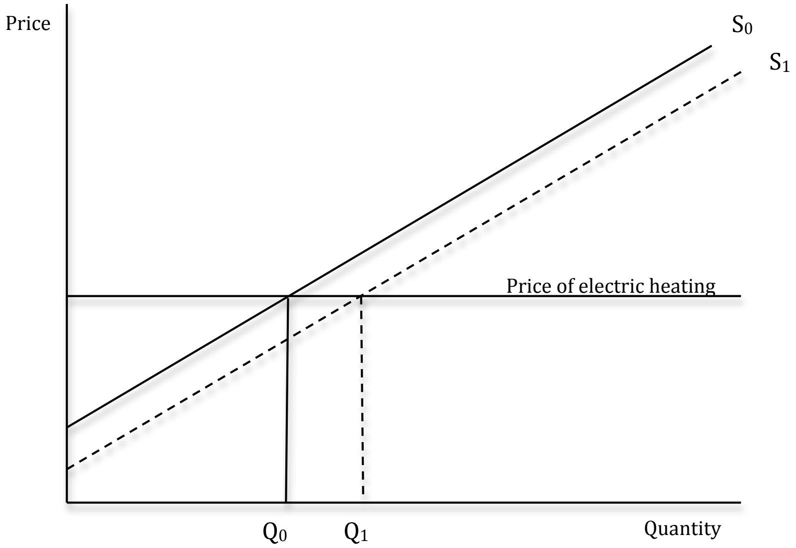


Figure 4.1: Supply of Heat via District Heating

The purpose of this study is to evaluate the importance of the SLF subsidy, one aspect of which is estimating how much financial support the subsidy provided. This can be visualized in Figure 4.1 by how far the subsidy would shift the supply curve to the right, or the distance between Q_0 and Q_1. The distance between Q_0 and Q_1 represents the additional facilities that would become financially attractive due to the subsidy.

In order to analyze the value of the SLF subsidy, this thesis will employ a financial investment model of a district-heating facility. Relevant investment costs, financial parameters, revenues, and fuel costs will be used to determine the Internal Rate of Return (IRR) and net present value (NPV) of a district heating facility dependent on various parameters and the SLF subsidy.

4.1 Equations

To determine IRR and NPV the model uses some relatively standard financial equations. For clarification, the formulas are briefly explained below. The assumptions and parameters for the specific equations can be seen in the analysis chapter.

A company's **operating profit (OP)** shows income in a particular year not including any financial costs or tax.

$$OP_t = revenue_t - operatingcost_t - fuelcost_t$$

4.1.1 Financial Costs

The **interest during construction** is calculated under the assumption that money is invested evenly throughout the construction period (Sweco AS *et al.* 2011).

$$\textit{Interest during Construction} = I\,\frac{(1+i)^t-1}{it}\left(1+\frac{i}{2}\right)-1$$

I = Initial Investment
t = Years of Construction
i = interest rate

$$\textit{Loan Installments per year} = \frac{\textit{Loan paid out}}{20\ \textit{years}}$$

Yearly **depreciation** is calculated using a simple straight-line method over twenty years. Depreciation is subtracted from the cumulative tax base, thus reducing the amount of taxes paid in a specific year.

$$Depreciation\ \ per\ year\ (dep)\ = \frac{I}{20\ years}$$

4.1.2 Tax

Yearly tax is calculated based on a specific years **cumulative tax base**. Tax base is calculated based on operating profit, loan interest, depreciation and the previous years **earnings before tax**.

$$Earnings\ before\ tax(EBT)_t = OP_t - Int_t - dep_t$$

$$Cumulative\ tax\ base(CTB)_t = if\ EBT < 0\ then\ EBT_{t-1} + EBT_t,\ Otherwise\ EBT_t$$

$$Yearly\ Tax(T)_t\ = CTB_t * CTR$$

CTR = Corporate Tax Rate

4.1.3 Investment Analysis

The **net cash flow** used in the model is for an income statement and is calculated based on operating profit, loan interest, and tax. This differs from a typical cash flow statement that shows a company's liquidity and therefore also includes loan installments.

$$Net\ Cash\ Flow_t = OP_t - I_t - Int_t - T_t$$

OP = operating profit
I = Investment
Int = Interest
T = Tax

The **weighted average cost of capital (r)** is a calculation of a firm's cost of capital based on the proportion of capital financed with equity and debt. The weighted average cost of capital represents the minimum internal rate of return an investor requires to decide to invest in a project.

$$r = \frac{E}{V}Re + \frac{D}{V}Rd$$

E = Market value of the firms equity
D = Market value of the firms debt

V = E+D
Re = Cost of equity
Rd = Cost of debt

The **internal rate of return (IRR)** can be thought of as the amount of growth a project will generate. It represents one method of ranking the financial attractiveness of different projects. The IRR is closely related to net present value (NPV) and represents the discount rate for which the NPV of a project is 0.

One determines the **net present value (NPV)** of a project by summing all the revenues and costs of a project over its lifetime and discounting the resulting values based on the year they occur and the weighted average cost of capital (r). Net present value is a method of valuing future cash flows. The cash flows are discounted based on the expected returns on other investment choices with similar risk.

$$NPV = \sum_{t-1}^{n} \frac{revenue - cost}{(1+r)^t}$$

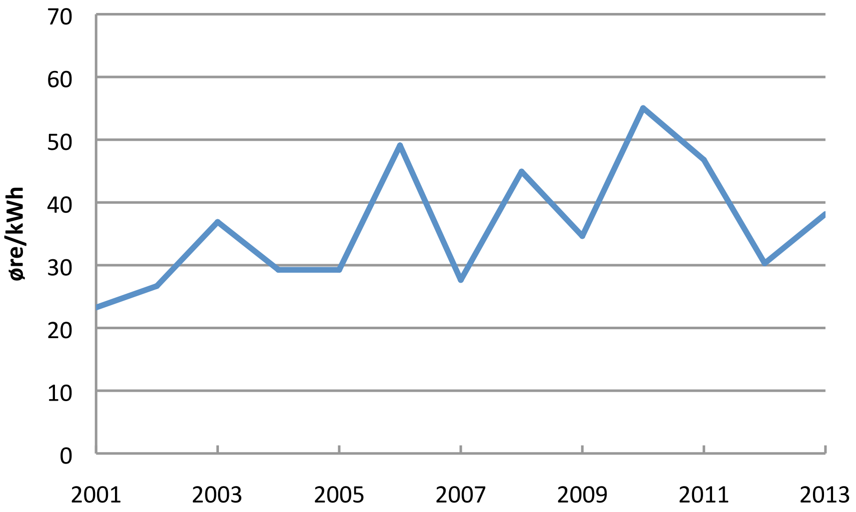
5 Analysis

This chapter will use both qualitative and quantitative data to analyze the effect of the Norwegian Agriculture Authority's (SLF) wood chip subsidy on district-heating companies. It begins by reviewing the financial health of the district-heating sector. Next it evaluates the current supply of whole-tree chips and wood chips from forest residues and attempt to determine the number of district heating facilities that use this type of wood chip. This will be followed by the more quantitative portion of the analysis, which will use a theoretical financial model of a heating facility to demonstrate the effects of the subsidy through various scenarios. Next it contains a brief sensitivity analysis of other relevant variables. After this evaluation of the profitability change associated with the removal of the SLF subsidy, the financial model will be expanded to examine how the SLF subsidy could interact with Enova investment support and also evaluate the potential for market distortions that may have yielded suboptimal investments in the sector.

5.1 Financial Health of the District Heating Sector

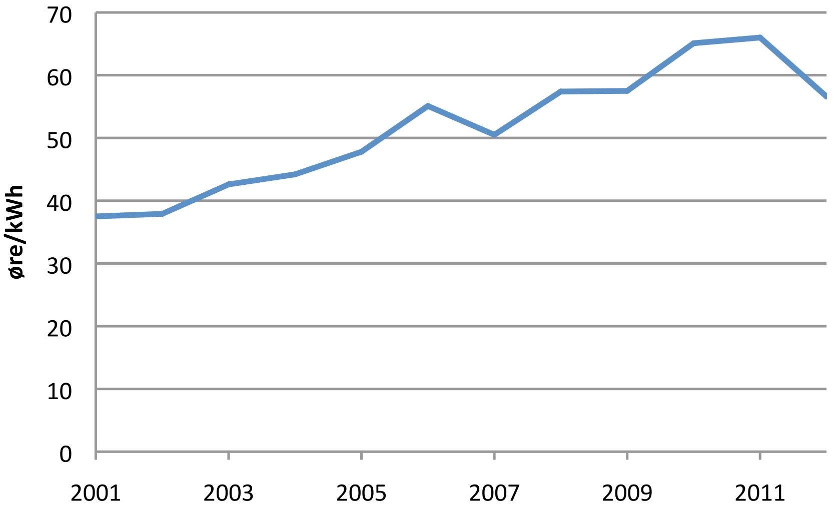
The district-heating sector in Norway has experienced a huge expansion in the past eight years primarily due to increasing prices for electricity and support from Enova (Statistics Norway 2013). Figure 5.1 and 5.2 show district-heating prices and Nordpool spot prices for electricity respectively. Both have experienced a gradual increase since the early 2000s, keeping in mind that district heating companies are regulated by the alternative cost of electric heating. Despite the increasing revenues associated with the increasing electricity price, a Pareto Securities report from 2010 shows that the sector is experiencing rather weak and variable financial results. It refers to an average of 5 percent rate of return on assets in 2010, and it reveals that there exists a large variation in profitability within the sector, with the larger actors generally doing much better than smaller companies (Securities *et al.* 2011). The

Pareto Securities report is now several years old; however, conversations with actors in the sector seemed to confirm that many companies are still struggling.



(Nordpoolspot 2014)

Figure 5.1: Nordpool average spot prices 2001-2013



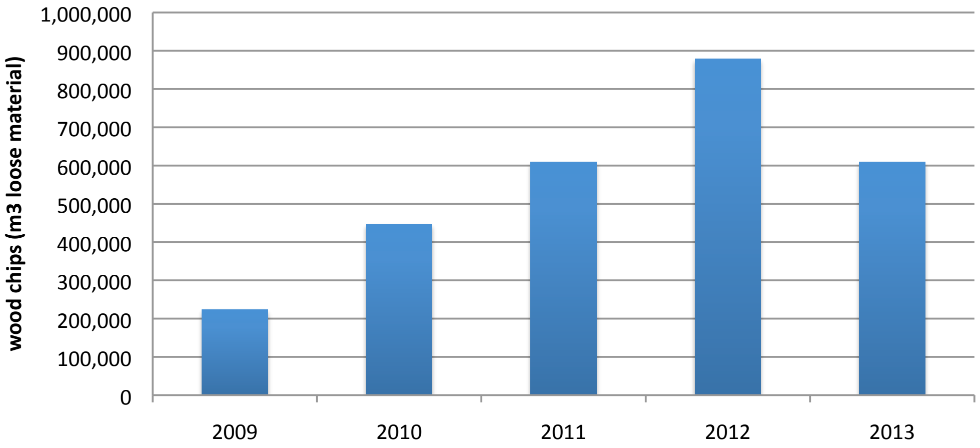
(Statistics Norway 2013)

Figure 5.2: Average District-Heating Price 2001-2012

5.2 Wood Chip Production

This brief overview of the wood chip market is included to provide insight as to what extent the SLF subsidy has served to stimulate wood chip production. I also, through some basic observations, discuss the potential price impacts of its removal.

The SLF subsidy resulted in a large expansion of wood chip production from the forest sector. As mentioned in the background chapter, the main types of wood chips produced through the subsidy were whole-tree chips and wood chips from forest residues. Before 2009 there was limited production of this type of wood chip (Bryhn 2014). Figure 5.3 shows that in the five-year period that the subsidy was in place it yielded a massive increase in production of forest wood chips, with a peak of approximately 879,000 lm^3 in 2012.



2009: Support began in july
2013: Includes support through 12.11.14

(Multiconsult 2014b)

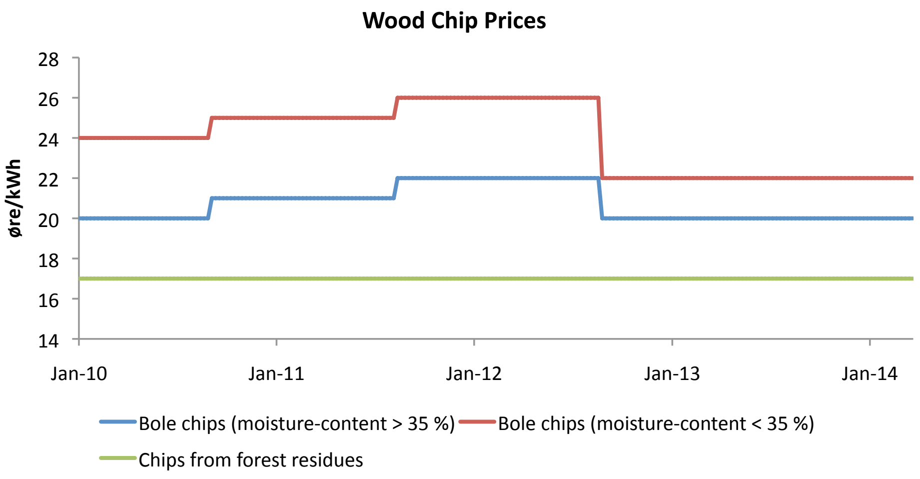
Figure 5.3: SLF Supported Wood Chip Production (Multiconsult 2014b)

These quantities represent a large percentage of total wood chip use in Norway, and one can stipulate that the subsidy has had a large effect on the availability of wood chips, particularly those of higher moisture content and lower quality.

