Possible reductions of greenhouse gas emissions by the use of wood fuels in Norway

Mulige reduksjoner av drivhusgassutslipp ved bruk av skogbasert bioenergi i Norge

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PREFACE

This master thesis has been written at the Norwegian University of Life Sciences, at the Department of Ecology and Natural Resource Management, in the special field of forest economics.

The work with the thesis has been of greatest interest for me. It is very motivating to work with a current issue which is high on the political agenda. Also I am happy to see which interest these topics have outside the specialist environment.

Firstly, great thanks to my tutors, Professor Dr. Agric Birger Solberg and Researcher Dr. Scient. Erik Trømborg at the Norwegian University of Life Sciences, and to Senior Analyst Dr. Scient Torjus Folsland Bolkesjø at Point Carbon. They have inspired me by motivating and interesting discussions, and they have answered all questions with great patience and given me very constructive feedback and advices.

I would also like to thank my family for many interesting discussions about policy, climate, energy and forest issues. Great thanks to my mother, Astrid Noreng Sjølie, for help with the outline of the study and always giving inspiration with scientific work. Great thanks to my father, Olav Sjølie, and my uncle, Øystein Noreng, for excellent proofreading. And *un grand merci* to Matthieu Warnier for very good help with proofreading too.

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CONTENT

SUMMARY

Norway has problems of reaching the Kyoto goal of reducing the emissions of greenhouse gases (GHG) and has in addition objectives of decreasing the use of electricity and increasing the consumption of other energy sources in space heating. As a result, bioenergy has gained attention the last years. But it is neither clear how much an increase in bioenergy use will influence the greenhouse gas account, nor how much these reductions will cost.

The study analyses firstly the avoided GHG emissions from substituting an energy unit of fossil fuel with forest – based bioenergy (wood fuel) in several heating technologies. Further, it is investigated how a policy mean may increase the use of wood fuels in a varying economic framework in Norway. By combining the results from these two analyses, the effects of the policy mean to reduce the GHG emissions in Norway are obtained. Relevant substitutions in several heating technologies and fuels are investigated. Earlier work of life cycle analyses for both wood fuels and fossil fuels are used and compared, to obtain the net effect of the substitutions. Wood fuels are assumed carbon neutral; no emissions of carbon dioxide (CO_2) from combustion of wood fuels are therefore taken into account. Emissions of other GHG from the combustion process, as methane and dinitrogen oxide, are included. The analysis is done with use of a partial, spatial equilibrium model of the Norwegian forest sector, including forest-based bioenergy, to study the economic potential of wood fuels. Use of this model makes it possible to investigate the development of bioenergy in an economic framework, included the effect of the competition of wood fibre between energy purposes and other forest industries.

One policy mean is investigated; financial support to investments in district heating installations based on wood fuels. Three policy scenarios are investigated; no subsidies and subsidies of 20 % and 50 % of the investment costs. All scenarios are run with energy (heat) prices from 400 to 800 NOK/MWh and with three different demanded rates of return; 7, 10, and 12 % p.a. The financial supports are compared both to the increased production of bioenergy and to the reduction of GHG emissions to display the efficiency of the policy mean to increase bioenergy production and to reduce GHG emissions. All results are given in a medium – term perspective.

The results show that at an energy price of 400 – 450 NOK/MWh, the annual production of bioenergy might be increased by 1 500 GWh to a cost of circa 400 000 NOK/GWh, when 20 % support is assumed. At the same energy price level, the annual bioenergy production might increase by 3 000 GWh to a cost of about 1 000 000 NOK/GWh, when 50 % support is assumed. This is a remarkable increase from today's yearly consumption of 12 000 GWh bioenergy in Norway.

The net unit effect on GHG emissions of substituting oil products in space heating is about 300 tonnes CO_2 equivalents (CO_2e)/GWh. The effect of substituting electricity is more ambiguous, that depends on the assumptions of what the electricity is produced of and the efficiency used in the production process.

If wood-based district heating installations are supported with 20 %, the national GHG emissions might be reduced with 0.45 M tonnes CO_2e, which is 25 % of the GHG emissions stemming from heating. This result might be achieved to a cost of 66 NOK/tonne CO_2e (≈ 8 € /tonne CO_2e). A 50 % subsidy level might reduce the national GHG emissions by 0.9 M tonnes CO_2e, which is 50 % of the GHG emissions from heating. The implementing cost might be 166 NOK/CO_2e (≈ 21 €/tonne CO_2e). These are lower than many other measures taken for reducing the GHG emissions. The costs for 20 % support are also lower than the forward price for CO_2 allowances in the first accordance period of the Kyoto protocol (2008 – 2012). The costs of implementing the support depend heavily on the future energy price, and the costs increase with increasing energy price. The measures are most efficient (cost-effective) at energy prices of 400 – 450 NOK/MWh. Few similar studies are carried out in this field, and the results might be of interest for the bioenergy industry and for energy policy authorities. While some of the results mostly apply to Norway, others might be of more general interest.

Key words: Wood fuels, greenhouse gases, district heating, policy means, economic analysis

SAMMENDRAG

Norge har problemer med å nå Kyotomålet om reduksjon av klimagassutslipp, og har dessuten målsetninger om å redusere bruken av elektrisitet og øke konsumet av andre energibærere til romoppvarming. Dette har ført til at bioenergi har fått økende grad av oppmerksomhet de siste årene. Men det er verken klart hvor mye en økning i bruk av bioenergi vil påvirke klimagassregnskapet, heller ikke hvor mye disse reduksjonene vil koste.

Dette studiet analyserer først virkningene på klimagassutslippene av å substituere en energienhet fossile brennstoff med skogbaserte bioenergi i ulike varmeteknologier. Videre er det undersøkt hvordan et politisk virkemiddel kan øke bruken av skogbasert bioenergi i varierende økonomisk rammeverk i Norge. Ved å kombinere resultatene fra disse to analysene oppnås effekten av virkemiddelet til å redusere utslipp av drivhusgasser i Norge. Relevante substitusjoner i ulike varmeteknologier og brennstoff er undersøkt. Tidligere arbeider av livssyklusanalyser av både skogbaserte og fossile brennstoff er brukt og sammenlignet, for å oppnå nettoeffekten av substitusjonene. Bioenergi er antatt å være karbonnøytralt, så ingen utslipp av karbondioksid (CO_2) fra forbrenningen er inkludert. Utslipp av andre drivhusgasser fra forbrenningsprosessen, som metan og dinitrogenoksid, er inkludert. Analysen er gjort ved bruk av en partiell, romlig likevektsmodell av den norske skogsektoren, inkludert skogbasert bioenergi, for å studere det økonomiske potensialet av skogbasert bioenergi. Bruk av denne modellen gjør det mulig å undersøke utviklingen av bioenergi i et økonomisk rammeverk, inkludert konkurranseeffekten av trefiber mellom energiformål og andre skogindustrier.

Et politisk virkemiddel er undersøkt, finansiell støtte til investeringer i fjernvarmeanlegg med skogbasert bioenergi. Tre politiske scenarier er undersøkt, ingen subsidier og subsidier på 20 % og 50 % av de totale investeringskostnadene. Alle scenariene er kjørt med energipriser (varmepriser) fra 40 øre/kWh til 80 øre/kWh, og med tre ulike rentekrav, 7, 10 og 12 % p.a. Den finansielle støtten er sammenlignet både med økning i bioenergiproduksjon og reduksjonen av klimagassutslipp, for å klarlegge effektiviteten av virkemiddelet til å øke energiproduksjonen og til å redusere klimagassutslipp. Alle resultater er gitt i et middels langt tidsperspektiv.

Resultatene viser at ved en energipris på 40 – 45 øre/kWh kan den årlige produksjonen av bioenergi økes med 1 500 GWh til en kostnad av cirka 400 000 kr/GWh ved 20 % støtte. Ved samme energiprisnivå kan den årlige bioenergiproduksjonen økes med 3 000 GWh til en

kostnad av omtrent 1 000 000 kr/GWh ved 50 % støtte. Dette er en betydelig økning fra dagens årlige bioenergikonsum på 12 000 GWh i Norge.

Netto enhetseffekt av å substituere oljeprodukter i varmeproduksjon er omtrent 300 tonn CO_2 – ekvivalenter (CO_2e)/GWh. Effekten av å substituere elektrisitet er mer uklar, det avhenger av antagelser om hva elektrisiteten er produsert av og hvilken virkningsgrad brukt i produksjonsprosessen.

Hvis fjernvarmeanlegg med skogbasert bioenergi støttes med 20 %, kan de nasjonale klimagassutslippene reduseres med 0,45 M tonn CO_2e, som tilsvarer 25 % av klimagassutslippene fra varmeproduksjon. Dette resultatet kan oppnås til en kostnad av 66 kr/CO_2e. 50 % støtte kan redusere de nasjonale klimagassutslippene med 0,9 M tonn CO_2e, tilsvarende 50 % av klimagassutslippene fra varmeproduksjon. Implementeringskostnadene kan være 166 kr/CO_2e. Dette er mindre enn mange andre tiltak som gjøres for å redusere drivhusgassutslippene. Kostnadene for 20 % støtte er også lavere enn forwardprisen på CO_2 – kvoter i Kyotoavtalens første periode (2008 – 2012). Implementeringskostnadene avhenger mye av fremtidige energipriser, og kostnadene øker med økende energipris. Tiltakene er mest kostnadseffektive ved energipriser på 40 – 50 øre/kWh. Få lignende studier er gjort i dette området, og resultatene kan være av interesse for bioenergiindustrien og for energipolitiske myndigheter. Mens noen av resultatene er mest relevante for Norge, kan andre være av mer generell interesse.

Nøkkelord: Skogbasert bioenergi, drivhusgasser, fjernvarme, politiske virkemidler, økonomisk analyse

1. INTRODUCTION

1.1 Background

By ratifying the Kyoto protocol, Norway has made a commitment to limit the average emissions of greenhouse gases (GHG) in the period 2008 – 2012 to 1 % above the 1990 level. In 2005, the GHG emissions had increased to 9 % over the 1990 level. Recently, the climate issue has again gained in political importance, and several measures are now being considered to reduce these emissions.

Practically the entire production of electricity in Norway is based on hydropower. During the last 15 years, electricity consumption has steadily increased, while the production capacity has remained stable. Because of cheap electricity for decades, electricity is being extensively used for space heating purposes in Norway. This fact results in high vulnerability for consumers, since the production varies and the opportunities to alternate between different energy sources often are limited. The electricity prices have doubled in a few years, and political measures to reduce the consumers' sensitivity are requested.

A white paper published in 2006, "A climate – friendly Norway" (The Norwegian Ministry of the Environment 2006), concluded that use of bioenergy may contribute to the elimination of GHG emissions from heating in the long term, by substituting fossil fuels used for heating. The government has recently increased the financial support to investments in the bioenergy sector, and will probably augment it even more in the years to come. There are two goals for increasing the use of bioenergy in heating; reduce the GHG emissions and reduce the dependence on electricity.

The Norwegian forests are accumulating; only a third of the annual increment is harvested annually. There is consequently a growing potential to use forest as a source for bioenergy purposes. Some forest-based bioenergy (wood fuels) is used for heating today, mainly in forest industries and as fire wood. Fire wood is mostly an additional heating source, and may have negative local impacts on air pollution. The potential of other bioenergy sources, as agricultural products, is only marginal. To increase the use of bioenergy, wood fuels like pellets and chips, especially in bigger installations for industry and multi-dwellings in urban areas, are of importance.

To be able to impose well-working policies to increase the use of bioenergy, knowledge about the energy market, and especially the bioenergy market, is a necessity. One aspect is the technical potential of bioenergy to reduce the GHG emissions, but the economic potential may be quite different. Consistent economic analyses are essential to investigate the market situation of bioenergy and to predict the impact of political measures. The raw material of wood fuel, fibre, is also a raw material for many other purposes, making use of an economic model advantageous.

1.2 Study objectives and report outline

Even if the attention of bioenergy has seen a remarkable increase during the last years, the knowledge about the economic potential of bioenergy to reduce the GHG emissions seems insufficient. The overall aim of this study is to increase the knowledge about environmental and economic aspects of bioenergy, and the interaction between these factors. More specifically, the objectives are to:

1: Discuss vital elements regarding the social, economic and theoretic base for analysis of these two aspects, focusing on the heating market, GHG emissions, political strategies, use and potential of bioenergy and previous research done in the field. This is done in chapter 2.

2: Make a quantitative economic scenario analysis, based on the findings in 1, of:

- How energy prices and policy measures may influence the use of forest – based bioenergy in Norway and hence the GHG emissions
- What the return of subsidies might be regarding the increased bioenergy production and reduced GHG emissions

Most work has been devoted to analyses of the objectives 2, for which the methodology applied is described in chapter 3, the results presented in chapter 4, followed by the discussion and conclusions in chapter 5.

2. SOCIAL, ECONOMIC AND THEORETIC BASE

2.1 The market for stationary energy

Norway is an energy-rich country. During the last three decades, exports of oil and natural gas have become an essential part of the economy, and contributed in 2006 with 23.1 % of the GDP (Statistics Norway 2006a). Norway is now the world's third biggest oil and gas exporter (British Petroleum 2006).

During the post World War II – period, a large power-demanding industry was developed. Parallel to this development, an intensive expansion of hydroelectric power production took place, especially between 1960 and mid 80s (NVE 2005), which makes Norway now the sixth largest hydroelectric power producer in the world (British Petroleum 2006).

2.1.1 Production and consumption of stationary energy

About 99 % of the Norwegian electricity production is hydro-based, which makes great variation in production according to the seasons and the precipitation intensity (Statistics Norway 2003). The yearly average production of hydroelectric power in Norway the last ten years is 120 TWh (NVE 2005). The total potential is about 205 TWh, of which 36.5 TWh is protected and 51 TWh is remaining (NVE 2006). Big installations are less and less politically feasible, because of the local environmental impacts, and further development of hydroelectric power has met stagnation. Both the parliament and the two last governments have stated that the period of constructions of big hydroelectric power plants is over because of "*the consideration of future generations and their possibility to enjoy nature*" (The Norwegian Ministry of Petroleum and Energy 2004, The Energy and environment committee 2005, the government's declaration (Soria-Moria declaration 2005)). Development of small hydroelectric power plants has on the other side gained attention during the last years. The potential of hydroelectric power plants smaller than 10 MW with an investment cost of less than 3 NOK/kWh is estimated to be 25 TWh (NVE 2004).

The political decision to stop further installations of big hydroelectric power plants is not the only reason for decreasing growth of electricity supply. The Norwegian electricity market was deregulated in 1991. Earlier, the entire electricity market was under governmental regulation, but the investments were too extensive compared to the increase in demand. The excess in investment, which made the return on capital very low, together with continual overflows, made the regulation's costs too high. The deregulation led to decreasing investment rate, and consequently to a lower growth in supply.

Until 10 – 15 years ago, the Norwegian electricity production usually covered the consumption with a large margin. But in six of the last ten years, Norway has been a net importer (NVE *s.a.*). The annual average electricity consumption the last ten years is 120 TWh, which is identical to the yearly average production. The electricity consumption in the period 1990 – 2004 increased in average by about 1 % or 1.2 TWh/year (NVE *s.a.*). Even if the electricity balance situation seems reassuring at the moment, the growth in consumption will soon lead to a deficit in electricity, which is one reason why the governments seeks to increase the use of other energy sources.

Norway has a partly common power market with Denmark and Sweden, and to a small extent with Finland and Russia. There are imports and exports every year, but the magnitudes of the trades vary due to the supply and demand in the respective countries. In 2004, when the imports reached a peak of 15 TWh, 73 % of that power originated in Sweden, 25 % in Denmark and 1 % in Finland and in Russia (Statistics Norway 2006b, Statbank Norway 2007). Because of capacity constraint in the grids between the countries, the trade possibilities are limited.

Half of the Swedish electricity production is nuclear-based, and almost half of the Danish is coal-based (IEA 2004). And here is one of the core problems of Norwegian electricity import. Since the Norwegian parliament stated in the 70s that no electricity production should be nuclear-based, the nuclear issue has been a "non-question" in Norway (The Norwegian Minister of Petroleum and Energy 2007), but there are some problems in importing electricity which is from a source that we do not accept ourselves. And the Danish coal production emits large quantities of GHG. The production situation in neighbouring countries is one of the reasons why the policy goal of being self-sufficient in electricity has high priority.

Norway has the highest per capita electricity consumption in the world (IEA 2002), and electricity makes up more than three fourth of the stationary energy consumption. 13 % of the consumption is covered by oil and gas, and 9 % by fire wood. District heating contributes to less than 2 % (Statbank Norway 2007). The stationary energy consumption is displayed in figure 2.1.

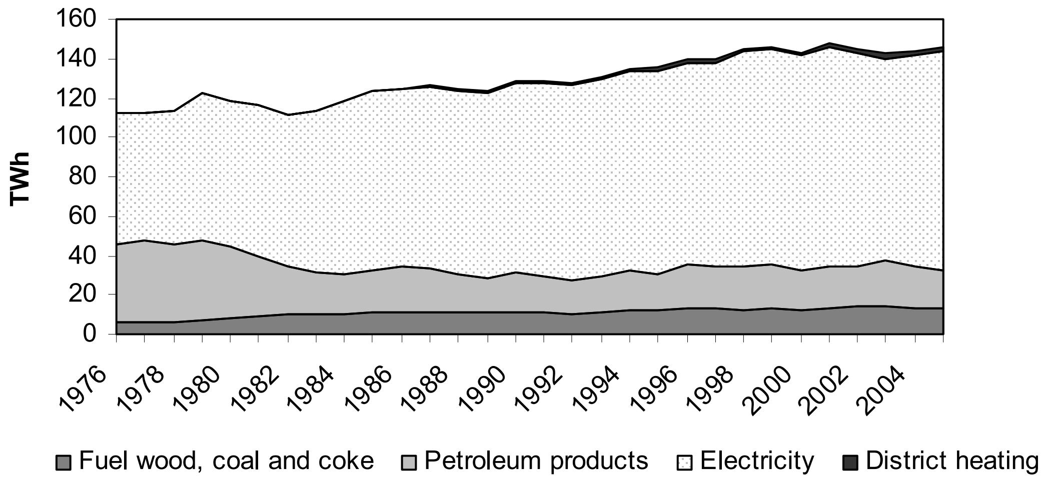


Figure 2.1: Domestic final energy consumption except use for non-energy purposes and transport. Total and by energy source. 1976-2005. TWh. (Source: Statistics Norway 2006c)

Due to historically low electricity prices, electricity is the main heating source, and often the only source, in household and in commercial buildings. According to Enova (2007a), the total Norwegian energy consumption for room and water heating and process heating was about 67.5 TWh in 2005. One half was electricity-based. The other sources were oil (25 %), biomass (18 %), gas (4 %) and district heating (4 %).

In total, 12 % of the Norwegian dwellings have water borne space heating system (either as the only system or in combination with other systems); the share is similar for newly constructed dwellings (Statistics Norway 2001). Another report (Norwegian Consumer Council 2006) states that almost all the prospects investigated have electricity as the main space heating source, and that the dependence on electricity for space heating is even higher in commercial buildings than in private dwellings. Enova states (Aftenbladet 2007) that electricity is the sole heating source in 99 % of Norwegian office buildings.

The fact that the most consumers are dependent on electricity for space heating makes them vulnerable to price shocks, as happened in December 2002 and January 2003, when the prices more than doubled in a few weeks. The prices increased also considerably during the summer and autumn of 2006 (Statistics Norway 2007a), leading to requests for political intervention to reduce consumers' vulnerability for high prices.

2.1.2 Energy prices

Since electricity dominates the heating market, the electricity price is a benchmark for comparing different heating sources' competitiveness. Electricity differs also from oil in the way that the electricity market is mainly national, while the oil market is highly global. This difference is now less clear than it used to be, because of increasing grid capacities between the Northern European countries. The electricity price is now partly decided in the international market, where it is influenced by the oil price, and as displayed in figure 2.2, the price developments for electricity and oil products see quite similar trends. But still, the electricity price is more a result of the national market situation and the national policy than what the oil price is. The supply growth of electricity may be directly limited by the government, since all bigger hydroelectric power plants (with capacity over 1 MW) need concession (NVE 2003a). Since the oil market is global, the governmental influence on this market may only be done via the demand, i.e. taxes or restrictions. The bioenergy market is mostly local or regional, and the competitiveness of bioenergy depends, in addition to costs, on electricity and oil prices. Consequently, the competitiveness of bioenergy may be influenced directly by the bioenergy policy, and indirectly via the policy on supply and demand of electricity, and via the policy on the demand of oil.

Even if the electricity prices for Norwegian households have seen a significant increase during the last years, they are still low compared to prices in many other Western European countries (Eurostat 2006, Statistics Norway 2007b). The power-intensive industry is the single sector with the highest energy consumption, with 30 % of entire domestic consumption (Statistics Norway 2007c). Since the development of the hydroelectric power and the power-intensive industry started in the 1950s, cheap electricity stated in long-term contracts for this industry has been an important policy measure to retain the industry in the country. Today, the consumers pay 2 – 3 times more for the electricity than the power – intensive industry pays (Statistics Norway 2007d). The fact that parts of the industry are favoured with cheap electricity is a reason for the priority of electric self – sufficiency, but also a reason for the high consumption.

Domestic heating oil is imposed a CO_2 – tax of 203 NOK/tonne CO_2 (The Norwegian Ministry of Finance *s.a.*), with an efficiency of 90 %, this corresponds to 0.06 NOK/kWh (SFT *s.a.*). As seen from the figures, oil is less and less used for heating purposes, and today it is unclear whether the energy price of oil is higher or lower than the electricity price.

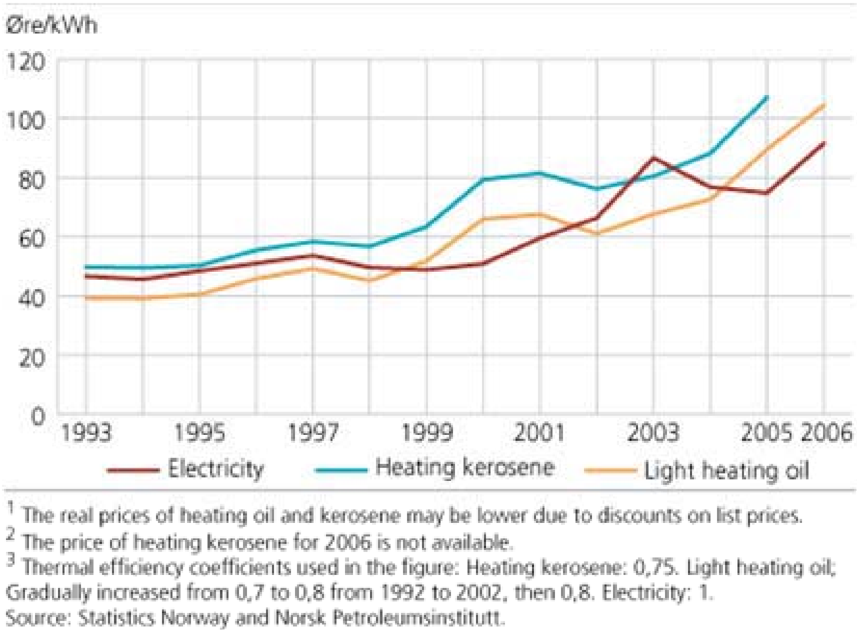
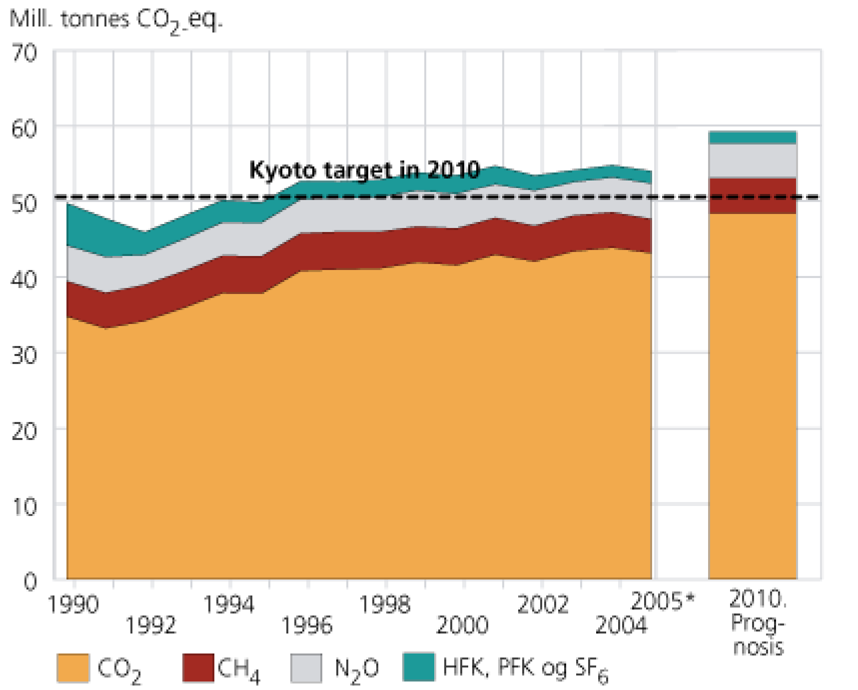