Now that the SLF subsidy has ended in 2014, there will most likely be a decrease in the production of forest wood chips. Mjøsen Skog, one of the major wood chip producers in Norway, reported that due to the end of the subsidy they would probably discontinue their production of wood chips from forest residues, and their production of whole-tree chips could fall by 80 percent. Mjøsen explained that they do not believe there is sufficient demand for wood chips from forest residues in Norway in order to warrant their continued production. Moreover, the availability of raw materials to make whole-tree chips would be severely reduced with the removal of the subsidy (Bryhn 2014). Mjøsen Skog has been a large supplier of these types of wood chips. Comparing Mjøsen Skog's production with the total SLF-supported wood chips displayed in Figure 5.3, one is able to calculate that for the years 2010 through 2013 Mjøsen Skog's production represented between 15 percent and 20 percent of the total contracted wood chips from the SLF subsidy. Therefore, even if only Mjøsen follows through with their reductions, there will be a relatively large impact on wood chip supply. However, it seems likely that other companies would reduce their production on a similar scale.

5.3 Price Impacts of SLF subsidy

An interesting side note is that during much of the time that the SLF subsidy was in effect, the price of wood chips actually increased. Figure 5.4 contains data from Energirapporten and demonstrates that from 2009 to late 2012 prices for bole chips (stammevedflis) actually increased.



(Energirapporten 2009-2014)

Figure 5.4: Wood Chip Prices

Meanwhile, the price for wood chips from forest residues remained constant, which seems to coincide with Mjøsen Skog's observations that there does not exist many facilities that can use these types of chips. These prices do not include whole-tree chips, but considering the fact that bole chips (moisture-content >35%) have similar qualities to whole-tree chips, it seems likely that whole tree chips would follow the price trends seen in Figure 5.4. The increase in wood chip price seen during the subsidy period could be the result of many large wood chip facilities coming online during this time period resulting in a large increase in wood chip demand. However, it is difficult to predict what causes changes in the price of wood chips because the production of wood chips is so closely linked to other products of the forest industry. Moreover, the price of wood chips is greatly dependent on transport costs. For example, increasing the transport distance from 15km to 100km increases the price by around 3øre/kWh (Multiconsult 2012). Another interesting observation is that despite the removal of the subsidy, the first few reports from 2014 show the price of bole chips remaining low. This is puzzling, but may be caused by the fact that wood chip prices are greatly affected by the demand for other forest products, and some large producers of whole-tree chips, such as Mjøsen Skog, have approximately 2 years' supply of contracted raw materials that are ready to be chipped (Bryhn 2014).

5.3.1 Options for Alternative Wood Chips

Despite the fact that wood chip prices have remained low in the beginning of 2014, it is likely that with the removal of the SLF subsidy the supply of whole-tree chips will drop and prices will increase. If this happens, district-heating companies will attempt to substitute to less expensive types of wood chips. Facilities generally have their own optimal mix of wood chips that have the correct moisture-content, size, proportion of fine particles, and ash content that yields optimal operating conditions. Larger facilities generally have the technology to utilize wood chips of many different qualities and moisture contents, but run optimally on a fuel mix that has a moisture-content of approximately 50 percent. Some small facilities may have similar capabilities as the large facilities, but are more likely to use a technology that runs optimally on wood chips with 30-40 percent moisture content. Moreover, small facilities frequently do not have the same capabilities to mix fuels on-site as large facilities. Whole-tree chips function as a fuel to decrease the average moisture content for large facilities and as an optimal primary fuel for smaller facilities. It should be noted that the difficulties associated with finding an optimal fuel mix are more challenging in Norway than in countries such as Sweden that have a more developed bio-energy market. In Sweden, wood chip suppliers often pre-mix chips to the desired moisture-content and deliver an optimal fuel mix directly to a facility (Lönngren 2014).

Large Facilities: These have the option of switching to bole chips (moisture-content >35%), which have similar moisture-content as whole-tree chips, or they can mix a combination of dry chips, such as dry wood shavings or Bole chips (moisture-content < 35 %), with a high moisture fuel such as raw sawdust, bark or even chips from forest residues. However, chips from forest residues will likely become scarce with the removal of the subsidy as well. Table 5.1 contains a few of the author's own assumptions on current wood chip prices based on various phone interviews, wood chip prices from Energirapporten, and some calculations based on data from Skogdata, a firm that consolidates data on the forest sector in Norway (*Energirapporten* 2009-2014; Skogdata AS 2013).

Small Facilities: Most of these facilities must either continue using whole-tree chips or could potentially switch to bole chips (moisture-content >35%)

Table 5.1: Wood Chip Prices

Type of wood chip	Price øre/kWh
Bole chips <35% (stammevedflis)	22
Bole chips >35% (stammevedflis)	20
Whole-tree chips (heltreflis)	16-18
Chips from forest residues(grotflis)	15-17
Industry wood chips (industriflis)	18-20
Dry wood shavings (tørr avkapp)	18-20
Raw sawdust (rå sagflis)	13-15

Pulpwood (massevirke)

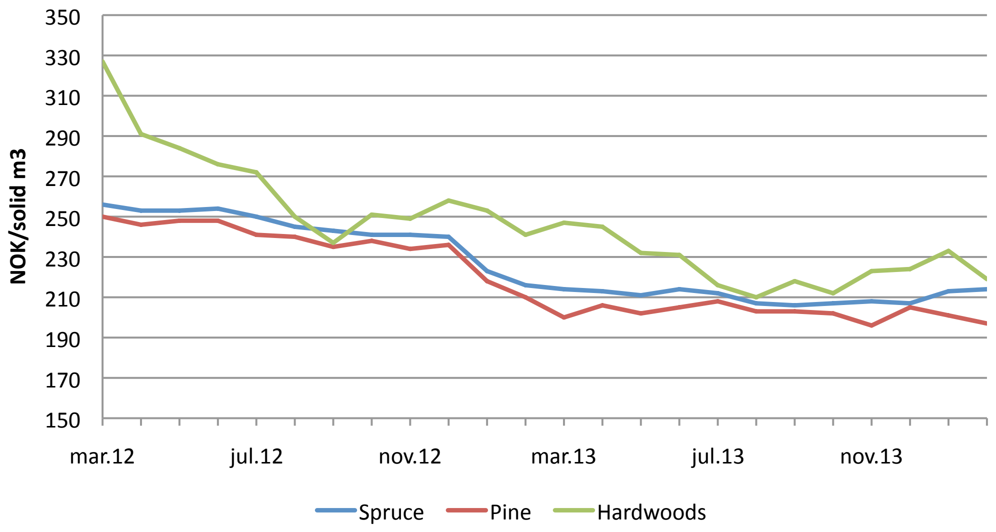
Several industry actors mentioned pulpwood as a viable source for wood chips should the pulpwood price remain low. In this thesis, pulpwood refers to trees or parts of stems of trees at logging sites that cannot be used at sawmills because they are too short, have too small diameter, or suffer from various other flaws. Historically, this type of raw material has been used in the paper industry or for the construction of wood composite boards and is therefore referred to here as pulpwood (Norwegian Agriculture Authority 2014a). If prices stay low, this material could be used to create wood chips to burn in district heating facilities. Prices for pulpwood have been falling in the past few years, and some simple calculations put wood chips from pulpwood in a competitive price range with whole-tree chips under the SLF subsidy. The cost assumptions for these calculations can be found in Table 5.2. It should be noted that this is a low-end cost estimate.

Table 5.2: Wood Chip from Pulpwood Calculations

Pulpwood	
Chipping	1.3 øre/kWh
Transport	2.5 øre/kWh
Administration	3.8 øre/kWh
Raw Material	10 øre/kWh
Total Price	17.6 øre/kWh

(Gjølsjø 2014; Nordhagen and Gjølsjø 2013; Skogdata AS 2013)

Figure 5.5 demonstrates how pulpwood has been falling in price the past few years. Currently, pulpwood is not commonly used in district-heating facilities and is therefore excluded from the analysis, but the price development of this resource should be watched closely.



(Norwegian Agriculture Authority 2014a)

Figure 5.5: Price Development of Pulpwood - Last Two Years

5.4 Utilization of Wood Chips in the District Heating Sector

After discussing how different sized wood chip facilities may adapt to a change in wood chips price, it is important to establish how many facilities use not only wood chips, but even more specifically whole-tree chips in their boilers. Only a select few facilities can utilize wood chips from forest residues in the their facilities. Therefore, whole-tree chips will be the primary focus of the analysis. Table 5.3 and 5.4 summarize some key data on actors in the district-heating sector in Norway and their use of wood chips. Table 5.3 is based on NVE's data on district heating companies, while Table 5.4 shows my survey results.

Table 5.3: District Heating: NVE Data

NVE Data		Notes
Number of District Heating Companies	101	Some companies such as Statkraft and Eidsiva have several facilities listed under various sub-firms or regional offices. This explains the large number of firms.
Companies that utilize bio-based fuels	48	

(Norwegian Water and Energy Directorate 2012)

Table 5.4: My Survey Results

Thesis Survey Results		**Notes**
Responses	33	Survey Includes 48 companies from NVE report that use wood chips + Ås facility
Companies that have utilized whole-tree chips in the past 5 years	23	
Number of wood chip boilers that have used whole-tree chips	32	This number refers to number of boilers and not facilities. There may be more than one wood chip boiler per facility.
% Whole-tree chips of total wood chips utilized	6-100%	
Size of wood chip boilers	0.75 –8MW	

The data in these tables gives some perspective on the prevalence of both wood chip use in the district-heating sector and size of bio-boilers. However, although my survey contains information on boiler size, it does not appropriately capture the number of facilities included per response. The fact that 48 percent of companies that use wood-based fuels have used whole-tree chips in the past five years is significant. Combined with the knowledge that some of these companies are relatively large actors in the industry, this lends credence to the notion that whole-tree chips are an important fuel for the sector. It should be noted that some whole-tree chips are undoubtedly produced without the SLF subsidy. The use of these chips cannot be separated from SLF-supported wood chips in the survey responses, which may result in some overestimation of the SLF subsidy's impact on the sector.

5.5 Financial Models

This section will present several variations of a financial Net Present Value model for a small and large heating facility. This will provide some insight into the profitability of the sector and determine the magnitude of support the wood chip subsidy constituted. The effect of the removal of the SLF subsidy will then be evaluated using a scenario-based approach to model an increase in whole-tree chip price. Thereafter the model will be used as context to discuss the interaction of Enova investment support and the SLF subsidy and to discuss the potential for suboptimal investments.

The analysis will include two models: a smaller facility with a maximum capacity of 4 MW and a larger facility with a maximum capacity of 16 MW. Although these models will most likely not mirror the investment decision of any one facility in Norway, they can provide important insight into the profitability of the sector. These sizes were chosen because they represent the size range revealed in my survey. The models in this study will work under the assumption that there already exists the appropriate district-heating infrastructure in a region and will therefore only include the costs of the actual facility. This simplifies the model and removes some of the regional differences and location-specific costs that could distort the overall picture.

5.5.1 Interaction between Enova and SLF Support Schemes

One of the main challenges of evaluating the effect of the disappearance of the SLF subsidy is to determine how it has worked in conjunction with Enova's support scheme. Enova provides support to district heating facilities through its program "district heating, new establishment" (Enova 2012). This support is provided on a case-by-case basis, and the level of support is determined by a company's internal rate of return requirement. In order to receive support, a company must fill out an application that includes a cash-flow analysis of the project and key financial indicators. Enova then evaluates the application, and support is given based on a reasonable, agreed upon IRR for the project with a maximum allowable IRR of 8 percent before taxes (Fallan 2014; PwC 2012). Applications are then ranked and given support based on a list of different criteria, see Table 5.5. As mentioned in the background chapter, Innovation Norway also supports various aspects of bio-energy production and utilization, and there is also some potential for interaction with their program as well. However, considering that most of the district-heating facilities are relatively large projects, Enova's investment support will generally be the most important factor.

Table 5.5: Enova District Heating Project Criteria

Ranking Criteria	• High renewable energy output relative to amount of financial support • High total energy output relative to support • High capacity relative to support • High growth potential in the delivery area • Low heating cost

The design of Enova's program complicates evaluating the SLF subsidy immediately after it has ended. If a district-heating facility was constructed before 2009, then clearly the lower wood chip price associated with the SLF subsidy would not be an issue. However, if a facility was constructed in the years 2010-2013 when the subsidy was in full effect, there is some a possibility that investment decisions were based on the low SLF supported wood chip prices. How much a district heating company will suffer from the increase in wood chip prices depends on whether the risk that the subsidy would end was accounted for in the financial analysis the company provided to Enova at the start of the application process. This makes it challenging to determine the effect of the SLF subsidy's removal. It would be desirable to somehow remove the interaction of the two support schemes from the analysis. However, this would give an unrealistic evaluation of the profitability of the sector. Instead, this analysis will assume the worst-case scenario, and work under the assumption that these facilities were built during the subsidy period and were based on wood chip prices lowered by the SLF subsidy. Reality would see something between the two, but in this situation it makes sense to display the worst-case scenario, realizing that reality will be somewhat milder. Both models will calculate Enova's investment support based on their highest allowable IRR, 8 percent before taxes. Taxes will then be added back to the model to determine a company's true IRR on the project.