Figure 2.2: Prices for electricity to households, and list prices[1] of light heating oil and heating kerosene[2] calculated as utilized energy[3]. 1993 – 2006. All taxes included. 1 Øre/kWh = 10 NOK/MWh. (Source: Statistics Norway 2007c)

2.2 The Kyoto protocol and GHG emissions

By ratifying the Kyoto protocol, Norway has committed itself to not increase the yearly GHG emissions beyond 1 % over 1990 level in the period 2008 - 2012. Norway's assigned quantity of GHG emissions for the period is 251 M tonnes CO_2e, or 50.2 M tonnes CO_2e/year. In 2005, the GHG emissions were 9 % over the 1990 level, and summed up to 54 M tonnes CO_2e. The prognosis states the main increase will continue to stem from carbon dioxide (Statistics Norway 2007e). The historical development and further prognosis of the GHG emissions is displayed in figure 2.3.



Source: Historical data: Emission inventory from Statistics Norway and Norwegian Pollution Control Authority; Prognosis: Report No. 1 (2006-2007) to the Storting: The National Budget 2007.

Figure 2.3: GHG emissions. 1990- 2005* and prognosis 2010. Million tonnes CO2 equivalents (Source: Statistics Norway 2007e)

CO_2 is not only the most important greenhouse gas, but also the only of these gases with increasing emissions in the period from 1990. The relative increase of this gas has been 25 %, from 34.8 M tonnes in 1990 to 43.1 M tonnes in 2005. The emissions from fluorinated gases have been reduced by 72 %, while the emissions from methane (CH_4) and dinitrogen oxide (N_2O) have remained more or less stable (Statistics Norway 2007e).

The development of the different sources' contribution to the GHG emissions account is shown in figure 2.4 Manufacturing industries, oil and gas extraction and road traffic count together for almost three fourth of the total national emissions. The relative GHG emissions from oil and gas extraction have augmented by 80 % in the period 1990-2004. During this period, emissions from road transport have also increased, by 25 %. Emissions from manufacturing industries have decreased by more than 20 %. Emissions from the other sources, which are not very important in quantity, have remained quite stable during this period (Statistics Norway 2007e).

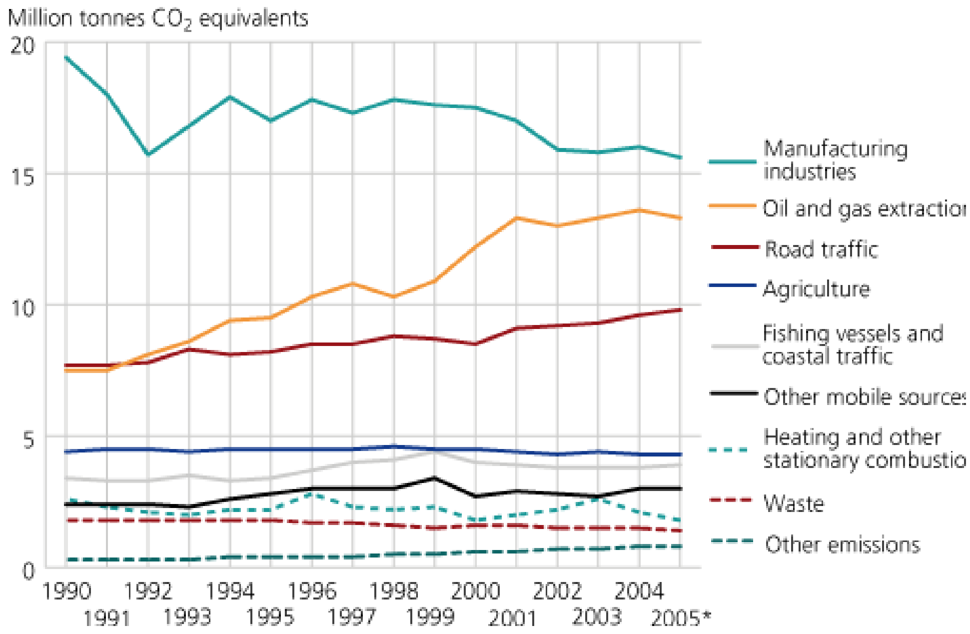


Figure 2.4: Emissions of GHG by source. 1990-2005. Million tonnes CO_2 equivalents. (Source Statistics Norway 2007e)

The emissions reported are total emitted quantities. But there are also great sequestrations taking place, which also have seen the trend increasing since 1990. One of the sectors in United Nations Framework Convention on Climate Changes (UNFCCC) reporting is Land use, land use change and forestry (LULUCF). It consists of six different land categories; grassland, cropland, settlements, forest land, wetland and other land, from which GHG changes in soil and biomass are reported. Both areas that remain in its category and areas that change category are reported. Depending on management, among other factors, these categories may be net emitters or net removers of GHG. In 2004, these categories removed totally 26 M tonnes CO_2 in Norway, or 48 % of the emissions in all other Norwegian sectors outside LULUCF. The only contributor to the sequestration was forest, for which the amount was 28.5 M tonnes CO_2. All other categories were net emitters; the biggest contributor was grassland that remained grassland with 1.9 M tonnes CO_2. The other categories had only very small amounts of emissions.

Because of the increase in forest biomass, the net Norwegian emissions have decreased over the last decade, even if the quantities emitted have seen an increase. These trends are shown in figure 2.5. In the Kyoto protocol, Norway is permitted to credit 1.5 M tonnes CO_2e/year of sequestration taking place in forest due to forest management, equivalent to about 2.7 % of the total national emissions, in the national GHG account (FCCC 2002). Norway has not made use of this opportunity (Norwegian Ministry of the Environment 2005).

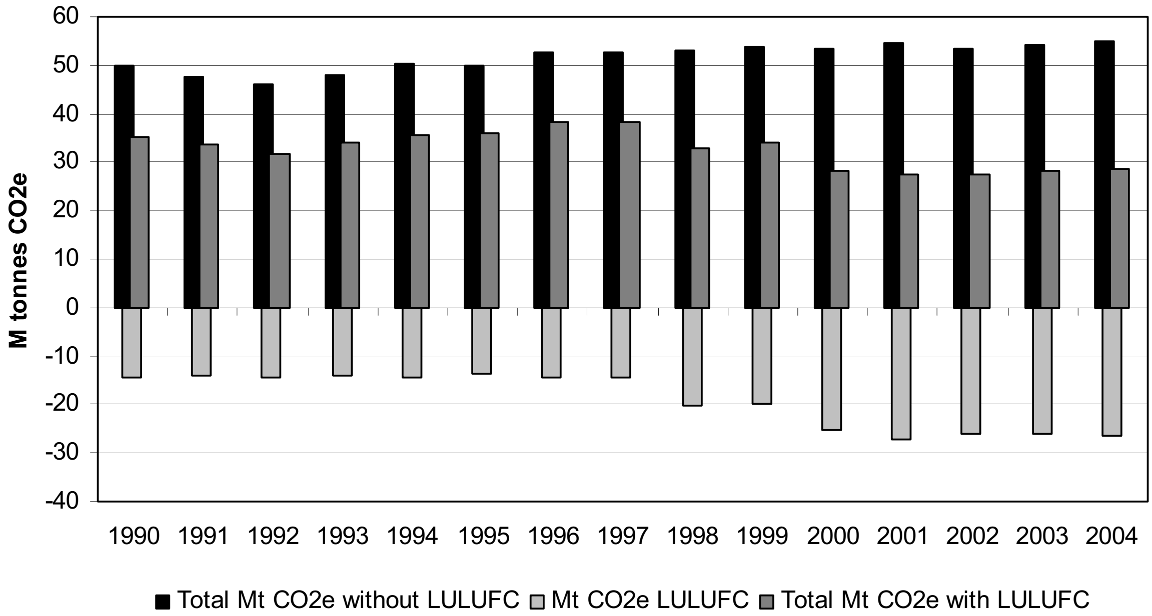


Figure 2.5: Emissions and sequestration of GHG. 1990 - 2004. Million tonnes CO_2e. (Source: SFT 2006)

The main part of the sequestration occurs in the biomass. 15 % of the amount sequestrated in biomass are removed through the forest soil and 3.5 % via change in dead organic matter. The amount sequestrated in forest soil is quite stable, while the change in organic matter may be influenced by harvesting. The main reasons for the huge increase in sequestration in biomass are forest policy of extensive planting in earlier years and a decrease of harvest recently. The annual harvest is today about one third of the growth (Statistics Norway 2006d, 2006e). Figure 2.6 shows the development of carbon stock changes in forest. Due to inventory methods, the carbon stock change is assumed to be constant over the period 1990 – 1996.

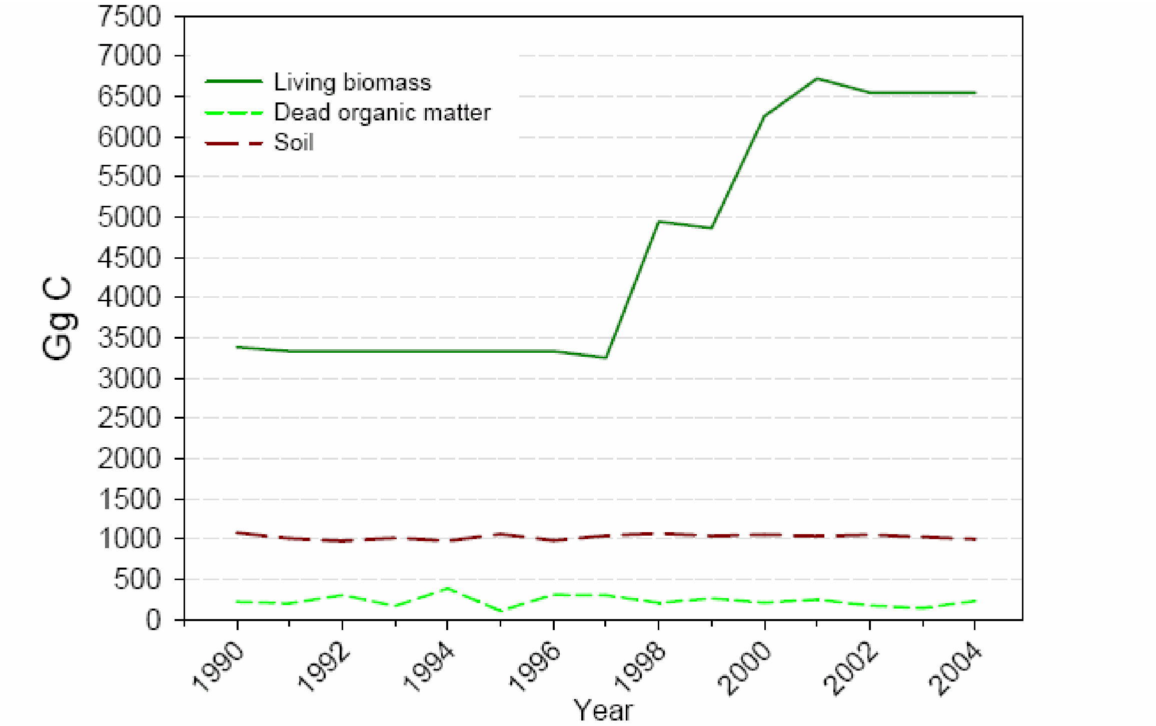


Figure 2.6: Carbon stock changes in forest living biomass, dead wood and soil organic carbon. 1990 - 2004. (Source: SFT 2006). 1 g C = 3.67 g CO_2. 1 Gg = 1000 tonnes.

Wood products are also carbon storages. But even with an extensive use of wood in house construction in Norway, the carbon storages in wood products seem very small compared to quantities stored in forests. According to the Norwegian Ministry of the Environment (2006), 11 M tonnes CO_2e are stored in tree products. This is equivalent to 0.57 % of the carbon stored in Norwegian forests. More interesting than the carbon stored is the annual changes in storage. The annual net increase of carbon in wood products corresponds to 0.5 M tonnes CO_2e, which is only 5 – 6 % of the annual harvest. This poor result is due to the fact that more than one half of the timber is used for paper purposes, and the average duration of paper is just more than one year. Demolition of old buildings and decomposition of waste also reduce the net increase.

2.3 Policy strategies

The increasing numbers of headlines on climate changes and the fact that Norway does not fulfil the Kyoto obligations on one hand, and the political difficulty and abatement costs of reducing the emissions on the other hand, do squeeze the government. In addition, there are challenges related to increasing electricity consumption and increasing electricity prices. The need of measures to decrease the GHG emissions as well as the dependence on electricity seems clear. As a result, the government has taken different measures to increase the use of renewable energy and to conserve energy. The current government's medium – term goal is 30 TWh of energy produced from renewable energy sources and economised energy in the period 2001 – 2016. In 2005, the result was 7 TWh (The Norwegian Ministry of Petroleum and Energy 2006). Christiansen (2002) states that the poor results of the governmental efforts to increase the share of renewable energy are due to weak demand-side policies, fluctuating patterns in public priorities and low electricity prices.

Enova is a state-owned enterprise, whose main purpose is to promote environmentally friendly production and consumption of energy in Norway. It is considered as one of the most important tools to increase the use of bioenergy and to promote the efficiency of energy use. The enterprise's activities are financed from a fund, made of a tax on electricity consumption. Enova's annual budget is today about 700 millions NOK. Thanks to another fund currently under establishment, approximately 1.6 billions NOK will yearly be at Enova's disposal from 2010. Two thirds of the funds are reserved for bioenergy, district heating, increasing the energy efficiency and energy economising (The Norwegian Ministry of Petroleum and Energy 2006). The parliament has stated a goal of 4 TWh water borne space heating based on renewable energy sources, heat – pumps and energy recycling by 2010 (Enova *s.a.*). The main measure for reaching this goal is investment support to heat production and heat distribution (Enova 2007b).

In October 2006, a white paper "A climate-friendly Norway" was published (The Norwegian Ministry of the Environment 2006). One of the paper's main conclusions was that it is possible for Norway to reduce the GHG emissions by two thirds by 2050. Two thirds means in this context a reduction from the reference path, the development of the emissions without any measures taken to decrease them. The emissions are in that case supposed to be almost 70 M tonnes CO_2e in 2050. The committee's suggested measures include among many others increased use of biomass for heating.

Today, the annual emissions from heating are 1.8 M tonnes CO_2e, where 0.8 M tonne stems from the households and 1 M tonne from the industry and service sector, mainly from the public sector. The white paper's authors conclude that half of the emissions from heating may be avoided in 2050 by economising the energy and the other half by changing the heating sources from oil, paraffin and gas to heat pumps and bioenergy.

2.4 Today's status of bioenergy consumption

Even if district heating is high on the agenda for increasing the use of bioenergy and studies show that some investments in district heating (in addition to bio burners and central heating systems) are profitable at actual market prices (Trømborg *et al. forthcoming*), district heating contributes only to 1 % of the total energy production in Norway, totally 2.45 TWh (2005). About two third of the consumption is in the service sector, the rest one third is divided between the industry and the households. Use of district heating does not necessarily mean use of renewable energy, since parts of district heating are based on fossil fuels, as shown in figure 2.7 (Statistics Norway 2006f). District heating is nevertheless seen as an important factor to increase the use of bioenergy in urban areas.

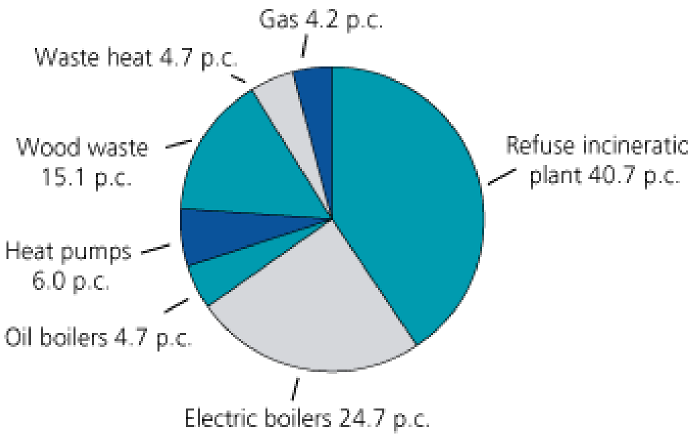


Figure 2.7: Net production of district heating by type of heat central. 2005. Per cent. (Source: Statistics Norway 2006f)

Different categories of consumers use bioenergy, and the consumption consists of varied types of bioenergy, which is displayed in table 2.1. According to the energy sources in district heating shown in figure 2.7, 15.1 % of the total district heating is taken into account here, supposing that this share is equal for all consumers.

Table 2.1: Bioenergy consumption in Norway 2005 (GWh) by type of fuel and categories of consumers (Sources: Statistics Norway 2006f, 2006g and 2007c, NOBIO *s.a.*, Energihuset *s.a.*)

BIOENERGY USE	District heating	Pellets	Fire wood	Wood, black liquor	SUM
Manufacturing industry	45			4411	4456
Service industry	248			106	354
Households	59	80	7364		7503
SUM	**352**	**80**	**7364**	**4517**	**12313**

2.5 Potentials of bioenergy production

There are several definitions of the potential of bioenergy production. It is therefore important to keep clear which kind of potential is analysed, since they differ a lot. One may say that the basic one is the *biological*, because the limits are then only set by the biological production. But these constraints are not fixed, since the biological production changes over time, with natural and human impacts. However, the other potentials are constrained by other limits in addition to the biological one, so they can never be greater than this first one. Today, only a third of the annual increment in Norwegian forests is harvested annually, which makes the stock of timber in the forests accumulate rapidly. The national growing stock has more than doubled in 70 years, and total volume is now 735 M m^3 under bark. Figure 2.8 shows the trends of annual increment and harvest the last twenty years in Norway.

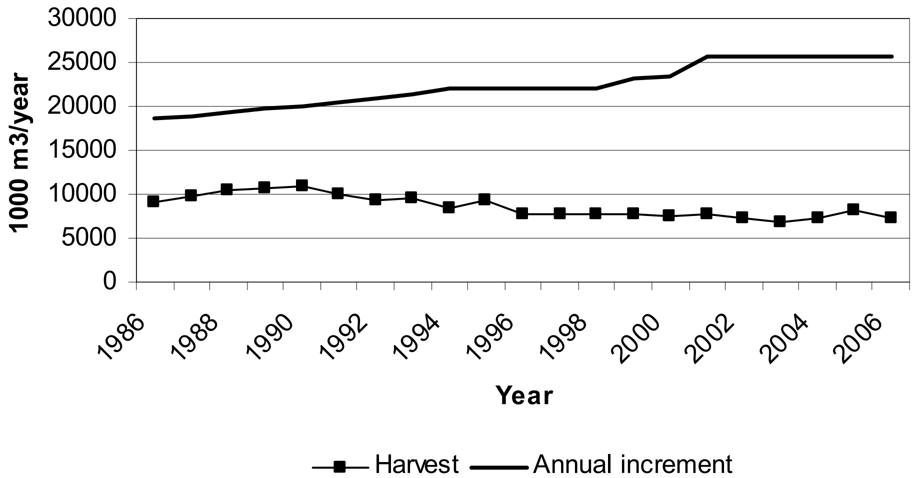


Figure 2.8: Annual harvest and increment in Norwegian forests. 1000 m^3. (Sources: Statistics Norway 2006d, 2006e)

The *technical* potential is the amount which is possible to exploit within the frames of today's technology. It is often referred to the technological potential instead of the biological one, since the former describes what really is possible to utilise. The *economic* potential is the quantity which is possible to exploit with a positive economic surplus. This potential is never bigger than the technical, and usually less, because of areas difficult accessible. The economic potential varies with the prices of the output, possible subsidies and the costs of exploiting.

In addition, there is an ecological potential, which is the possible output without harming the forest ecology. This potential's limits are vaguer than the others', since the constraints can fluctuate over time, and it is possible to have a trade-off between harvests in different areas, while taking more or less consideration to the ecology constraints. It does not fit directly into the “hierarchy” mentioned above. Huge amounts of information about biology and ecology are needed to know these constraints exactly; much of it is not known today.

In NVE (2003b), the potentials of all kinds of forest-based bioenergy in Norway are investigated and compared to the current production. The use of the term “potential” was not fully consistent in the study, and the calculated potentials are mixtures of technical, economic and ecological potentials, compounded in the term “reasonable potentials”. It is stated that with the actual, annual growth of 22 millions m^3 timber under bark, and a supposed addition of 40 % of biomass from bark, tops and branches, the biological potential adds up to about 62 TWh per year.

The report states that about 7.2 TWh of bioenergy stemming directly from forest (mostly fire wood) is used yearly in Norway. In addition, 6.9 TWh is produced in the forest industry; the main part is consumed on site.

The total potential of increased use of wood fuels stemming directly from forest is in the report estimated to be between 12.4 and 16.2 TWh/year. Hardwood and harvest waste constitute the major parts of this potential, harvest waste is hardly utilised today. Bioenergy from the forest industry has an estimated potential of increased use of 4.4 TWh.

The report evaluates the total, additional “reasonable” potential of forest-based bioenergy to be between 17 and 21 TWh/year, the difference is from uncertainties of the potential of wood fuels directly from forest. The sum of today’s use and the additional potential is then between 31 and 35 TWh from forest and forest industry, which might be seen in figure 2.9.

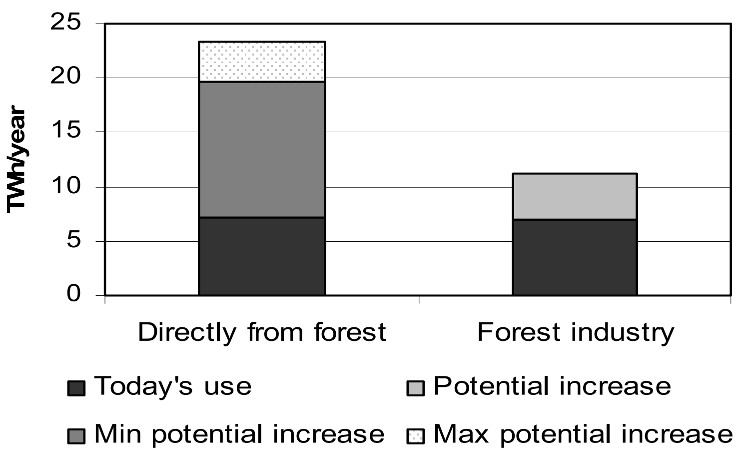


Figure 2.9: Today’s use and potential increase of forest-based bioenergy in Norway (TWh/year), according to NVE (2003b).