5.6 Scenario Analysis

Table 5.7 reveals both the financial parameters of the model and the relevant technical specifications of the modeled heating facilities. Unless otherwise noted, these assumptions will be held constant in all the scenarios.

Table 5.7: Financial Parameters and Facility Specifications

Parameters	**Assumption**
Capital Expenditure (CAPEX)	Detailed in Appendix X
Enova Investment Support	Calculated based on **8%** IRR before taxes
Operational Expenditure (OPEX)	**4%** of construction cost
Construction time	Assumed **1 year** for simplicity
Loan Repayment	Loan will be repaid in **20 years** starting the first year of generation
Depreciation	**20 years** using straight line method
SLF subsidy	Included for the **lifetime** of the facility
Debt-to-equity ratio	**65:35 (Securities et al. 2011)**
Interest on loans	**4.5%**
Weighted Average Cost of Capital (WACC)	**5%**[3]
Prices	Prices are in **2011 NOK**

Parameters	**Small Facility**	**Large Facility**
Maximum load for facility	4MW	16MW
Capacity wood chip boiler	2MW	8MW
Capacity oil boiler backup 1	2MW	8MW
Capacity oil boiler backup 2	2MW	8MW
Efficiency	85%	85%
Total energy production per year	9200 MWh	36800 MWh
Energy production wood chip boiler per year	8000 MWh	32000 MWh
Energy Production oil boilers	1200 MWh	4800 MWh
Cost of oil /kWh (held constant)	77.1 øre/kWh	75 øre/kWh
Price received for heat (Avg. last 5 years. Held constant)	62.1 øre/kWh	62.1 øre/kWh
Variable cost for wood chip boiler/kWh (excluding wood chip price)	5 øre/kWh	4 øre/kWh
Fixed costs for wood chip boiler/kWh	12.8 øre/kWh	11 øre/kWh

(Bioen AS and Rosenberg 2010; Soma *et al.* 2001; Sweco AS et al. 2011)

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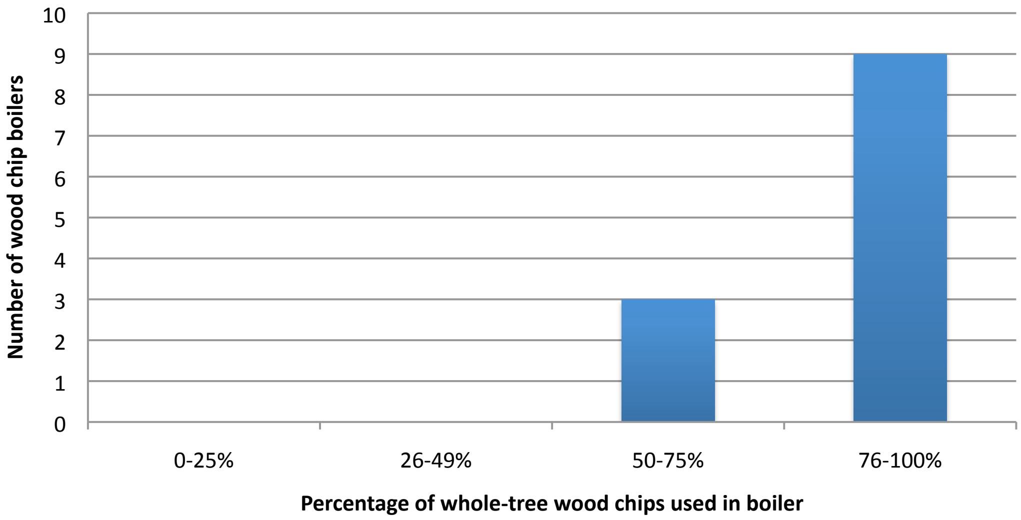
[3] WACC is based on a 6 percent return on equity.

5.6.1 Base-case Scenario

This scenario will estimate key financial indicators for both a large and a small heating facility under the assumption that the wood chip subsidy is active throughout the facility's entire lifespan. Table 5.8 displays the relevant fuel costs for the two differently sized facilities in the model. The small facility is assumed to have very little capability to mix different wood chips onsite and is therefore assumed to use only whole-tree chips. Based off several phone interviews with industry experts, larger facilities normally have access to some sort of lower-cost fuel from the sawmill industry, such as raw sawdust. My survey supported the aforementioned conclusions for the small facility. However, for the large facility, results were less conclusive most likely due to fewer survey responses in the large-plant category. The results are summarized in Figure 5.6 and 5.7.

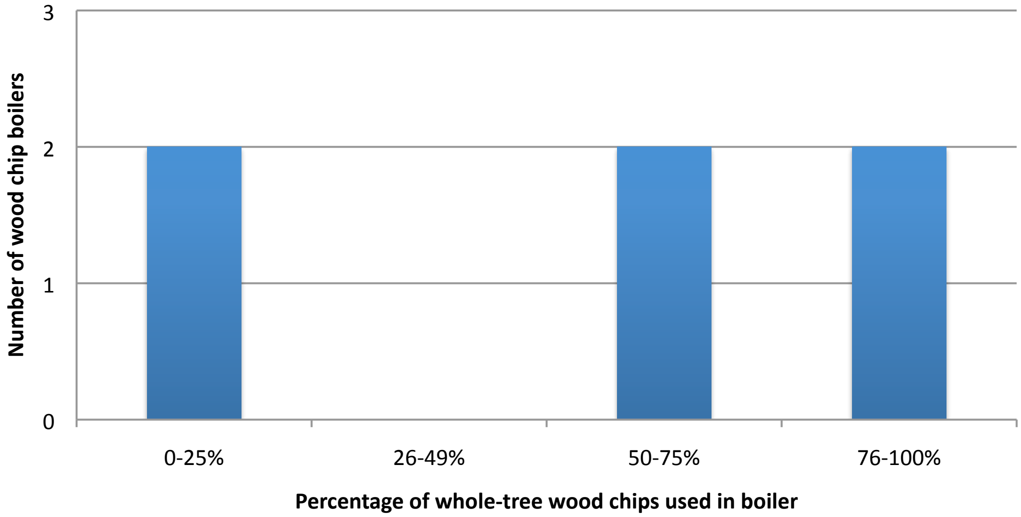
Table 5.8: Model Fuel Types and Prices

Parameters Base-case-scenario	**Small Facility**	**Large Facility**
Fuel makeup	100% Whole-tree chips	50/50 Whole-tree chips and sawdust
Price whole-tree chips	17 øre/kWh	17 øre/kWh
Price sawdust	N/A	14 øre/kWh
Average wood chip price	17 øre/kWh	15.5 øre/kWh
Enova support	4,890,019 NOK	15,037,163 NOK



(My survey results)

Figure 5.6: Percentage Whole-Tree Chips in Fuel Mix (1-2 MW Boiler)



(My survey results)

Figure 5.7: Percentage of Whole-Tree Chips in Fuel Mix (7-8 MW Boiler)

Important financial indicators for the base-case scenario are provided in cash-flow diagram Figure 5.9. Large upfront costs are combined with relatively modest profitability and little liquidity. In some cases for smaller firms, this lack of liquidity can make investing in upgrades or additional equipment challenging.

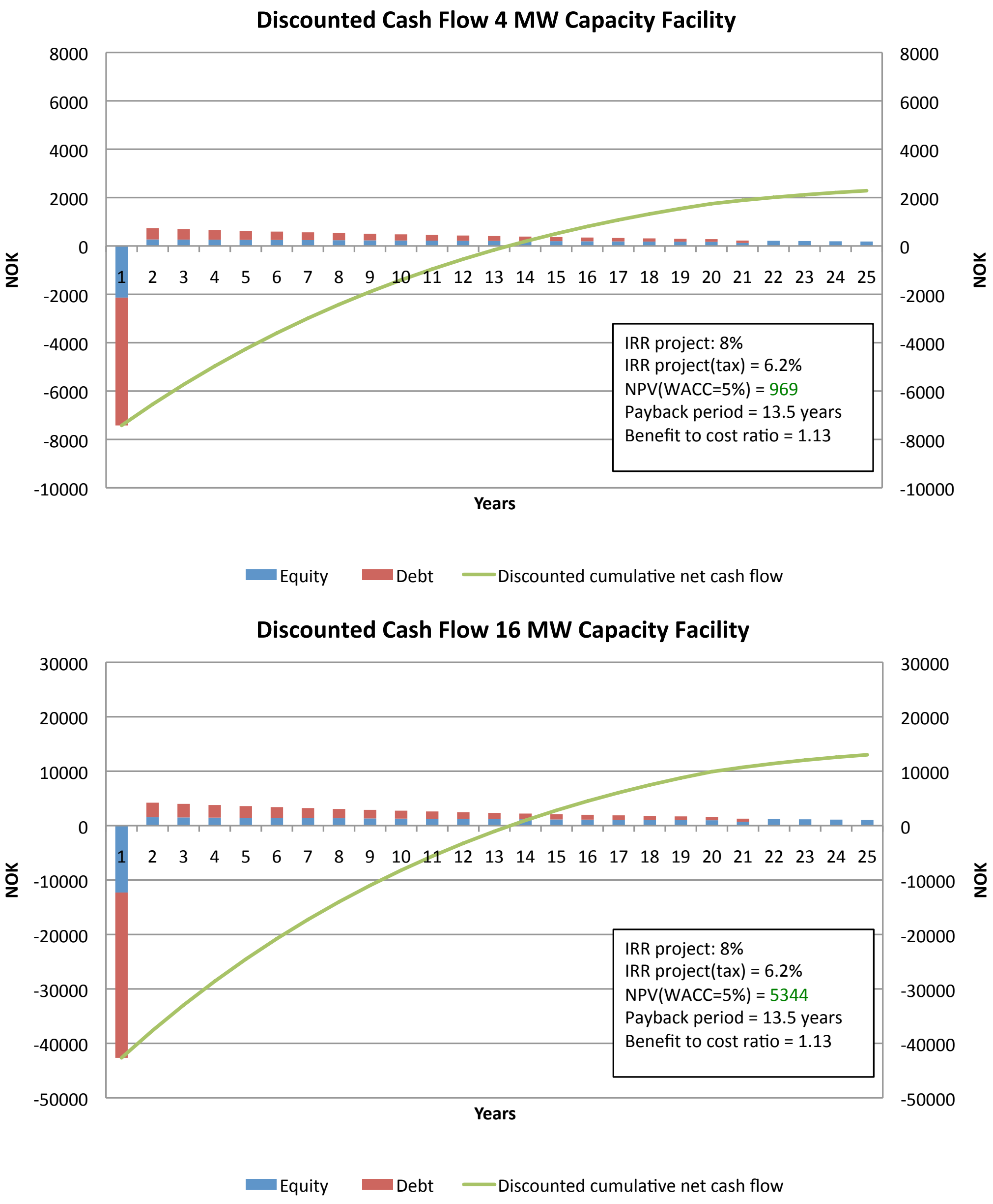
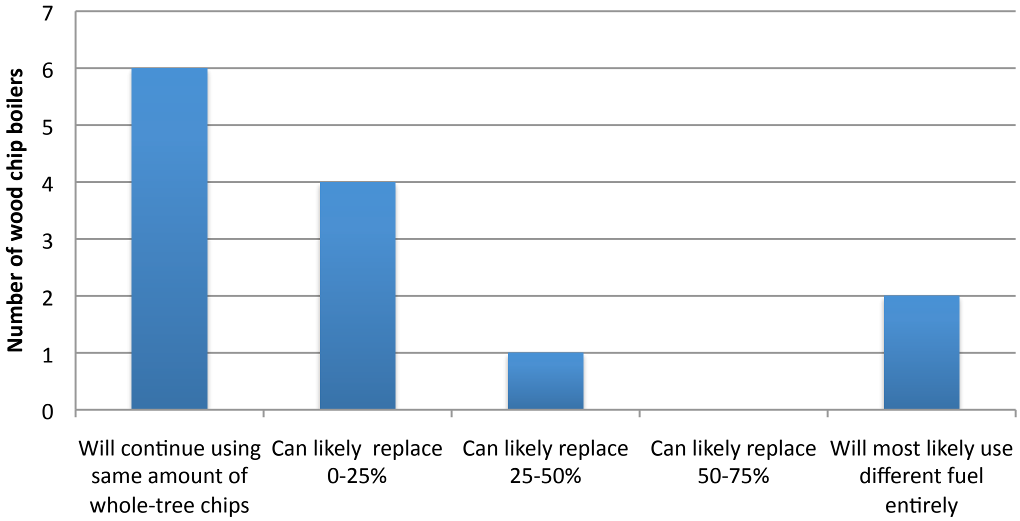


Figure 5.8: Cash-flow analysis

5.6.2 Price-change Scenarios

These next scenarios will under various assumptions evaluate the profitability of the modeled facilities without the SLF subsidy. Once again, this scenario is based off of the assumption that the investor assumed the subsidy as permanent.

Small Facility: Most smaller facilities don’t have the equipment or manpower to mix wood chip types on site. Therefore, they have less flexibility when it comes to fuel type and consequently rank their ability to substitute to other fuels lower. Moreover, there are not many options for single fuel types that have a similar moisture-content and composition as whole-tree chips. These observations are reflected in the survey results, which are displayed in Figure 5.9.



(My survey results)

Figure 5.9: Fuel Flexibility Small Facilities (1-2MW Wood Chip Boilers)

One must remember that the wood chip market is regional and that not all wood chip types are available at competitive prices in all regions. Consequently, Table 5.9 displays the financial indicators for two scenarios. One in which the facility uses whole-tree chips at the unsubsidized price, a 5øre/kWh increase, and the other where they substitute to 100 percent bole chips (moisture-content >35%), a 3 øre/kWh increase (*Energirapporten* 2009-2014; Norwegian Agriculture Authority 2013). A switch away from whole-tree chips would increase demand for bole chips and most likely increase their price. This would result in a scenario between the two extremes shown in Table 5.9.

Table 5.9: Financial Indicators Small Facility

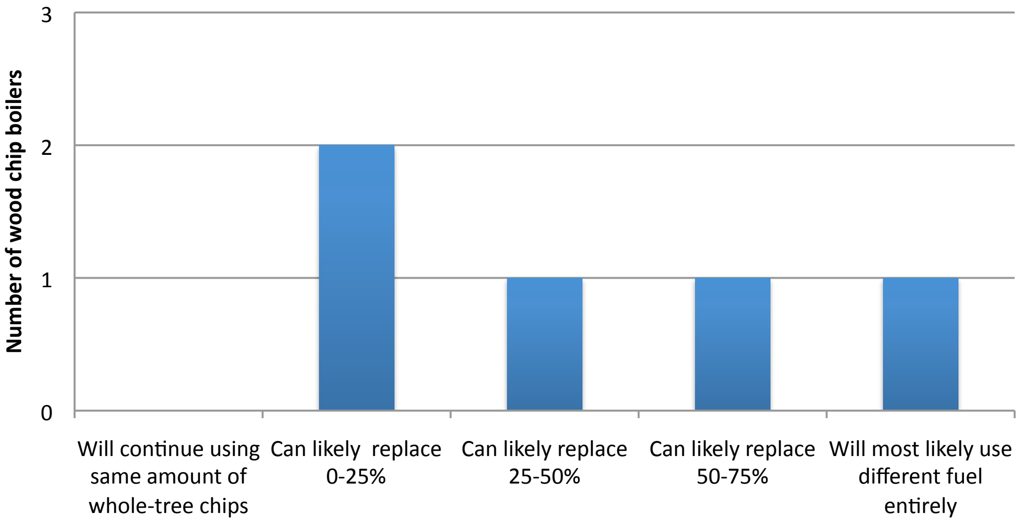
Small Facility 4 MW	**Scenario A**	**Scenario B**
Wood Chip Price Changes	+3 øre/kWh	+5 øre/kWh
Average Wood Chip Price	20 øre/kWh	22 øre/kWh
IRR	2.2%	-1.4%
NPV (WACC=5%)	-2066	-4501
Payback	19 years	None
Benefit to cost ratio (discounted)	0.73	0.42

Table 5.9 demonstrates that the removal of the subsidy would in both scenarios result in a negative NPV for the project and in Scenario B result in a negative IRR as well.

Large Facility: Larger facilities generally have the ability to mix different qualities of wood chips onsite. It is difficult to predict exactly how they would respond to an increase in price of whole-tree chips. Figure 5.10 summarizes my survey results and indicates that larger facilities have the ability to substitute between 25 percent and 75 percent of their whole-tree wood chip use with other sources. The company that reported that it would likely convert to other wood chips entirely was using very little whole-tree chips to begin with. Therefore, 75 percent substitution seems a more reasonable upper limit. Though, once again, it should be noted that there are only a few facilities that responded.

Remembering that in the modeled facility whole-tree chips constitute only 50 percent of the total fuel used, Table 5.10 shows the overall increase in fuel price for both a scenario where a firm replaces 25 percent of whole tree chips with an alternative wood chip and one where a firm replaces 75 percent with an alternative wood chip. This alternative fuel is assumed to cost 1 øre/kWh more than the original subsidized whole tree chip price. The remaining whole tree chips are assumed to increase in price by 5 øre/kWh. These price changes cause the average price of wood chips to increase by 1 øre/kWh in scenario A and 2 øre/kWh in scenario B. The financial indicators for these two scenarios can be seen in Table 5.10.

This substitution to an alternate wood chip could be accomplished in numerous ways. One way would be mixing more raw sawdust with either bole chips (moisture-content <35%) or dry wood shavings.



(My survey results)

Figure 5.10: Fuel Flexibility Large Facility (7-8MW Wood Chip Boilers)

Table 5.10: Financial Indicators Large Facility

Large Facility 16 MW	**Scenario A**	**Scenario B**
Wood Chip Price Change	1 øre/kWh	2 øre/kWh
Average Wood Chip Price	16.5 øre/kWh	17.5 øre/kWh
IRR	5.3%	4.4%
NPV (WACC=5%)	1345	-2655
Payback	14.5 years	16 years
Benefit to cost ratio (discounted)	1.03	0.94

The results for the two facilities are shown more readily in Figure 5.11, where one quickly notices that smaller facilities will be the most affected by the removal of the

SLF subsidy. The difference will likely be magnified due to the fact that larger facilities are more likely to have long-term contracts for various types of wood chips and will therefore have more time to adjust to changing prices. This notion was confirmed in conversations with district heating companies. Furthermore, large facilities may have more capital to re-invest if switching to a new fuel requires new machinery or equipment upgrades.

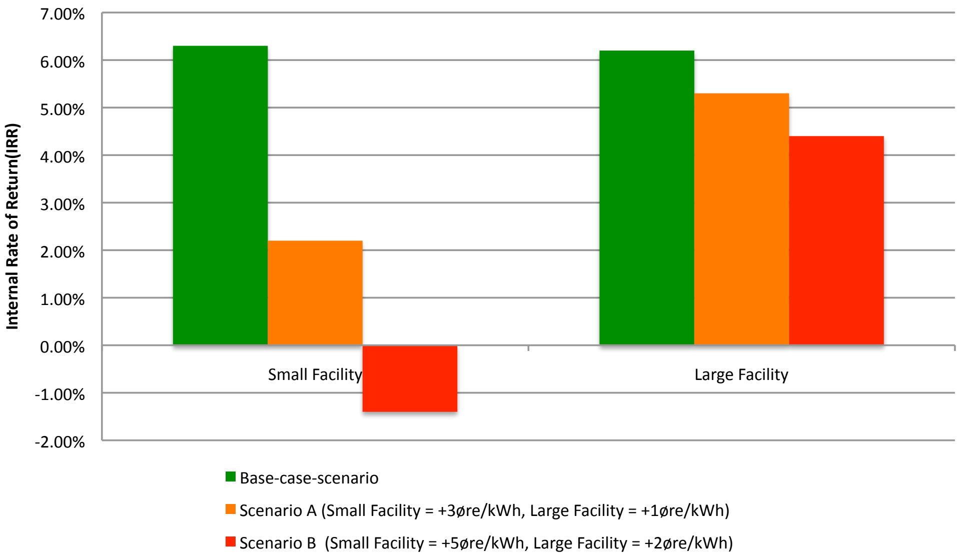


Figure 5.11: Effect of Removal of SLF Subsidy

This graph, particularly for the smaller facility, paints a relatively drastic picture for a company that has based itself on whole-tree chips. However, in order to put these numbers into perspective one needs to gauge its importance relative to other uncertainties for the industry. In 2012 Enova contracted PriceWaterHouseCooper (PwC) to evaluate its support scheme. In their final report PwC isolated the effect of changes in various parameters of 6 "new establishment" projects in Enova's district heating program. They determined which factors since the initial Enova contract had the greatest influence on the companies' IRR. They isolated the effects of district heating price, investment cost, wood chip cost, and operational expenses. Of these parameters, district-heating price had the largest effect, changing the IRR of the 6 projects anywhere from .1 percent to 10 percent. Four of the six projects had a change of between 2 percent and 6 percent. The other factors tested had a less prominent effect. The change in IRR for the above SLF subsidy scenarios ranges between .9 percent and 7.6 percent. It should be noted that a permanent decrease in IRR due to the removal of the SLF subsidy is likely much more important than the price fluctuations of district heating prices in the past few years. However, comparing it to the result from the PwC (ibid.) report puts the uncertainty surrounding the end of the subsidy in the appropriate size perspective. District heating companies now have an additional uncertainty factor on the same scale as district-heating price that can greatly affect their financial results.

5.7 Sensitivity Analysis

There are many factors that can significantly affect the profitability of a district-heating facility. Therefore, to put the removal of the SLF subsidy in proper perspective, this section will conduct a short sensitivity analysis on other parameters that can adversely affect the profitability of a heating facility. The risk factors that will be highlighted are interest rate on loans, wood chip prices, volume of heat delivered, and the price of electricity. This section will look at these factors separately and in combination with the price-change scenarios associated with the removal of the SLF subsidy.

5.7.1 Loan Interest Rates

Industries such as district heating have high upfront costs, which mean they rely heavily on access to affordable capital. Often a company will have a combination of loans with fixed and variable interest rates, which reflect the amount of risk a firm is willing to tolerate. Figure 5.12 and 5.13 display a small and a large facility's sensitivity to changing interest rates. The baseline rate used in the scenarios is 4.5 percent. The graphs show that if the SLF subsidy stays in place, then a small facility can tolerate an interest rate up to 5.8 percent and a large facility up to 5.7 percent while still yielding a positive NPV. There is no realistic decrease in interest rate that make Scenario A (+3øre/kWh) and Scenario B (+5øre/kWh) for the small facility yield a positive NPV.

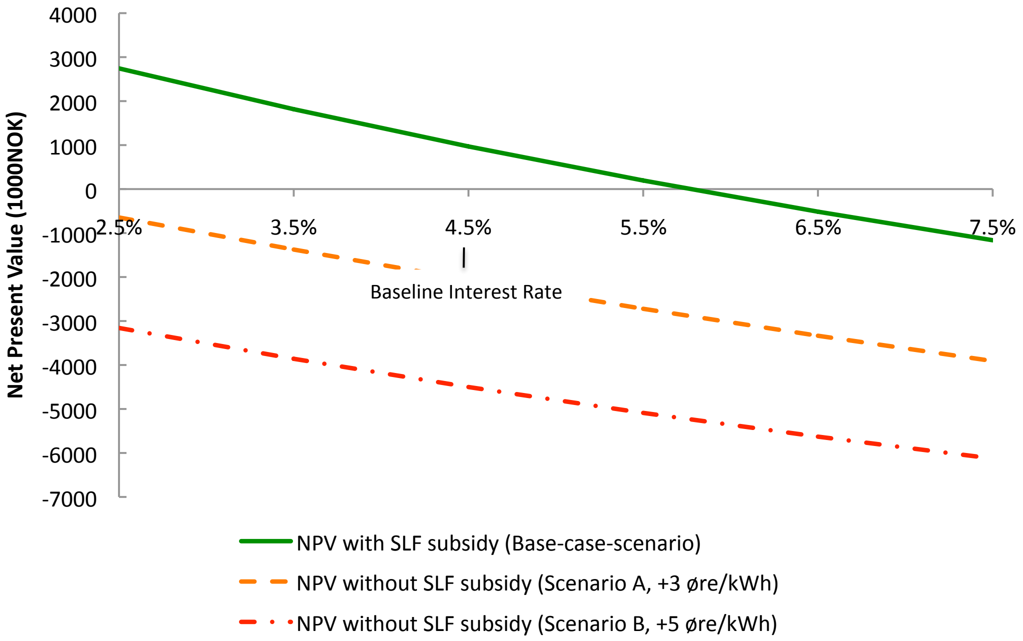


Figure 5.12: Small Facility Sensitivity to Loan Interest Rates

For the large facility, Scenario A (+1 øre/kWh) can tolerate an interest rate up to 4.8 percent while still maintaining a positive NPV, and Scenario B (+2 øre/kWh) will become financially viable with a interest rate of 3.9 percent.

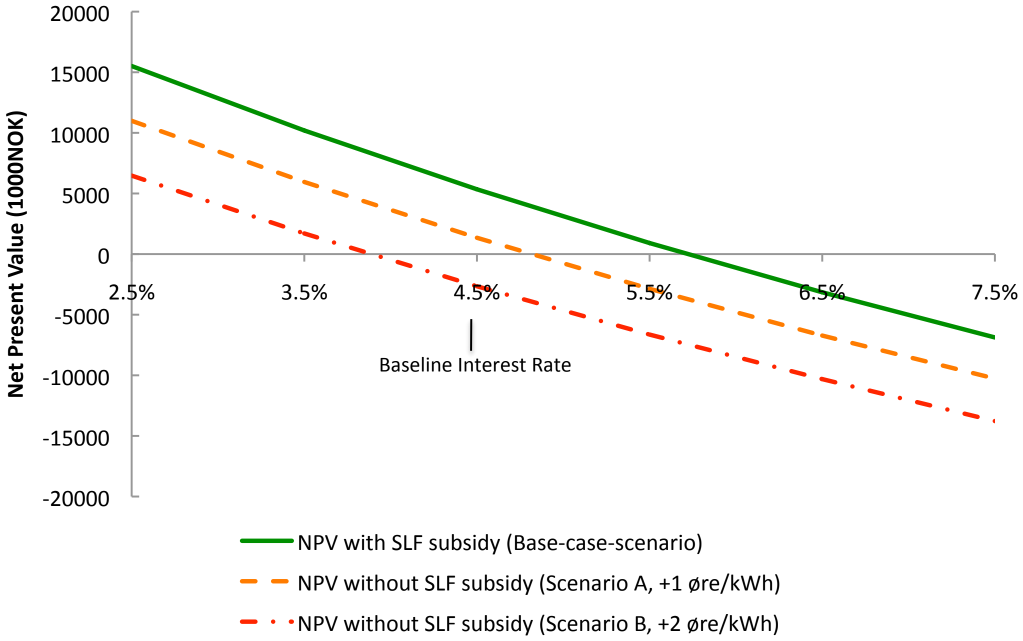


Figure 5.13: Large Facility Sensitivity to Loan Interest Rates

5.7.2 Wood Chip Prices

The scenario analysis in the previous section showed how a small and large facility's profitability is affected by the change in wood chip price associated with the removal of the SLF subsidy. However, it is also useful to examine their complete sensitivity to changing wood chip prices. Figure 5.14 and 5.15 demonstrate this graphically with the orange and red lines representing the mild and more severe scenarios associated with the removal of the SLF subsidy. A small facility can tolerate up to a 1 øre/kWh increase in wood chip price while still maintaining a positive NPV, whereas a large facility can tolerate a 1.3 øre/kWh increase.