According to Gjølsjø (2006), the annual growth in Norwegian forests is about 36.2 million solid m^3, or approximately 72.4 TWh, included bark, tops, branches and stumps, cultural landscape and areas beside roads. The maximum volume which might be harvested without ever reducing it is about 21.1 million solid m^3 or 42.2 TWh. The annual exploitation accounts for about 23.5 TWh (11.75 million solid m^3), which makes this never – decreasing additional biological potential 18.7 TWh/year. In comparison, the biological potential of bioenergy from the agricultural sector in Norway is estimated to be about 1 TWh/year.

2.6 Previous research

Research on both economic and environmental issues related to bioenergy has been carried out, mostly in neighbouring countries, but also some in Norway. Bolkesjø *et al*. (2006) analysed the economic potential of forest-based bioenergy, as well as the interactions with other forest industries. A spatial, partial, equilibrium model for forest industry, including bioenergy from the forest sector, was used. Three energy price scenarios were investigated, one where the prices where held constant at today's level, a second where the prices increased a little (Low growth) and a third where the prices increased more (High growth). The results show that the competitiveness of some bioenergy technologies is at a breaking point and that the energy price is an important factor for the bioenergy production. The production of bioenergy in wood stoves and in forest industry, which are the only bioenergy technologies with a considerably production today, may hardly be affected by the energy price development. But with a minor increase in the energy price, the bioenergy production in district heating installations (for new buildings) and in wood – burning boilers (in existing central heating installations) may increase remarkably. The difference of bioenergy production between the Low growth and the High growth scenarios is negligible. This implies that these technologies might only need a small increase in energy price, alternatively a small decrease in the raw material price, to be competitive.

Other research regarding the effectiveness and the efficiency of policy means to increase the use of forest based bioenergy has been done. Trømborg *et al.* (*forthcoming*) investigated the effectiveness of policy means in different energy price scenarios, while Hektor (1998) analysed the cost – effectiveness of the policy measures. The first study looked at four bioenergy supporting measures; subsidies of investments in district heating installations (50 % of the investments), deposit grant for replacement of oil burners with burners based on bioenergy (50 % of the investments), a combination of these two and a feed-in system supporting energy production in district heating installations. The same model as in Bolkesjø *et al.* (2006) was applied. The results show that the bioenergy competitiveness relies highly on the energy price development. Further, the policy measures are most effective at an energy price level of 450 – 600 NOK/MWh. District heating may becomes profitable without subsidies at an energy price of 550 NOK/MWh. Above this level, the subsidies do not have a great effect, since the investments are profitable anyway. The effectiveness of the investment support is also reduced at energy prices below 450 NOK/MWh. At such a low level, the investments will not be profitable even with financial support. At an energy price of 450 NOK/MWh, a 50 % subsidy may improve the bioenergy production in district heating installation by about 80 %. The corresponding number at an energy price of 500 NOK/MWh is around 50 %.

Hektor (1998) compared the cost effectiveness of two measures to reduce the net accumulation of CO_2 in the atmosphere, sequestration in biomass and replacement of fossil fuels by bioenergy in district heating plants. To examine the effects of this last measure, the emissions from different fossil and wood fuels were compared. The fossil fuels investigated were fossil gas, light fuel oil, heavy fuel oil and coal, while the wood fuels were bark, industrial residues (saw dust, shavings and chips), logging residues, *Salix* from short rotation plantations and upgraded wood fuels (briquettes, pellets and pulverised wood). The emissions from extraction, handling, treatment and transport were added for each fuel, in addition to the emissions from the combustion of fossil fuels. All variable costs and capital costs for each fuel were calculated and compared with the unit emissions, to obtain the costs in SEK/kg CO_2, one for existing plants and one for new plants, where the investment costs are included. For all substitutes, the total costs are in the area – 0.08 (bark for coal) to 0.26 (*Salix* for gas) SEK/kg CO_2. Bark and sawdust are in general the most cost effective substitutes, while it is most profitable to eliminate coal, because of high CO_2 – emissions and very high investment costs, compared to the other fossil fuels. Heavy fuel oil also has high emissions, but is less expensive and therefore less cost effective to substitute. Without investment costs, the wood fuels are considerably more competitive. The costs of substituting, without investments, vary from – 0.24 (bark for gas) to 0.19 ("upgraded" for coal) SEK/kg CO_2. All wood fuels except "upgraded" may substitute fossil gas or light fuel oil with negative costs, i.e. with a profit. For the coal case, the substitution is less profitable when the fixed costs are not included, since these are huge for coal heating plants. When comparing these costs with the costs of tree planting, one sees that the costs of the two measures are in the same order of magnitude in a

20 years perspective, while the planting costs are higher in a longer perspective, due to increasing costs to keep the forest as a net sink.

Both the industrial and the political sides have increased their attention on the development of the heat market based on bioenergy. And it is stated that to increase the use of bioenergy in Norway, the potential is mainly to find in the forestry and forest industry sector. Studies regarding the impacts of substituting one unit of fossil fuel with forest-based bioenergy on GHG emissions have been carried out. There are also analyses showing the economic potential of bioenergy and the effectiveness of some political measures in different energy price scenarios. But there is a lack of studies which combine these two problems, and look at the quantities reduced GHG emissions in different economic frames. As far as I know, there are no such studies carried out in the field of forest-based bioenergy.

As mentioned, a Swedish analysis compares the cost effectiveness of tree plantations and increased use of bioenergy to reduce the accumulation of CO_2 in the atmosphere. But this study overestimates the effect of changing the energy fuel from fossil to wood, since GHG emissions as methane and nitrous oxide which are emitted during the burning process of bioenergy are not taken into account. There is also a lack of studies comparing the net GHG effect of replacing fossil fuels by bio fuels with the implementing costs in a policy perspective with varying economic frames. The increased energy production and the implementing costs are also interesting to compare, regarding the political goal of reducing the electricity imports and the pressure on the electricity grid. There is also a scarcity of this kind of efficiency analysis.

2.7 Problems

In my opinion, the following topics seem to be of particular interest for future research given the context discussed in the previous sections:

1. How may energy prices and policy measures influence the use of forest – based bioenergy and hence the emissions of GHG?

2. What is the return of subsidies regarding the increased bioenergy production and reduced GHG emissions?

To address the topics, it is necessary to investigate at least the following questions:

1. How may the quantities of avoided GHG emissions from substitution in heating develop in different energy price scenarios?

2. How effective are subsidies to district heating installations to increase the bioenergy production, and how does the energy price influence the effectiveness?

3. How efficient (cost-effective) are subsidies to district heating installations to increase the bioenergy production, and how does the energy price influence the efficiency?

4. How effective are subsidies to district heating installations to reduce the GHG emissions, and how does the energy price influence the effectiveness?

5. How efficient (cost-effective) are subsidies to district heating installations to reduce the GHG emissions, and how does the energy price influence the efficiency?

6. How may the rate of interest influence production in district heating installations and hence the quantities of avoided GHG emissions?

This I have tried to do in the following chapters.

3. METHODS AND MATERIALS

3.1 Main outline and assumptions

3.1.1 Outline

The analysis' objective is to clarify the effects use of a policy measure may have on the GHG emissions from space heating in Norway under different market conditions. The policy measure considered is financial support to district heating installations using wood fuels. Emissions of GHG may be reduced as a shift in the energy consumption takes place from fossil fuels to wood fuels. The energy price is one of the most important factors for the competitiveness of bioenergy, and the analysis is therefore done with several energy prices. Further, the costs of implementation are compared with the results of reductions to obtain the measure's efficiency (cost-effectiveness).

Two main factors have to be elucidated to study the environmental effect of the policy mean. The first is the effect on bioenergy production, i.e. how much the bioenergy production increase with augmenting financial support. The second is the avoided GHG emissions from substituting one unit of fossil fuel with bioenergy.

To model the changes in bioenergy production under changing policy and economic frames, a model called the Norwegian Trade Model II (NTM II), is applied. In the NTM II, the development in the Norwegian forest industry, including forest-based bioenergy, may be predicted. This modelling will cover the major parts of the bioenergy, since almost the entire production and further potential of bioenergy in Norway is forest – based.

Results from several studies of unit emissions from fossil fuels and bioenergy are applied in this analysis, as described in section 3.1.3. The net effect of substituting one unit of fossil fuels with bioenergy is the unit emissions from fossil fuels subtracted the unit emissions from the bioenergy.

The model's output, the bioenergy production in GWh, is multiplied with the unit avoided GHG emissions (CO_2equivalents/GWh) to obtain the total avoided emissions.

3.1.2 Geographical and product scope

The study's geographical scope is Norway. The analysis is delimited to the forest industry sector, including wood fuels. The bioenergy produced in the NTM II are fire wood, chips made of pulp wood and harvest waste, and pellets stemming from pulp wood, sawdust, bark and harvest waste. All wood fuels may be produced of Scots pine, Norway spruce and non-coniferous. Wood fuels may in the model be produced for use in different installations; fireplaces for wood and pellets, central heaters in single houses, multi-dwellings and commercial buildings, district heaters and forest industry. Even if all these wood fuels are included in this analysis, the emphasis is on district heating installations and the subsidies to increase the production in district heating installations based on wood fuels.

3.1.3 Assumptions of emissions, policies and scenarios

For all fuels, the unit emissions include the emissions from the product's entire life cycle, included exploitation, processing and transport, but not included construction, running and demolition of buildings and machines. Raymer (2006) analysed the unit GHG emissions per cubic metre or tonne from wood fuels, and these results are translated into unit emissions per GWh. Data of unit emissions from fossil fuels are from other studies; LCA of oil products from Statoil (1999) according to Petersen (2003), LCA of coal from Spath et al. (1999) and emissions from combustion of fossil fuels from SFT (s.a.).

The policy measure analysed is financial support to investments in district heating installations using wood fuels. Three types of district heating technologies are considered in the analysis:

A: Existing water borne heating systems based on bioenergy. No investments.

B: Existing water borne heating systems based on other sources than bioenergy. Investments for heating plant and feeding system equal 4 M NOK.

C: New buildings. Investments for heating plant and feeding system (4 M NOK) and water borne distribution system (5 M NOK) add up to 9 M NOK.

There are investment costs only in technologies B and C, and consequently only these two may receive financial support. Bioenergy production also takes place in A, independently of policies. B and C receive identical support as shares of the respective investments. The subsidies include support to both the plant and other infrastructure.

Three policy scenarios are analysed:

Basis: No investment support to district heating installations.

Alternative 1: District heating installations (B and C) are supported 20 % of the investment costs.

Alternative 2: District heating installations (B and C) are supported 50 % of the investment costs.

Since the results depend heavily on the energy price, nine energy price scenarios are run, with energy prices from 400 to 800 NOK/MWh.

All three scenarios are run with an interest rate of 7 % p.a. In addition, all scenarios are run with 10 and 12 % p.a. interest rates, to investigate how the interest influences the investment pace. 7 % in chosen as the internal rate of return in the base scenarios because it reflects the rate level used in the heat market in Norway.

20 % support to district heating installations is chosen because this is the average support level today to district heating installations (personal communication Trude Tokle, Enova).

3.2 Description of the model used

3.2.1 General description

A partial, spatial and static equilibrium model, Norwegian Trade Model II (NTM II), was applied in this study. The model describes production, consumption, trade and transport in the Norwegian forestry sector, including forest-based bioenergy.