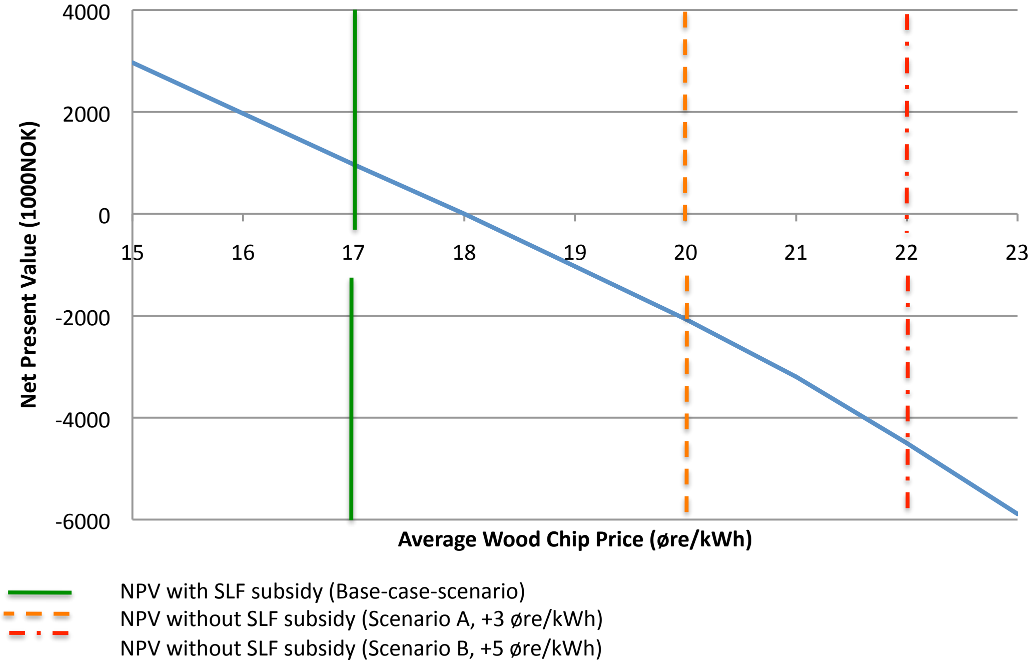


Figure 5.14: Small Facility Sensitivity to Wood Chip Price

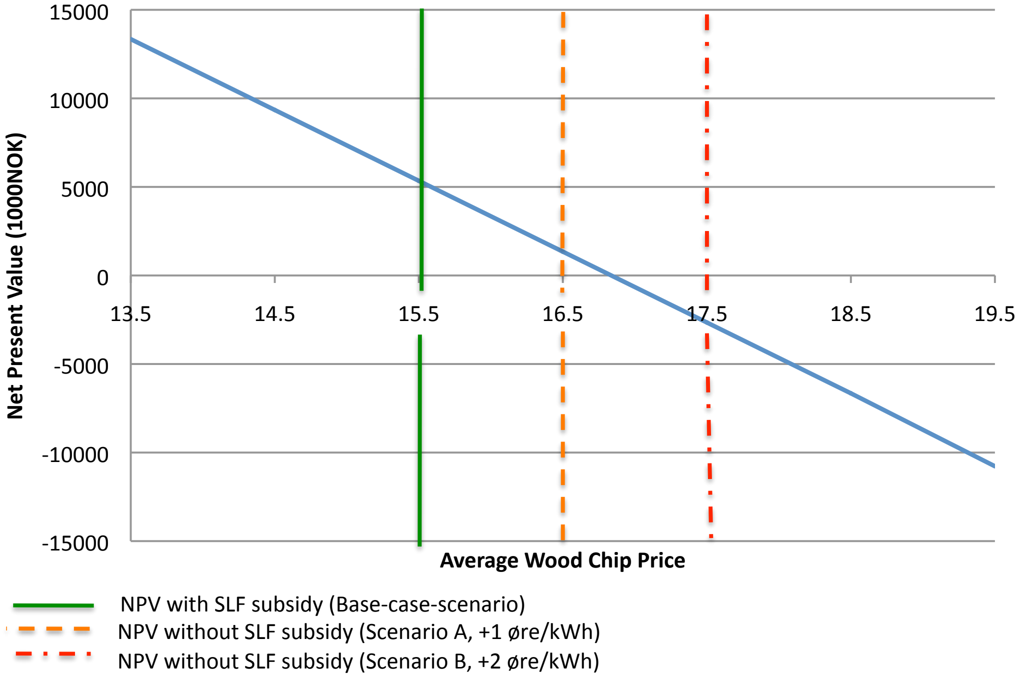


Figure 5.15: Large Facility Sensitivity to Wood Chip Price

5.7.3 Volume of Heat Delivered

The volume of heat a district heating facility delivers can differ substantially between years. Demand for heat is dependent on user preferences, temperature, and construction of new buildings in the area. It should be noted that the true effect of changes in delivered heat is difficult to predict. This is due to the fact that depending on when the additional demand for heat occurs, it may have to be covered by additional use of the oil boilers, which have a much higher fuel cost. Figure 5.16 and 5.17 demonstrate a small and large facility's sensitivity to changes in volume of heat delivered, but works under the assumption that the additional heat will be delivered by the same proportion of wood chip and oil boiler use as in the original scenarios. With the SLF subsidy, a small facility can tolerate up to a 7 percent decrease in volume before yielding a negative NPV. Meanwhile, Scenario A (+3øre/kWh) requires an almost 20 percent increase in volume delivered to yield a positive NPV.

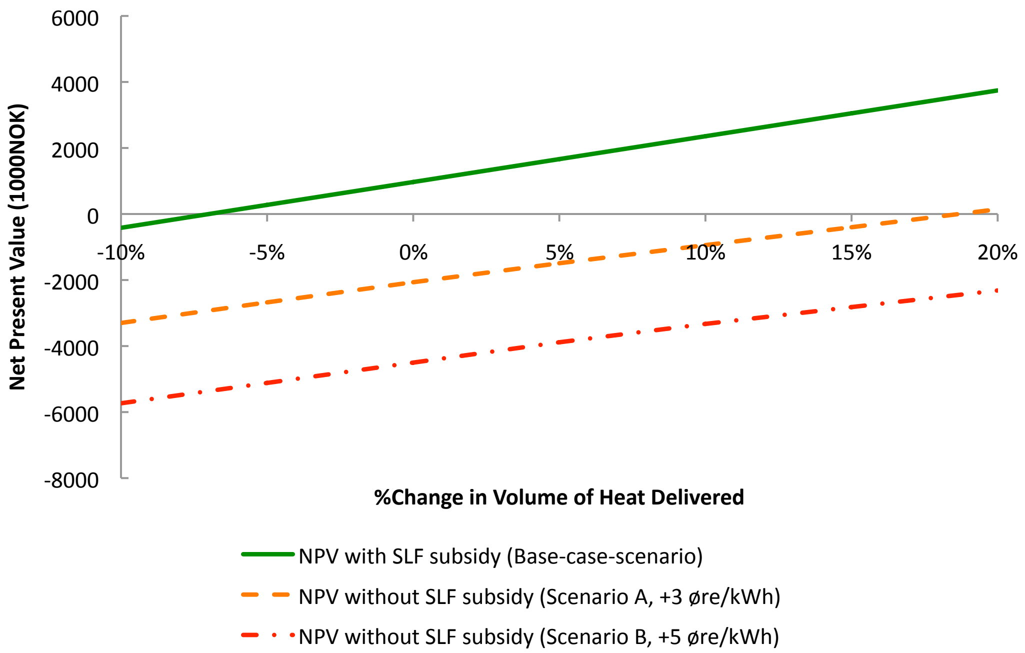


Figure 5.16: Small Facility Sensitivity to Volume of Heat Delivered

Figure 5.17 shows that with the SLF subsidy a large facility can endure a 7.4 percent decrease in heat delivered. Without the SLF subsidy this shrinks to 2 percent for Scenario A (+1 øre/kWh). Scenario B (+2 øre/kWh) requires a 4.1 percent increase in heat delivered to become financially viable.

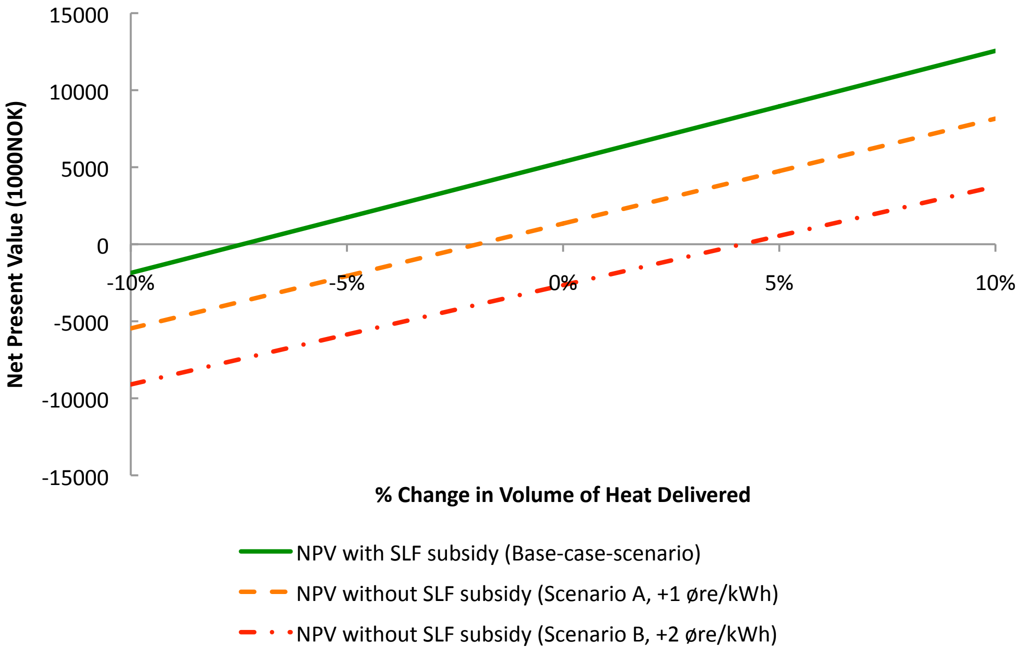


Figure 5.17: Large Facility Sensitivity to Volume of Heat Delivered

5.7.4 Electricity Prices

A common theme in conversations with representatives from district-heating companies was their worry that decreasing electricity prices would erode profits. In several conversations this issue was framed as particularly damaging if the industry suffered from removal of the SLF subsidy and decreasing electricity prices simultaneously. Moreover, it was also mentioned that projects could remain profitable, even without the SLF subsidy, if electricity prices increased. This section will explore these ideas, remembering that the price district heating facilities are allowed to charge for heat is linked to electricity prices. For the convenience of this analysis it is assumed that change in electricity price equates to a corresponding change in district heating revenues.

Uncertainty in the future of electricity prices has become particularly relevant with the advent of a joint market for green certificates between Norway and Sweden. There is some uncertainty as to whether these certificates will increase or decrease electricity prices, but it is likely that the market will experience a price change in the coming years due to the policy (Bye and Hoel 2009). Figure 5.18 demonstrates that with the continuation of the SLF subsidy, a small facility can tolerate a 1.7 percent decrease in electricity prices. Meanwhile, Scenario A (+3 øre/kWh), and Scenario B(+5 øre/kWh) require a 3.7 percent and 7.2 percent increase, respectively, to yield a positive NPV.