The first model of this type, Global Trade Model (GTM), was developed in Finland in the 1980's (Kallio *et al*. 1987). Later, several models are developed from this first one, as the EFI – GTM (Kallio *et al*. 2004) and the Norwegian version, NTM. The first Norwegian model was developed in the 90s (Trømborg and Solberg 1995). In 2004, bioenergy was included in the model, the data updated to 2003 and 2003 set as the base year. Some other changes were done as well, as increasing the number of regions and the commodity groups. This newest model is the NTM II. Not all input data will be reported here, only the most important data for bioenergy production. More data, main assumptions and the mathematical specification of the model are reported in Bolkesjø (2004).

The model's purpose is to analyse the consequences for Norwegian forest industry of shifts in conditions, like increased or decreased supply or demand, or changed economic framework. The changes may either take place within the forest sector or in the economy in general. Earlier, this model has been applied for studies of interactions between bioenergy and forest product markets (Bolkesjø *et al*. 2006), consequences of increased forest conservation (Bolkesjø *et al*. 2005a) and development of future pulpwood prices (Bolkesjø *et al*. 2005b).

Recently, the NTM II was used to analyse the effect of policy means for increasing the use of bioenergy (Trømborg *et al. forthcoming*).

For a partial forest sector model, all input prices except forest and wood products are exogenous. This is opposite to a general model, where all the input prices are endogenous and determined in the model. It is by then supposed in a partial model that activities in the forest sector do not influence the prices of capital, labour, energy and others factors, neither the exchange rate. The fact that the forestry sector's contribution to the Norwegian GDP is less than 1.1 % makes this a reasonable assumption.

The model's objective function is to maximise the welfare. The welfare is defined as the producers' surplus plus the consumers' surplus minus the transport costs. This is done for each region, product and period. All actors are supposed to be profit maximizing. At the same time, there has to be equilibrium between sale and purchase of all goods. Equilibrium price and quantity for each good is determined from the optimal solution, as well as the production, trade and consumption of each product, region and period. The demand curves are linearized, while the supply curves are not. Therefore, the objective function is non-linear. All constraints are linear. Perfect competition in the sector is assumed. This might cause a problem on one side, because the Norwegian pulp and paper sector is dominated by a few actors. On the other side, Norway takes a part of an international market of roundwood, and several cointegration analyses conclude that the Nordic roundwood markets are integrated and fairly competitive (Riis 1996, Thorsen 1998, Nyrud 2002 and Størdal and Nyrud 2003, all according to Bolkesjø 2004). The fact that the model is based on economic theory also makes an advantage for the consistency of the results.

The model is static in the optimisation, but multi – periodic. The results from one year are then the initial values for the year after. In principle, the model might be run as long in the future as desired, but the scenarios are usually run until 2015 or 2020. One period in the model is one year.

The NTM consists of four main components, or partial models: Timber supply, Forest industry, included bioenergy, Products demand and Transport and trade.

3.2.2 Timber supply

Observed prices and quanta decide the base year's supply. Timber supply is positively price elastic; a higher price will consequently result in a higher supply. All elasticities are exogenous. The supply shifts with changes in the growing stock. Annual growth subtracted harvest determine the change in growing stock and the next year's initial value. The elasticities are described on a region level, for all timber products.

In total, there are six timber products in the NTM II, saw logs and pulp logs of Scots pine, Norway spruce and non-coniferous (mainly birch). Harvest waste is also a possible raw material for bioenergy, but corresponding data are not available, because the trade quanta of this product are marginal. The harvest waste supply is defined as a gradual increasing function, reflecting increasing transport costs, based on Aalde and Gotaas (1999).

The substitution possibilities for timber assortments are asymmetric, in the way that saw logs may be used for pulp, but not vice versa, and pulp logs may be used for energy, but not opposite. Saw logs will be sold to the pulp and paper industry if this industry pays more than the saw mill industry does. As a result, the saw log price has to be as high as or higher than the pulp log price, and the pulp log price as least as high as the energy log price.

The supplied commodity quantities and the respective prices in the base-year are from 2003. Product categories and transformations in the model are shown in figure 3.1.

3.2.3 Forest industry, including bioenergy

The Norwegian pulp, paper and board industries are very concentrated, so these industries are described at enterprise level. The saw mill industry is described at a regional level. This sector is divided into two groups, with an annual production of more or less than 25 000 m^3 sawn wood. The production of all forest industry products is modelled by input and output coefficients. The input coefficients for raw material, capital, labour, energy and other inputs show the necessary amounts of all factors for producing one unit of the output. Together with the respective prices, these coefficients determine the production costs. As a result of the profit maximizing assumption, all factories produce up to the level where marginal costs equal marginal revenues.

All enterprises have capacity constraints. Pulp and paper enterprises do normally produce near up to the capacity limit, while most saw mill only use one work shift. For this last group, the variable unit costs will increase with an expansion to two shifts. The investment costs corresponding to the different productions are calculated and integrated in the model. A 15 % sunk cost share of existing machinery is applied. Investments will take place as long as the profit (revenues – variable costs) covers the investment costs.

In the saw mill industry, a share of the residues from the sawn wood production is used internally for heating and drying. The surpluses of chips, dust and bark are sold as by-products. Chips may be sold to the pulp industry, or for bioenergy. Dust may supply the particle board industry or bioenergy industry. Bark may used for bioenergy, or for other purposes (as gardening or sanitary products). The prices of the by-products are endogenously determined in the model. The development of bioenergy used in the forest industry is simply modelled by the production growth in the industry. The model is therefore not applicable for modelling the development of bioenergy use in forest industry.

The bioenergy market is divided into eight segments, with varying technologies. These eight technologies cover together the heat market based on biomass. Since the energy price is exogenously given in the model, an artificial, non – existent main product had to be modelled from the bioenergy industry, while the bioenergy production had to be modelled as a by-product. The possible products for bioenergy are fire wood, chips and pellets, made of Scots pine, Norway spruce and non-coniferous. Pellets may be produced of logging residues, bark or sawdust.

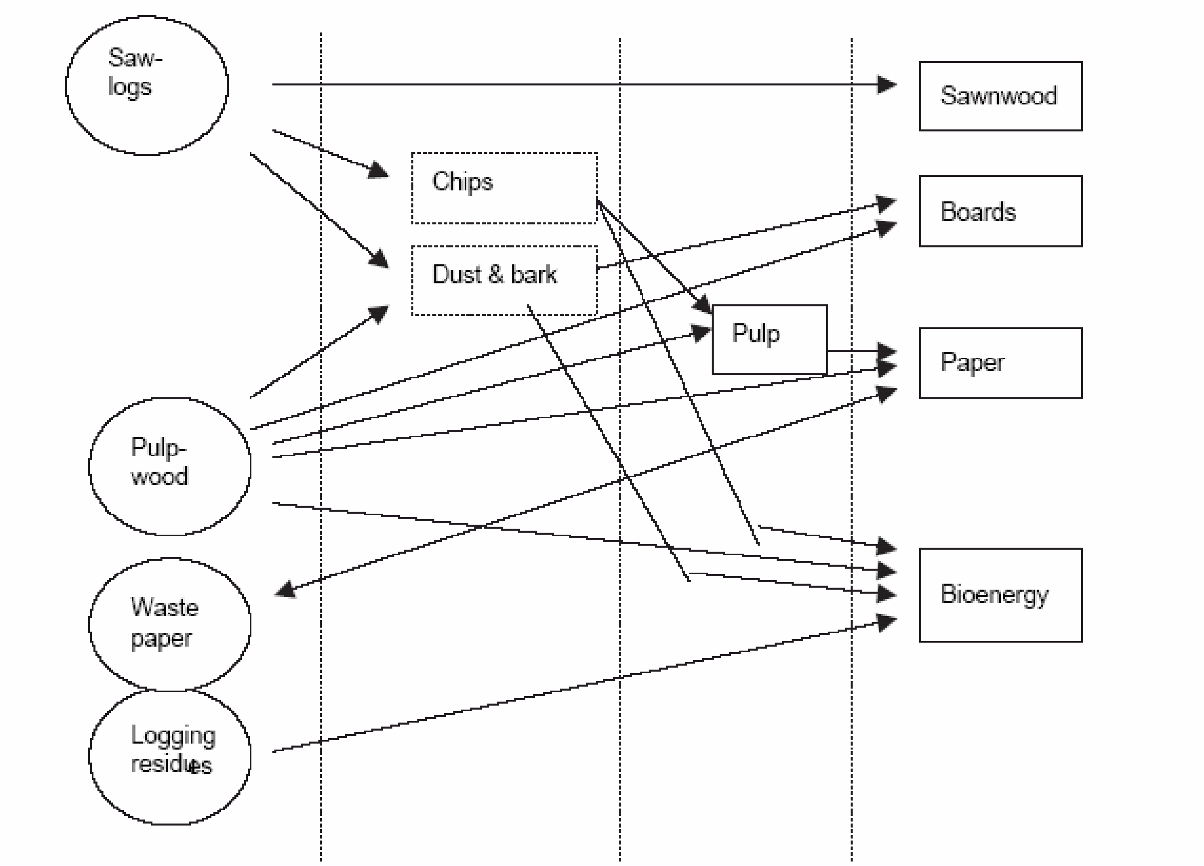


Figure 3.1: Product categories and transformations in NTM II (each product category may include several products). (From Bolkesjø 2004)

3.2.4 Product demand

Sawn wood of pine, spruce and non-coniferous, particleboard, fibreboard, different pulp and paper qualities and bioenergy in the form of fire wood, chips and pellets make up the assortment of final products. The domestic consumption is calculated as domestic production plus imports minus exports. The import and export data are from Statistics Norway. The consumption is assumed to be proportional to the population in all Norwegian regions. The consumption in "the rest of the world" is for sawn wood and board limited to the consumption in Sweden, Denmark, Germany, Belgium, Netherlands and the UK, since these countries are the most important trading partners of these products.

Like the supply functions, the demand functions are based on data from the base – year in addition to exogenous price elasticities for each product. But in this case, the curves are linearized. The price elasticity is defined for each product and is similar in all regions. The demand curves are positively elastic to the exogenously given GDP, which vary as the price elasticity does. It is also possible to make shifts in the demand as a result of changed consumption pattern, interest rate or other influential factors. Changed exchange rate may adjust the consumption in Norway versus abroad.

Since the energy prices are exogenous, the demand curve for bioenergy is horizontal (∞ elastic). The production of bioenergy in the model will therefore increase until the point where the marginal costs equal the exogenous energy price. This energy price, or the "heat price", is determined by the energy market made of electricity and oil, as well as network charges and taxes, excluded VAT.

All bioenergy technologies defined in table 3.1 has a technical potential determined by total energy consumption, structure of population and buildings, as well as heating systems and construction activity. The capacity constraints are defined for each technology and region in accordance to regional population structure, based on data from Statistics Norway. Some of these capacity constraints are based partly on ad hoc assumptions, as there are not any historic estimates for new energy sources. In addition, the pace of growth is restricted, to avoid unlikely increases from one year to another in bioenergy consumption. For other assumptions and data of bioenergy in the NTM II, see Trømborg *et al. (forthcoming).*

Table 3.1: Description of bioenergy technologies analysed. Based on Trømborg *et al.* (*forthcoming*)

Technology	Description	Fuel	Efficiency	Potential for increased production
Wood stove	Traditional wood stoves in private households.	Firewood	60%	In households with wood stoves, limited to 7000 kWh for single houses and 3000 kWh for other. Min/max increase per county set to 25%/100%
Pellets stove	Stoves in private households using wood pellets.	Pellets	90%	Replacement of ovens for kerosene in private household with potential production set to 10 000 kWh. Replacement of 90% of the kerosene consumption in service sectors. Implies investment in pellet stoves.
Wood based central heating – single houses	Bio boilers in private households with water borne heat distribution.	Wood, pellets or briquettes	80%	Replacement of oil boilers. Potential production set to 90% of the net energy production based on light fuel oil in private households and agriculture.
Wood based central heating	Bio boilers in buildings in service sectors and multi-dwelling buildings with water borne heat distribution.	Wood, pellets or briquettes	80%	Replacement of oil boilers. Potential production set to 90% of the net energy production based on light fuel oil in service sectors and multi-dwelling buildings
Wood based district heating	Water borne distribution to several buildings from a central bio boiler.	Wood chips, or forest fuel (waste)	80%	Substitution of up to 90% of the consumption of light fuel oil in service sectors and multi-dwelling buildings in urban areas. Implies investments in bio boiler and infra structure to buildings.
Bioenergy in industries	Bio boilers in industrial buildings	Wood, pellets or briquettes	80%	Replacement of oil boilers. Potential production set to 75% of the net energy production based on light fuel oil in industrial sectors.
Bioenergy in forest industries	Existing energy production for heating and drying in forest industries.	Bark and residues	80%	Closely linked to the production in the forest industries.