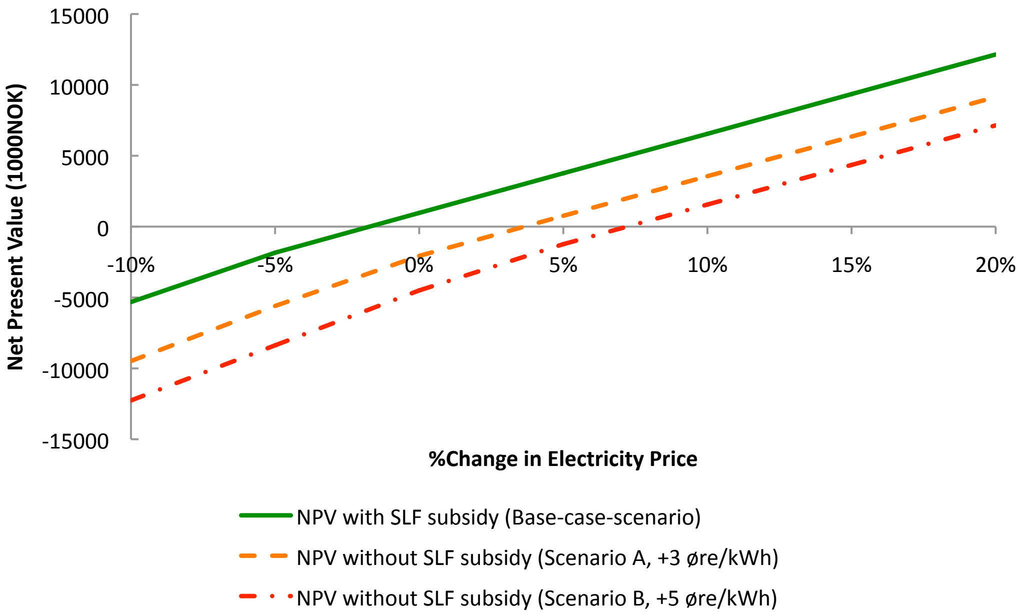


Figure 5.18: Small Facility Sensitivity to Change in Electricity Prices

Figure 5.19 demonstrates that a large facility can handle a 3 percent and 0.6 percent decrease for the baseline scenario and Scenario A (+1øre/kWh), respectively, while still yielding a positive NPV. Scenario B (+2øre/kWh) requires a 1.1 percent increase to become financially viable. Remembering that the real price of electricity increased by approximately 30 percent from the mid 1990s to mid 2000s, these are not unfathomable changes (Forbord and Vik 2009). However, it should be noted that the market for electricity is much more mature today than immediately after deregulation in the mid 1990s.

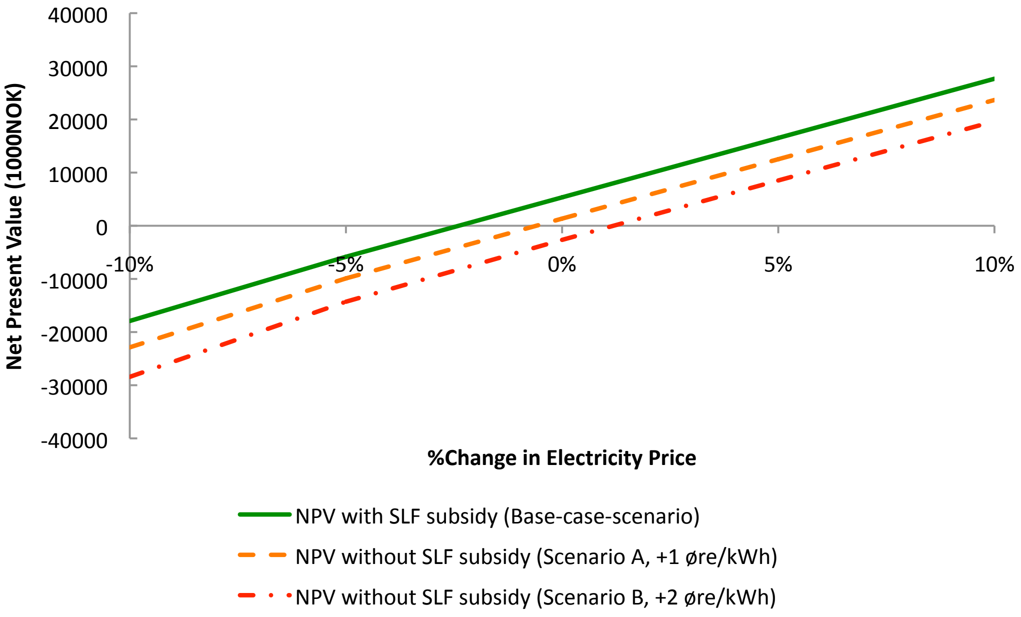


Figure 5.19: Large Facility Sensitivity to Electricity Prices

5.7.5 Summary Sensitivity Analysis

This short sensitivity analysis reveals several interesting observations. An increase in interest rate has a large effect on both a small and a large facility's profitability even with the SLF subsidy. Since this risk is familiar and well understood, it is likely that district-heating companies have taken this factor into account and have a safe portfolio of loans with a relatively consistent interest rate.

Another interesting observation is that, for the baseline scenario, a small and large facility can tolerate a 6 percent (1øre/kWh) and 9 percent (1.4øre/kWh) increase in wood chip price respectively. Meanwhile, they can only tolerate 1.7 percent and 3 percent decrease in electricity prices. The facilities are more capable of handling price changes in the wood chip market than in the electricity market. However, the removal of the SLF subsidy constitutes a large increase in wood chip price. It corresponds to an 18-29 percent increase for the small facility and 6-13 percent increase for the large facility. The graphs demonstrating the effect of a change in volume of heat delivered follows the relatively predictable pattern already established in the analysis, i.e. the large facility displaying much more robust financial results than the small facility.

5.8 Potential for Suboptimal Investments

Enova’s support is technology neutral; meanwhile the SLF subsidy may have inadvertently created a setting that favors particular technologies. The SLF subsidy has primarily supported whole-tree chips, which tend to have a moisture-content in the range of 30-40 percent (Nordhagen and Gjølsjø 2013). In order to utilize this type of wood chip, a heating facility must use a more robust and complex feeding system and boiler design. Consequently, the facility becomes more expensive (Sweco AS et al. 2011). For facilities below a certain size it does not make financial sense to install the necessary machinery that allows a boiler to burn high-moisture, lower quality fuels. It is easy to get lost in different boiler and feeding system designs; thus, detailed design information will not be included here. However, the most important points are as follows:

- The most inexpensive facilities use dry fuels such as briquettes or pellets, while the most expensive can use a wide range of wet/raw wood chips as long as they mix them to keep the moisture content at around 50 percent and can manage the fuel’s ash and fine-particle content.
- There is also a technology that occupies a middle ground. Certain facilities can use wood chips that have moisture content between 30 and 40 percent; however, they have limited mixing capabilities and have a lower tolerance for varying chip size, impurities, and fine fractions (Multiconsult 2012; Parat Halvorsen AS).

If the SLF subsidy was interpreted as permanent, it would have distorted investment decisions in favor of choosing facilities that could handle wet wood chips. In effect, it would have artificially lowered the critical facility size where it made sense to invest in a wet wood chip system.

There are also advantages associated with using different types of technologies. Large facilities that use wet wood chips and employ the most advanced feeding and mixing systems, are able to use many different types of fuel. This not only allows them to use the cheapest fuels, but is also an “insurance” against price spikes or a lack of availability of one particular type of wood chip. Likewise, the advantage of using a more processed fuel such as pellets or briquettes stems not only from the lower investment cost, but also from the fuel’s higher energy content and associated lower transport cost. Therefore, if there is a price shock associated with pellets or briquettes from a particular supplier, a lower transport cost means it is easier to switch to another supplier. These two technologies provide flexibility and thus increased stability of fuel prices for the heating facility. However, those facilities that use wet wood chips, but do not have the mixing abilities of the larger facilities may not benefit from either advantage.

Figure 5.20 and 5.21 show the NPV for facilities of various sizes based on technology choice, capacity and the SLF subsidy. They compare the returns to scale of a heating facility that uses wet wood chips and one that uses briquettes. The graphs include a curve for a wet wood chip facility with and without the SLF subsidy. In order to simplify the models, the costs used to create the graph below are for industrial heating facilities. This differs from the previous scenarios, which also include the extra costs associated with district heating such as: building aesthetics, extra fuel storage and automation. It uses the conservative price changes from scenario A for wood chip prices without the subsidy (small facility: +3øre/kWh, large facility: +1 øre/kWh). The price for briquettes is assumed to be 22 øre/kWh. This analysis uses briquettes as an alternate technology, because they are one of the cheaper alternatives to wood chips. Moreover, during conversations with representatives from district heating companies, briquettes were mentioned as a low-cost alternative for new investments if wood chip prices were to increase with the removal of the SLF subsidy. However, it should be noted that Figure 5.20 and 5.21 show just one example of an alternative technology. There may be many reasons other than price that make briquettes an inappropriate fuel for a small facility. It is merely used as an example to demonstrate how the SLF subsidy may have created a recipe for suboptimal investment.

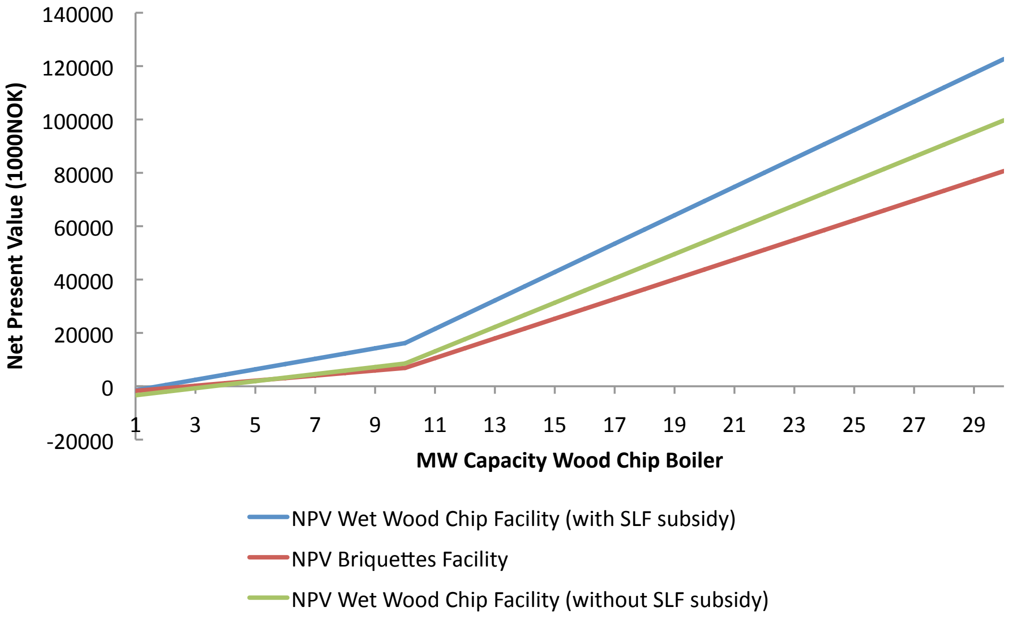


Figure 5.20: Returns To Scale Boiler Technologies (1-30MW)

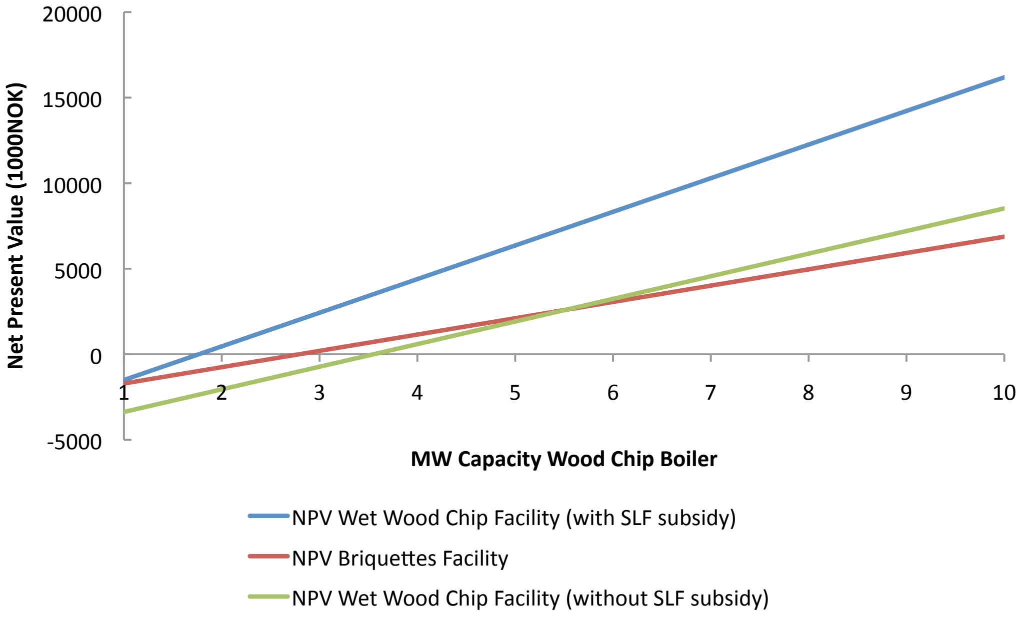


Figure 5.21: Returns to Scale Boiler Technologies (1-10MW)

Determining whether suboptimal investment has occurred is challenging. The above figures do not realistically represent the returns to scale of the two technologies. This is due to the fact that they likely do not appropriately differentiate between the investment costs of wet wood chip facilities, some of which can handle a much greater range of fuels and are consequently more expensive. Although there is some uncertainty in the above graphs, they still represent some rough guidelines for investment decisions. When comparing a wet wood chip facility to a briquettes facility one can envision that, particularly for boilers in the 1-3 MW size range, the incentives for wrong investment may be especially pronounced. In the survey responses 19 of the 32 boilers were in the 1-3 MW range. However, it should be noted that the construction dates for many of these facilities is unknown, which makes it challenging to directly link these investment decisions to the SLF wood chip subsidy.

Another avenue to explore is whether Enova investment subsidies have enhanced incentives for ill-advised investment. One can imagine that for a small county there exists a strong push to establish district heating based off renewable energy. In their study PwC (2012) mentions that, due to asymmetric information, there is potential for district heating companies to adjust numbers in their cash-flow analysis to land on the project IRR that generally yields Enova support. Their report provides the following quote, translated here for your convenience, from an anonymous district-heating company,

"To get Enova support NN needed to be as optimistic as possible. The project was so unprofitable that you needed to be optimistic to get financial support. As an applicant you know what numbers you need to end up with for your bottom-line in the application. We would avoid many strange calculations with a more uniform support scheme. Everyone can adjust their results significantly by being optimistic, or pessimistic in the right places" (PwC ibid).