3.2.5 Trade and transport

Forestry is a transport intensive industry, so the spatial aspect is important. In the model, Norway is divided into 19 regions, which mainly follow the county borders. There are four exceptions; the counties Oslo and Akershus are put together to one region, Finnmark is not included in the model and Oppland and Hedmark are both divided into two regions (north and south). Sweden is one region and the "Rest of the world" also. Trade between two regions takes place if the difference in the product prices exceeds the transport costs.

Transport costs are calculated for transport within a region and between regions. Within a region, all carriage is done by lorry. The transport cost is here included in the product price, so the product price is actually the price delivered industry area (cif). The costs of transport and distribution are consequently paid by the supplier.

Between regions, lorry, train or ship may be used for transport. The cheapest alternative is chosen in every single case. The carriage costs are based on the distances between the region centres. It is therefore supposed that the commodity firstly is transported to the region centre, and from there to another region.

3.3 Avoided GHG emissions from substituting fossil fuels with wood fuels

3.3.1 Energy technologies and fuels

This analysis' objective is to link the economic and policy parts of bioenergy with the environmental part. This means to look at how the policy measure works to reduce the GHG emissions with changing economic conditions. Further, the costs of the policy measure (investment support) should be compared with the quantities of reduced emissions to clarify the efficiency of the policy mean.

A very central factor is then the quantities of avoided GHG emissions when substituting existing energy technologies and fossil fuels with bioenergy technologies and wood fuels. To obtain these results, two elements have firstly to be clarified. The first is which bioenergy technology and wood fuel might substitute which fossil energy technology and fossil fuel. The second step is to find the GHG emissions from the production process and the combustion of both the fossil and wood fuels.

Table 3.2 shows the energy technologies and wood fuels which are supposed to substitute fossil energy technologies and fossil fuels. All combinations of fossil fuels and wood fuels could in theory be investigated. But not all combinations are relevant, because of practical or economic reasons. In addition, the order of magnitude of emissions is similar for all wood fuels. To keep the number of combination at a reasonable level, only the most likely combinations are analysed.

Table 3.2: Energy technologies and fossil fuels substituted by bioenergy technologies and wood fuels in the analysis.

		Bioenergy technology and wood fuel			
		Fire wood stove	Pellet stove	Central domestic bio boiler (pellets)	District heating bio boiler (chips)
Energy technology substituted and fossil fuel	Electric wall heater	X			
	Paraffin stove		X		
	Central domestic oil boiler (domestic heating oil)			X	X

Fire wood stove is supposed to substitute electric wall heating. The electricity is firstly assumed to be produced of coal, but the case of hydro – based electricity will also be analysed. This assumption is based on the fact explained in chapter 2, that the Nordic electricity markets are partly integrated, and that the Danish electricity is in high degree coal – based. Since the marginal costs of electric power based on coal are higher than the marginal costs of hydroelectric power production, it may be supposed that the coal is the first to be substituted. But since the markets are not totally integrated because on capacity constraints in the grids, this assumption may not always be valid, and fire wood may therefore sometimes substitute hydroelectric power.

Pellets stoves are assumed to substitute paraffin stove, because they resemble in some ways. They both require a chimney and are point heaters, so it is quite easy to change a paraffin stove with a pellet stove.

Central heating in dwellings (houses and apartment buildings) is supposed to be heated by domestic heating oil (fuel oil number 1). When changing the heating system, either only the fossil fuel is changed or also the technology is replaced. If only the fuel is replaced, it might be substituted by different kinds of bioenergy, like fire wood, pellets or chips. Pellets are the only substitute considered in this analysis, since pellets probably is the wood fuel mostly used in this case. Central heating may also be replaced by district heating burning chips in densely populated areas.

District heating boilers may burn gas, oil, coal, different types of bioenergy and waste. They may also be based upon electricity, excess heat or heat pumps. But the actual quantities of fossil fuels used in these installations are very small, as described in chapter 1. The potential of change from fossil fuel to wood fuel in district heating installations lies mainly in substituting central heaters, which in the analysis are based on domestic heating oil. Bio boilers in district heating installations are in the analysis assumed to burn chips, since pellets usually are too expensive.

3.3.2 Unit GHG emissions of fossil fuels and wood fuels

Raymer (2006) executed life cycle analyses (LCA) to obtain unit GHG emissions from wood fuels. Some of her results are applied in this study. LCA give a detailed view of the emissions from the good's entire life cycle, including extraction, transport to refinery or mill, production process, transport to consumer and combustion process.

Depending on the harvest method, refinement process and transport distance and method, bioenergy emits some CO_2 and other GHG during the production process. All these emissions are included in the GHG account for bioenergy.

During the combustion process, fuels based on bioenergy emit the same amount of carbon dioxide that the plant sequesters during the growth. Consequently, bioenergy is carbon neutral in itself. In the analysis, no emissions of carbon dioxide stemming from the combustion are therefore taken into account. But during the combustion process, other GHG are emitted, as methane (CH_4) and nitrous oxide (NH_4). All emissions of these two gases are included in the analysis.

Data from Statoil of GHG emissions from exploitation, refining and transport of diesel and heating oil were applied to study the net effect of substitution in Petersen (2003). The CO_2 emissions in paraffin and domestic oil are similar to the GHG emissions stemming from processing and transport of coal. These latter data are from an American LCA report on coal production (Spath *et al.* 1999). While the emissions from the exploitation, processing and transport of coal include other GHG than CO_2, as CH_4 and N_2O, the corresponding data of paraffin and domestic oil include only the CO_2 –gas. This gas contributes to about 70 % of the emissions outside combustion from coal. The lack of data of other GHG emissions than the CO_2 in the LCA of oil products is not very important compared to the uncertainties in the modelling. Data of GHG emissions from combustion of fossil fuels are from SFT *(s.a.)*.

Three different GHG are taken into account in Raymer (2006), CO_2, methane (CH_4) and dinitrous oxide (N_2O). But making them directly comparable in the context of global warming entails use of *Global warming potential (GWP)* coefficients, since the gases' potential to heat the globe are not identical. A gas' coefficient indicate how it contributes to global warming in proportion to how the CO_2 –gas does it. The product of the gas' amount and the coefficient is reported as CO_2-equivalents (CO_2e). Which GWP coefficients should be used may be a theme of discussion, because the gases have different GWP depending on the time horizon chosen. Methane has for example very short life span (12 years), but a great GWP in these few years. A short time horizon will therefore mean a huge GWP coefficient of methane. Nitrous oxide has a medium life span, 120 years, so its GWP will increase if time horizon increases to a medium term, and decrease with a longer horizon (Miljøstatus i Norge 2007). Table 3.3 shows the GWP coefficients used in Raymer (2006), and in this study.

Table 3.3: Global warming potential (GWP) coefficients used in Raymer (2006) and in this analysis.

	CO_2	CH_4	N_2O
GWP	1	11.6	270.1

Raymer (2006) assumed in the calculations that the fire wood stems from birch or pine, and pellets and chips are made of spruce. In the NTM, the non-coniferous wood is assumed to reflect the volumes actually growing in Norway. This results in some lower density for the non-coniferous in the model, but the difference from the density of only birch is negligible (3 %). Chips and pellets might both be produced of spruce, pine and non-coniferous. The proportion of the species in the model is assumed to reflect the actual production in the saw mill industry, where spruce contributes to 76 % and pine 24 %. This density differs with 4 % from the density of pellets or chips made only of spruce, for which the calculations are done in Raymer (2006). The differences are small compared to the uncertainty in the measures. Pellets and chips of non-coniferous are like the fire wood assumed in the model to reflect the growing stock in Norway.

Table 3.4 shows the energy content in wood fuels, dependent on the base density and the moisture content. The formula

$$\text{KWh/ solid m}^3 = [(5.32 - 0.67*F\%)/(100 - F\%)]*D$$

is applied,

where F% is the moisture content and D the base density (Gjølsjø 1990).

Table 3.4: Physical properties of wood fuels

Wood fuels	Energy content kWh/tonne pellets (Hohle 2005)	Base density roundwood kg/solid m^3 (Heje/Nygaard 1997)	Moisture content	Energy content roundwood, kWh/solid m^3	Solid m^3 roundwood/ tonne pellets
Fire wood coniferous		440	35 %	2182	
Fire wood non-coniferous		489	35 %	2425	
Pellets coniferous	4800	394	8 %	2067	2.322
Pellets non-coniferous		489	8 %	2565	2.322
Chips coniferous		394	35 %	1954	
Chips non-coniferous		489	35 %	2425	

From which tree species the augmented bioenergy production comes from may vary with the production level. The results from NTM scenarios show that when the production is quite low (i.e. energy prices and subsidy level are low, rate of interest is high), the increased bioenergy production will mainly stem from the saw mill industry. This means that the increased production will in high degree be based on spruce, partly on pine and less on non-coniferous. When the bioenergy production is high (i.e. energy prices and subsidy level are high, rate of interest is low), the saw mill industry has more or less reached its capacity level of supply to bioenergy production, and a higher part has to come from other sources. With a higher production level, an increased bioenergy production will in higher degree be based on non-coniferous than if the production level is low. The model's results show that in a low production scenario, 72 – 74 % of the bioenergy will stem from coniferous. This share decreases to 67 % in a high production scenario. But this difference does only have a minor impact on the emissions from bioenergy production; the difference is 0.7 % from the lowest coniferous production level to the highest. To avoid complicating, a fixed share of 70 % coniferous and 30 % non – coniferous is assumed for all production levels.

4. RESULTS

4.1 Unit GHG emissions

As described in chapter 2, the net avoided GHG emissions are the total avoided GHG emissions from the fossil fuel substituted subtracted the total GHG emitted from the wood fuel which replaces it. In the following, the unit emissions of fossil fuels and wood fuels will be shown, and in the end, the net effect of substitution.

In table 4.1, the unit GHG emissions from LCA of fossil fuels are displayed. The efficiency of coal is in accordance with the efficiency of plants which only produce electric power.

Table 4.1: GHG emissions from combustion, exploitation, production and transport of fossil fuels. Tonnes CO_2e/GWh.

Fossil fuel	Tonnes CO_2/GWh from exploitation, production and transport (energy input)	Tonnes CO_2/GWh from combustion (energy input)	efficiency	**Total tonnes CO_2/GWh**
Coal	12	310	40 %	**805**
Paraffin	12	253	80 %	**331**
Domestic heating oil	12	273	90 %	**317**

Table 4.2 displays the unit emissions from fire wood in wood stoves, pellets burned in pellets stoves and central heaters and chips burned in district heating systems from Raymer (2006). The unit emissions for fire wood (kg CO_2e/solid m^3) are reported both for coniferous and non – coniferous. The unit emissions for pellets (kg CO_2e/tonne pellets) and chips (kg CO_2e/solid m^3) are in her analysis only reported for coniferous, the corresponding emissions are assumed equivalent for non – coniferous. To transform the unit emissions for pellets from kg CO_2e/tonne pellets to CO_2e/solid m^3 (solid m^3 roundwood supplied), the density in pellets from Hohle (2005) is applied together with the energy content in roundwood. Similar proportion between amounts of roundwood and weight of pellets (solid m^3 roundwood/tonne pellets) is assumed for pellets made of coniferous and of non – coniferous.