This moral hazard gives companies that have projects that may be too profitable the incentive to be overly conservative. In addition, as demonstrated in the quote above, it may also give incentives for some actors with smaller and more borderline viable projects to be more optimistic with their parameters. This may seem a bit far-fetched, but it is worth bearing in mind that counties generally have low return on investment requirements and may place more weight on factors other than profitability. In this case, if a project was at the limit of being profitable enough to qualify for Enova support, one perceived justification for using overly optimistic parameters in the initial Enova application could have been relying heavily on the low SLF wood chip prices. In order to do so, they would have to invest in a facility that could use wet wood chips, thus exacerbating suboptimal investments. Moreover, PwC (2012) mentions that many of the companies report Enova's system as favoring smaller facilities, which may have placed additional projects within the likely range for suboptimal investment. However, they were unable to confirm this claim empirically (PwC ibid).

5.9 Analysis Summary

This chapter brings to light several potential impacts of the SLF subsidy, which will be briefly summarized here. Numbers from SLF and Mjøsen Skog reveal that in the five-year period the subsidy was in place it successfully stimulated the production of large quantities of wood chips, particularly whole-tree chips. Moreover, the supply of whole-tree chips and chips from forest residues will most likely decrease drastically after the removal of the subsidy in 2014, though the effect will be delayed due to a large existing supply of contracted raw materials. My survey results and conversations with representatives from district heating companies reveal that whole-tree chips are widely used in heating facilities across the nation, and that several of these facilities use it as the sole fuel for their base-load boilers. A financial analysis reveals that the removal of the subsidy can have a relatively large adverse effect on the profitability of district heating facilities, particularly those of smaller size that have limited chip mixing capabilities. Furthermore, the sensitivity analysis puts the uncertainty surrounding the subsidy in perspective with other factors, and demonstrates that the only factor that with reasonable changes can substantially improve the financial prospects of the small facilities is increasing electricity prices. It is also worth noting that if the subsidy was interpreted as permanent, it likely has created a recipe for suboptimal investment that may have been enhanced by the design of Enova's support scheme. These effects may have undermined Enova's goal of creating an economically robust district-heating sector, which is especially important since the industry has been experiencing somewhat variable and weak financial results. Finally, it should again be noted that these results and interpretations of the subsidy are uncertain and that the extent to which the sector was dependent on SLF support will only reveal itself over time and when Enova has the opportunity to again evaluate how projects have deviated from their contracted IRRs.

6 Discussion

The analysis portion of the thesis reveals that the end of the Norwegian Agriculture Authority's (SLF) wood chip subsidy will undoubtedly have an adverse effect on the district-heating sector and that this effect may be amplified if it has caused suboptimal investments. This conclusion prompts a discussion of what is prudent policy design for the bio-energy and district-heating sectors. This chapter will discuss: the unique challenges associated with designing policy for bio-energy and district heating; how the wood chip subsidy may have been misguided; and some of the SLF policy's design elements. This will be followed by a discussion of the importance of framing policy objectives and an overview of how bio-energy has been framed in Norwegian politics.

6.1 Complexity of the Bio-energy Sector

The bio-energy industry is inherently complex. There exists a wide span of bio-energy sources that can be used to create fuels that range from wood chips to jet fuels (Rambøll 2013). However, even if one only examines wood chips, the picture is still complicated. There exist many types of wood chips stemming from a variety of different sources. They can be a by-product of the sawmill industry or can originate as a primary or secondary product of the timber industry. Forbord *et al.* (2012) refer to the utilization of forest resources not as "supply chains", but rather as "supply networks", a term that indicates that the sector's profitability is more dependent on economies of scope than of scale. The creation of wood chips is merely a part of a larger forest utilization network. However, the complexity of the system does not stop at fuel creation; district-heating companies use various boiler technologies that require wood chips with specific moisture, size, and ash content. The complexity of forest supply networks, the lack of transparency surrounding wood chip qualities, and the variety of available boiler technologies presents a unique challenge in policymaking.

6.2 Policy Analysis

The SLF subsidy was established to aid in the goal of increasing bio-energy use by 14 TWh by 2020, promote job creation in the forest sector, and make it profitable to produce bio-based fuel that would otherwise not be utilized. It was put together partially as a response to the 2008 financial crisis (Norwegian Agriculture Authority 2010; Norwegian Agriculture Authority 2014b). The available literature on policy design consistently stresses various attributes that create good policy. The three most important criteria that the SLF subsidy may have violated are: one policy per objective, technological neutrality, and stability.

Tinbergen in his book “On the Theory of Economic Policy” made famous the rule that for each target there should exist one policy. He presents mathematically the conclusion that if the number of targets differs from the number of instruments, then there will not be a unique mathematical solution. In layman’s terms, one of the implications of this result is that if a policy has numerous targets at least one of the targets cannot be fully attained (Tinbergen 1952). The SLF subsidy was put together as a policy with numerous goals. Therefore, it is unlikely to have fulfilled all of its goals in an appropriate manner. This may be particularly true for its goal of increasing bio-energy use. For example, the subsidy supported the creation of wood chips from forest residues. Meanwhile, as mentioned in the analysis section, Mjøsen Skog, a large actor in wood chip production, concluded that there does not exist an adequate market for wood chips from forest residues to warrant their production. Moreover, the analysis reveals that the prevalence of whole-tree chips promote the establishment of a certain type of boiler technology and feeding system. When this policy was designed there seems to have been a focus on employment and homegrown biomass solutions, but a lack of foresight related to how these fuels would be used. This may be partially due to the policy’s focus on numerous objectives, which may have reduced the likelihood of fulfilling any one goal in a prudent fashion.

Literature on economic policy design typically stresses the importance of economic incentives being technology neutral. Jaffe *et al*. (2005) explain that focusing on specific, seemingly beneficial technologies can result in technology lock-in. This is where government support of a particular technology stifles the development of other more beneficial technologies (Jaffe *et al.* ibid). Enova's program for the establishment of new district-heating facilities manages this risk by ensuring that their support for district heating is technology neutral within the available renewable options. These criteria can be seen in Table 5.5 in the analysis chapter.

These criteria do not favor any particular renewable technology, but rather attempt to support those projects that have a higher societal value and are more economically robust. The SLF wood chip subsidy, which supported a particular type of wood chip, may have eroded this goal by providing incentives for companies to invest in bio-boilers that utilize a specific technology.

In their article "The effectiveness of policy instruments in promoting bioenergy", Cooper and Thornley (2008) evaluate the effectiveness of bio-energy support programs in four European states: Germany, Italy, the UK and Sweden. All the countries at some point had investment subsidies, and two of the countries experimented with fixed price tariffs for bio-facilities that produced electricity. The combination of investment subsidies and a fixed price tariff was particularly effective in Germany, while in Italy, a country with little history of bio-energy use, the fixed price tariff did not last long enough to have a pronounced effect. Their results seem to demonstrate that a fixed price tariff needs to be set at a sufficiently high level for at least 8 years to be effective (Cooper and Thornley ibid). These cases cannot be directly compared to Norway. However, they do introduce some relevant themes. Combining investment subsidies with a policy that ensures a certain amount of revenues may be particularly effective, and that these two policies need to be present for at least eight years. Without a feed-in tariff, a bio-based heating facility will normally have two major variable factors: revenue per kWh delivered and the cost per kWh for bio-fuel. A feed-in tariff would stabilize one of these two variables. In Norway, although it may have been poorly designed, the SLF subsidy worked to ensure fuel supply at reasonable prices in an undeveloped bio-fuel market, thus also providing stability to one of two variable factors. This combined with Enova investment subsidies may explain some of the dramatic growth in the sector. However, when it comes to establishing stability, the SLF subsidy had several flaws. There was no clear communication between the state and private actors on how long the subsidy would be in place, and it ended after only five years. These attributes may not have created the necessary stability to ensure the profitability of district-heating facilities and the economic robustness of the sector.

6.3 Framing of Bio-energy Use in Norway

Another important issue surrounding the SLF subsidy is how the use of bio-energy from Norwegian forests has been framed in public policy. Framing refers to how the government has articulated the future of bio-energy use in Norway. This framing may have affected how district-heating companies interpreted the SLF subsidy. There have been reports by both the Ministry of Petroleum and Energy and the Ministry of Agriculture and Food that have highlighted the importance of increased bio-energy use in Norway (Bioenergi strategi 2008 ; St. meld. nr 9 2011-2012). In these reports there has been a particular emphasis on the use of resources that have historically not been utilized in Norway. In particular, chips from forest residues and whole-tree chips have been stressed as important resources. If not used to create wood chips, forest residues would most likely remain as waste at logging sites. Meanwhile, the production of whole-tree chips serves the dual purpose of cleaning up roadsides and keeping the cultural landscape open. Of the two resources, forest residues have been the most emphasized since they can be continually harvested under normal logging operations. Whole-tree chips are dependent on a demand to clear roadsides and clean up the cultural landscape, a demand that will naturally decrease over time as the most important and desirable areas for clearing have been taken care of. Meanwhile, the two reports evaluate using additional tracts of forest land with the sole purpose of wood chip production as less desirable due to competition with other sectors, biodiversity issues, and higher greenhouse gas emissions. The higher greenhouse gas emissions stem from the fact that rather than the carbon being stored in building materials, it would be released when the chips are burned. Forest residues are emphasized as an environmentally friendly fuel because branches and needles break down rather quickly and, if left at logging sites, would result in little storage of CO_2 anyway (Bioenergi strategi 2008).

In light of the government's framing of what constitutes environmentally friendly bio-energy use, it does not seem surprising that many companies and counties based on a desire to be environmentally friendly and take advantage of the SLF subsidy have chosen to base themselves on SLF-supported wood chips. The government's framing of how bio-energy should be used is an important factor when stimulating climate-friendly investments. In their study on framing of bio-energy in Finland, Kivimaa and Mickwitz (2011) comment on the fact that government framing of problems and intervention can influence the meaning associated with technology. In this case, the government may have framed wood chips from forest residues or whole trees as the responsible and environmentally friendly alternative, and may have influenced the choices of private actors. They also mention that in order to shift towards low-carbon, sustainable energy systems, the framing of bio-energy policy needs to be consistent over time (Kivimaa and Mickwitz ibid). With the establishment of the new government in 2013, there is a risk that this consistency may be broken, as the new government has signaled changes in the agriculture and forest sectors.

The bio-energy sector has unique challenges that make policy design difficult. The design of the SLF subsidy and the framing of bio-energy use in Norway may have created a recipe for investments in less profitable technologies. Future policy needs to improve the interface between goals in the district-heating sector and the desire to increase the use of Norway's bio-energy resources.

7 Conclusion

The removal of the Norwegian Agriculture's (SLF) wood chip subsidy has been a hotly debated topic within the bio-energy and district-heating sectors. The main goal of this thesis has been to evaluate how the SLF subsidy has affected the profitability of district-heating facilities and what effects its removal in 2014 will have on the sector. Although there is some uncertainty in the results, this thesis can serve as a preliminary guide for policymakers and consolidates some important information on the SLF subsidy and use of wood chips in the district-heating sector.

7.1 Main Findings

Although the analysis portion of the thesis goes into detail concerning costs and use of wood chips, the facilities modeled are theoretical. It is therefore important to realize that the numbers and results can best serve as a reference point for policymakers while also illuminating important concepts and relations.

Conversations with both suppliers of wood chips and district heating firms revealed that chips from forest residues are not widely used; in fact there are only a few large facilities in Norway that have a robust enough feeding and mixing system to use these chips. Therefore, the focus of the thesis has been on whole-tree chips. The short survey I conducted revealed that whole-tree chips are widely used by district heating facilities, although to varying degrees. Some facilities use whole-tree chips as a primary fuel, while for others it serves as only a smaller fraction of their wood chip supply. Likewise, smaller facilities are more likely to use whole-tree chips as their primary or sole fuel, and consequently evaluate their ability to substitute to other fuels lower than do larger facilities as shown in Figure 5.9 and 5.10.

The financial models reveal that a small facility will be much more affected by the removal of the SLF subsidy than a large facility. Assuming the worst-case scenario that the lowered prices associated with the SLF subsidy were taken into account in the initial Enova support applications, then the distortive effects on investments are particularly severe. The modeled small facility experiences a negative Net Present Value (NPV) of investment in both scenarios, while the large facility maintains a positive NPV in one of the scenarios. The overview of these results can be seen in Figure 5.11. In addition to these basic scenarios, the sensitivity analysis revealed the economic robustness of facilities with respect to interest rate on loans, wood chip price, volume of heat delivered, and electricity price. For the small facility, it was particularly telling that the only factor that, with reasonable changes, could greatly improve the profitability of the facility after the removal of the SLF subsidy was the electricity price. A 3.7 percent and 7.2 percent increase in electricity price would make the small facility in scenario A (+3øre/kWh) and B (+5 øre/kWh), respectively, yield an NPV of 0.

7.2 Additional Findings

In addition to the main problem statement, the thesis introduction brought up several topics closely linked to evaluating the SLF subsidy:

- Does sawdust directly compete with forest wood chips?
- Have suboptimal investments taken place in the district-heating sector?
- The bio-energy and district heating sectors lack data and consolidated information.
- The SLF subsidy may have created unnecessary uncertainty within the district-heating sector.

Through research and conversations with district-heating companies it has become apparent that sawdust does not directly compete with forest wood chips. For example, raw sawdust can be mixed with whole tree chips to form a fuel with an approximate moisture-content of 50 percent, ideal for large wet wood chip facilities. Meanwhile, smaller facilities may not have the mixing capabilities or feeding mechanisms to handle sawdust.

A simple example using briquettes as an alternate technology demonstrates that the wood chip subsidy may have created a recipe for suboptimal investment in the sector. Moreover, this adverse effect may have been enhanced by the design of Enova's district-heating support scheme. Without access to the private information of actors in the sector, it is impossible to determine if suboptimal investment has occurred, though it should be noted that many of the firms that responded to the survey have wet wood chip boilers that fall into the size range where suboptimal investments are the most likely.

Although the above-mentioned results prompt interesting discussions, the most important concept stemming from this thesis is that the bio-energy and district heating sectors are exceedingly complex. The production of wood chips is often linked to the production of other forest products, which may make the impact of support schemes hard to predict. Moreover, the various bio-boiler and feeding system designs that handle different types of wood chips further complicate the analysis. This complexity is exacerbated by a lack of consolidated information on the sector. Little data exists on wood chip use and the characteristics and importance of different wood chip sources and qualities. This observation was reflected in conversations with various actors in the sector including wood chip producers, district heating companies, interest organizations, and bio-boiler producers.

The complexity described above, combined with the design of the SLF subsidy may have created unnecessary uncertainty for both wood chip producers and district heating companies. Combine the potential distortive effects of the subsidy's narrow focus on certain types of wood chips with a lack of clarity surrounding how long the subsidy would be in place, and the result is a recipe for uncertainty in the two sectors.

7.3 Future Research and Further Implications

Hopefully this thesis has provided a preliminary prognosis of the impact of the SLF subsidy and served to consolidate some information on bio-energy use in Norway. To truly determine the importance of the SLF subsidy, further study and more data on bio-energy use is needed. These future studies could, as the sector develops, provide important information on policy design and how best to utilize Norway’s bio-energy resources. My thesis introduces some policy concepts in an industry that, due to its complexity, may require more in-depth knowledge and innovative policy design than the rest of the energy sector. It is likely that the SLF subsidy was designed without the necessary foresight and caution needed to stimulate appropriate investment in both bio-energy production and district heating. With the coming shift to more climate-friendly technologies in many sectors of the economy, it may be dangerous to pursue policies such as the SLF subsidy that have multiple goals and implicitly favor certain technologies. Results from this thesis indicate that in order to reduce investment uncertainty, it would be beneficial to have a more comprehensive plan for district heating and bio-energy accompanied by targeted and flexible policies that better mirror goals within the sectors.

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Definitions and Abbreviations

SLF	Norwegian Agriculture Authority
NPV	Net Present Value
lm^3	cubic meters (loose material)
sm^3	cubic meters (soild material)
IRR	Internal Rate of Return
NN	Anonymous
NOK	Norwegian Kroner
SSB	Statistics Norway

Wood chips: For the purpose of this study, the term wood chips refers to all fuels used in a wood chip boiler, whether they stem from the forest or as a by-product of the sawmill industries. This includes whole-tree chips, chips from forest residue, raw sawdust, bark etc.

Forest wood chips: Includes all wood chips that stem directly from the forest. This includes bole chips, forest residue chips, whole-tree chips and chips from pulpwood. However, when forest wood chips is used in association with the SLF subsidy it is usually referring to only whole-tree chips and chips from forest residues.

Wet wood chips: Wet wood chips can technically refer to any wood chips that have a moisture-content higher than 20%. However, in this thesis when I refer to wet wood chips I am usually referring to chips in the 30-50% moisture-content range.

Norwegian Translations and Brief Overview of Wood Chip Types

Forest Wood Chips

Bole Chips (Stammevedflis): Wood chips made from chipping of the main stem or bole of a harvested tree. The moisture-content of this type of chip can vary dependent on the process used(BERC 2011; *Energirapporten* 2009-2014). They are generally sold in two varieties:

- Dry bole chips <35% moisture-content
- Wet bole chips >35% moisture-content

Whole-Tree Chips (Heltreflis): Wood chips made from the chipping of entire trees and have a moisture-content of 30-40%. Generally contain more fine particles and have a higher ash content then Bole Chips (Nordhagen and Gjølsjø 2013).

Chips from Forest Residues (Grotflis): Wood chips made from small trees, branches, tops, and other organic material left after a logging operation. This fuel contains even more fine particles the whole-tree chips and also has a higher ash-content. Moreover it may contain a high proportion of impurities (ibid)(European Biomass Industry Association).

Chips from Pulpwood (Massevirke): Pulpwood usually originates from trees or parts of stems of trees at logging sites that cannot be used at sawmills because they are too short, have too small a diameter, or suffer from various other flaws. Currently pulpwood is not frequently used as bio-energy, as the name implies it generally goes to paper construction and the production of wood composite boards. However, this may become a viable fuel if prices stay low (Norwegian Agriculture Authority 2014).

By-products of the Sawmill Industry

Chips from Sawmill Residues(industriflis): Wood chips made from leftover slab wood that is not suitable for lumber. Moisture content may vary depending on the lumber being produced, but will generally be between 12-55%. In Norway this fuel may have chips that vary greatly in size (BERC and Maker 2004; Viken Skog).

Green Sawdust(rå sagflis): Stems from the cutting of un-dried timber and has a moisture content of around 60%. It will often contain chips of varied size, and the high moisture content makes it prone to freezing. Facilities that use this fuel must have a robust storage, feeding and combustion system designed to handle this fuel(BERC and Maker 2004; Södra Timber AS).

Bark: Another by-product of the sawmill industry that can be used for fuel in heating facilities. The moisture content of bark is very variable, but generally resides in the 50-75% range. Bark also tends to contain many impurities (ibid).

Dry Wood Shavings (tørr avkapp): Can be produced from planing operations in sawmills. Generally stems from more processed lumber and may have a relatively low moisture content of 14-17% (Södra Timber AS).

Jeg heter Borge Håmsø og er Master student på NMBU universitetet ved Ås. Jeg skriver masteroppgave om energiflistilskuddet og **håpet du kunne hjelpe meg med å svare på noen spørsmål om deres bruk av heltreflis?** Eller om du kunne videresendt denne eposten til noen som kan. Data blir kun brukt som oversikt og aggregerte tall vil ikke kunne spores tilbake til individuelle firma.

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Spørsmål

Har dere brukt heltreflis i noen av deres anlegg i de siste fem årene?

Visst ja, hvor mye effekt har fliskjelen og omtrent hvor stor prosent andel av total flisforbruk utgjør heltreflis?

Hvordan rangerer du muligheten til å erstatte heltreflis med andre typer brensel?

1 - Ikke mulig, skal fortsette å bruke heltreflis.
2 - Kan muligens erstatte 0-25%
3 – Kan muligens erstatte 25-50%
4 – Kan muligens erstatte 50-75%
5 – Regner med å bruke annet brensel.

	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 25
Revenue									
	5256	5256	5256	5256	5256	5256	5256	5256	5256
Capex									
Total investment	-8130								
Opex									
regular operation	-478	-478	-478	-478	-478	-478	-478	-478	-478
Major overhaul									
wood chip cost	-3022	-3022	-3022	-3022	-3022	-3022	-3022	-3022	-3022
oil cost	-929.209	-929.209	-929.209	-929.209	-929.209	-929.209	-929.209	-929.209	-929.2092
Operating profit	827	827	827	827	827	827	827	827	827
Financial Costs									
loan interest	0	-226	-214	-202	-190	-178	-166	-155	0
loan installments	0	-264	-264	-264	-264	-264	-264	-264	0
total financial costs	0	-490	-478	-466	-454	-443	-431	-419	0
depreciation	-407	-407	-407	-407	-407	-407	-407	-407	0
earnings before tax	421	195	207	219	231	242	254	266	827
cumulative tax base	421	195	207	219	231	242	254	266	827
tax	-118	-55	-58	-61	-65	-68	-71	-75	-232
Profit after tax	709	547	555	564	572	581	590	598	596
Net cash flow (before tax)	-7303	601	613	625	637	649	661	673	827
Net cash flow (after tax)	-7421	547	555	564	572	581	590	598	596
cumulative net cash flow	-7421	-6874	-6318	-5755	-5182	-4601	-4011	-3413	7411
discounted net cash flow	-7421	521	504	487	471	455	439	424	184
discounted cumulative net cash flow	-7421	-6545	-5728	-4967	-4259	-3601	-2989	-2422	2285

FIRR (before tax)	8.0%
FIRR (after tax)	6.3%
NPV (after tax)	kr 969
benefit to cost ratio	1.13

Appendix 5

Profit and Loss Statement Large Facility (1000 NOK)

	year 1	year 2	year 3	year 4	year 5	year 6	year 7	year 8	year 25
Revenue									
	21025	21025	21025	21025	21025	21025	21025	21025	21025
Capex									
Total investment	-46718								
Opex									
regular operation	-2048	-2048	-2048	-2048	-2048	-2048	-2048	-2048	-2048
Major overhaul									
wood chip cost	-10628	-10628	-10628	-10628	-10628	-10628	-10628	-10628	-10628
oil cost	-3615.6	-3615.6	-3615.6	-3615.6	-3615.6	-3615.6	-3615.6	-3615.6	-3615.6
Operating profit	4733	4733	4733	4733	4733	4733	4733	4733	4733
Financial Costs									
loan interest	0	-1298	-1230	-1162	-1093	-1025	-957	-888	0
loan installments	0	-1518	-1518	-1518	-1518	-1518	-1518	-1518	0
total financial costs	0	-2817	-2748	-2680	-2612	-2543	-2475	-2407	0
depreciation	-2336	-2336	-2336	-2336	-2336	-2336	-2336	-2336	0
earnings before tax	2397	1099	1167	1235	1304	1372	1440	1509	4733
cumulative tax base	2397	1099	1167	1235	1304	1372	1440	1509	4733
tax	-671	-308	-327	-346	-365	-384	-403	-422	-1325
Profit after tax	4062	3127	3176	3225	3275	3324	3373	3422	3408
Net cash flow (before tax)	-41986	3435	3503	3571	3640	3708	3776	3845	4733
Net cash flow (after tax)	-42657	3127	3176	3225	3275	3324	3373	3422	3408
cumulative net cash flow	-42657	-39530	-36354	-33128	-29854	-26530	-23157	-19735	42206
discounted net cash flow	-42657	2977	2880	2784	2691	2601	2513	2428	1051
discounted cumulative net cash flow	-42657	-37639	-32958	-28597	-24537	-20762	-17256	-14002	13012

FIRR (before tax)	8.0%
FIRR (after tax)	6.2%
NPV (after tax)	kr 5,344
benefit to cost ratio	1.13

Wet Wood Chip Based District Heating Facility

Facility specifications			
Max capacity heating facility	MW	4	16
Heat produced	MWh	9200	36800
Boiler capacity	MW	2	8
Investment costs			
Wood chip boiler	NOK	10240000	36864000
Oil boiler	NOK	800000	6553600
Oil boiler	NOK	800000	6553600
Interest under construction	NOK	100125	1224000
Total investment cost (before district-heating factor)	NOK	100125	1224000
Total investment cost (after district-heating factor)	NOK	17910187.5	76792800
Operating expenses and fuel cost			
Operating expenses	NOK/year	477605	2047808
Fixed costs wood chip boiler	øre/kWh	12.8	11
Variable cost wood chip boiler (excluding wood chip cost)	øre/kWh	5	4
Cost of oil	øre/kWh	77.1	75

Costs
Source: (Sweco AS *et al* 2011)

District Heating factor: Investment costs are multiplied by 1.5.
Source: (Bioen As and Rosenberg 2010)

Briquette Based Stand Alone Industrial Heating Facility

Facility Specifications

Max capacity heating facility	MW	2	20	60
Heat produced	MWh	4600	46000	138000
Boiler capacity		1	10	30

Investment costs

Briquette boiler	kr	4096000	35840000	92160000
Oil boiler	kr	400000	3200000	8100000
Oil boiler	kr	400000	3200000	8100000
Interest under construction	kr	125000	1080000	2756250
Total investment cost	kr	5021000	43320000	111116250

Operating expenses and fuel cost

Operating expenses	kr/year	140000	900000	2006250
Fixed costs wood chip boiler	øre/kWh	10.7	8.9	7.4
Variable cost briquette boiler (excluding briquette cost)	øre/kWh	5	4	3
Cost of oil	øre/kWh	77.1	75	74.5

Wet Wood Chip Based Stand Alone Industrial Heating Facility

Facility Specifications

Max capacity heating facility	MW	2	20	60
Heat produced	MWh	4600	46000	138000
Boiler capacity		1	10	30

Investment costs

Wood chip boiler	kr	5120000	46080000	116736000
Oil boiler	kr	400000	3200000	8100000
Oil boiler	kr	400000	3200000	8100000
Interest under construction	kr	50125	1530000	3862500
Total investment cost	kr	8955187.5	54010000	136798500

Operating expenses and fuel cost

Operating costs	kr/year	358207.5	2160400	5471940
Fixed costs wood chip boiler	øre/kWh	12.8	11	9.1
Variable cost wood chip boiler (excluding wood chip cost)	øre/kWh	5	4	3
Cost of oil	øre/kWh	77.1	75	74.5

Costs used for suboptimal investment analysis

Source: (Sweco AS et al 2011)

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