Table 4.2: Unit GHG emissions from wood fuels and technologies. Kg CO_2e/tonne, kg CO_2e/solid m^3. (Source: Raymer 2006)

Wood fuel	Kg CO_2e/tonne pellets from the production process and transport	Kg CO_2e/tonne pellets from combustion	Total kg CO_2e/tonne pellets	Kg CO_2e/ solid m^3 roundwood from production process and transport	Kg CO_2e/ solid m^3 roundwood from the combustion	Total kg CO_2e/solid m^3 roundwood
Fire wood coniferous in wood stove				22	39	**61**
Fire wood non-coniferous in wood stove				23	50	**73**
Pellets coniferous and non-coniferous in pellets stove	37	22	**59**	15.98	9.50	**25.48**
Pellets coniferous and non-coniferous in central heating systems	37	22	**59**	15.98	9.50	**25.48**
Chips coniferous and non-coniferous in district heating systems				14	11	**25**

In table 4.3, the unit emissions in tonnes CO_2e/GWh are displayed for each fuel and for coniferous and non – coniferous. The unit emissions in tonnes CO_2e/GWh are displayed separately for coniferous and non – coniferous, even for pellets and chips, which are assumed to have equivalent unit emissions in kg CO_2e/solid m^3. The reason is that the energy content, displayed in table 3.4, is different for coniferous and non – coniferous. To obtain the emissions per GWh utilised, following formula was applied (after Raymer 2006):

Tonnes CO_2e/GWh = (kg $CO2_e$/solid m^3)/ (MWh/solid m^3*efficiency)

For all fuels, except for fire wood, the unit emissions (tonnes CO_2e/GWh) are lower for the non – coniferous than for the coniferous, because of higher density in the non – coniferous.

As shown in table 4.2, the unit emissions per m^3 are not identical for coniferous and non – coniferous of fire wood.

Table 4.3: Unit GHG emissions from wood fuels and technologies. Tonnes CO_2e/GWh.

Wood fuel	Efficiency (NTM II)	Tonnes CO_2e/GWh from production process and transport	Tonnes CO_2e/GWh from combustion	Total tonnes CO_2e/GWh
Fire wood coniferous in wood stove	60 %	16.80	29.71	**46.52**
Fire wood non-coniferous in wood stove	60 %	15.81	34.29	**50.10**
Pellets coniferous in pellets stove	90 %	8.56	5.09	**13.66**
Pellets non-coniferous in pellets stove	90 %	6.90	4.10	**11.00**
Pellets coniferous in central heating systems	80 %	9.64	5.73	**15.36**
Pellets non-coniferous in central heating systems	80 %	7.76	4.62	**12.38**
Chips coniferous in district heating systems	80 %	8.96	7.04	**15.99**
Chips non-coniferous in district heating systems	80 %	7.22	5.67	**12.89**

As described in section 3.3.2, all wood fuels are assumed to consist of 70 % coniferous and 30 % non-coniferous. Table 4.4 displays the unit quantities of GHG emissions for the wood fuels, weighted with the shares of coniferous and non-coniferous.

Table 4.4: GHG emissions from wood fuels assumed to consist of 70 % coniferous and 30 % non-coniferous. Tonnes CO_2e/GWh.

GHG emissions wood fuels	Tonnes CO_2e/GWh
Fire wood in wood stove	47.59
Pellets in pellets stove	12.86
Pellets in central heating system	14.47
Chips in district heating system	15.06

The net effect of substitution is as explained the emissions from fossil fuels subtracted the emissions from wood fuels. Table 4.5 displays the net effect for different wood fuels and technologies which are supposed to substitute the presented fossil fuels in their technologies, i.e. the results in table 4.1 subtracted the results in table 4.4.

Table 4.5: Net effect of substitution. Tonnes CO_2e/GWh.

Wood fuel	**Substitutes**	**Fossil fuel**	**NET EFFECT OF SUBSTITUTION tonnes CO_2e/GWh**
Fire wood in wood stove	Substitutes	Coal-based electricity	**758**
Pellets in pellets stove	Substitutes	Paraffin in stove	**318**
Pellets in central heating system	Substitutes	Domestic heating oil in central heater	**302**
Chips in district heating system	Substitutes	Domestic heating oil	**301**

4.2 Total avoided GHG emissions

The results reported are only partial results, since they show the unit emissions. In the following section, the unit emissions are put together with the results from the scenarios in the NTM II to show the total net effects of the substitutions.

4.2.1 Energy prices and quantities of avoided GHG emissions

Figure 4.1 shows the projected bioenergy production for different energy prices without any subsidies. Increasing the energy price from 450 NOK/MWh to 650 almost triples the bioenergy production. Fire wood and chips in district heating installations are the most important contributors to the production.

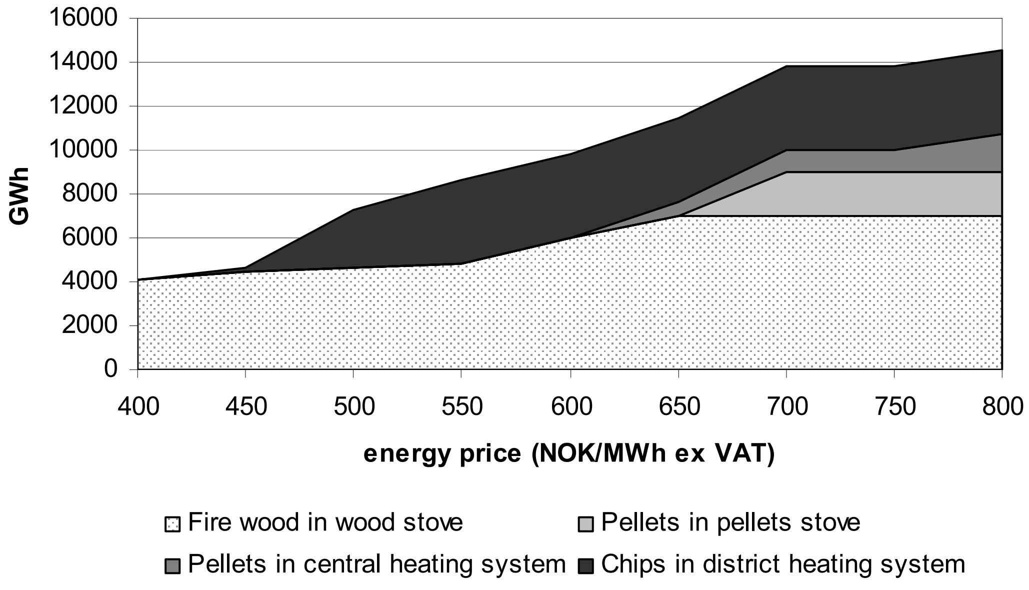


Figure 4.1: **Total projected bioenergy production (GWh) in year 2015 for different energy prices (NOK/MWh ex VAT). Rate of interest 7 % p.a. No Subsidies.**

Figure 4.2 displays the development of avoided GHG emissions according to the energy price. The avoided GHG emissions from the replacements vary from 3.1 M tonnes CO_2e at an energy price of 400 NOK/MWh to 7.6 M tonnes CO_2e at an energy price of 800 NOK/MWh. Fire wood's relative contribution of all wood fuels is greater in this picture than in figure 4.1. This is due to the assumption that fire wood substitute coal – based electricity, causing a large net effect of substitution.

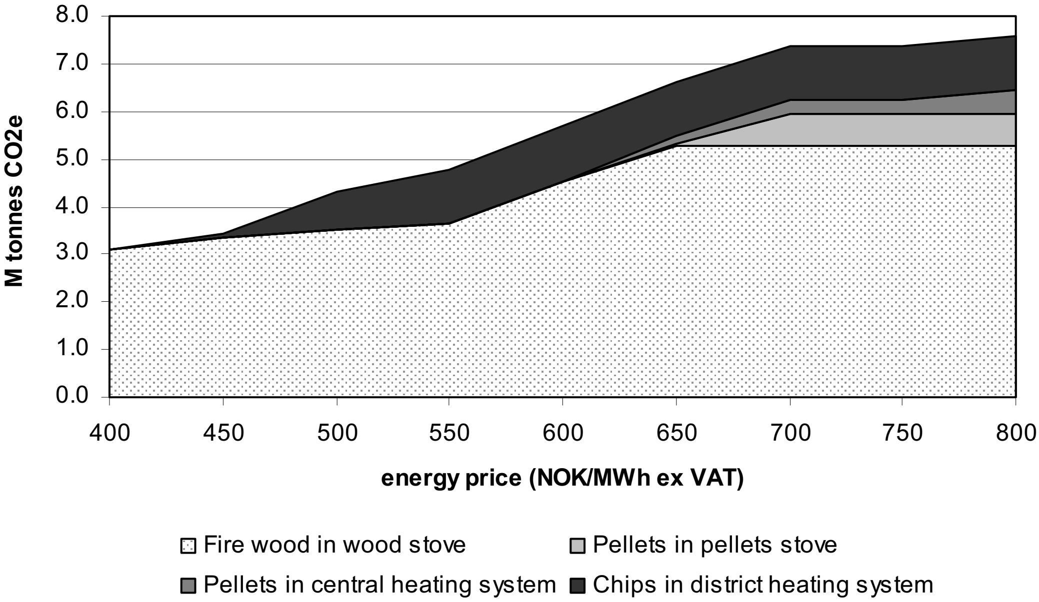


Figure 4.2: Total projected net effect of substitution (M tonnes CO_2e) in year 2015 for different energy prices (NOK/MWh ex VAT). Rate of interest 7 % p.a. No subsidies.

If the fire wood is not supposed to substitute coal – based electricity, but electricity purely based on hydropower, the count looks rather different, as shown in figure 4.3. Then there is a negative effect of substitution. The negative effect is due to the fact that there are some CO_2 emissions from harvest and transport of fire wood. In addition, other GHG emitted under combustion of wood fuel, as NH_4 and N_2O, are included, as explained in chapter 3.3.2.

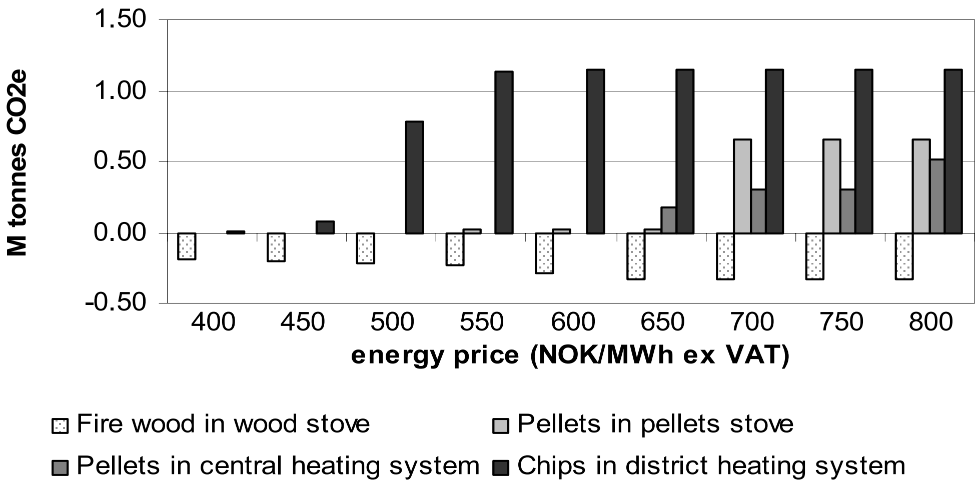


Figure 4.3: Projected quantities of avoided GHG emissions (M tonnes CO_2e) in year 2015 for different energy prices (NOK/MWh ex VAT), with the assumption that fire wood only substitutes hydroelectric power. Rate of interest 7 % p.a. No subsidies.

Figure 4.4 shows the projected avoided GHG emissions in 2015 from district heating. Without subsidies, there is only projected production in buildings with already installed water borne heating (A and B), and nothing in new buildings (C). The both technologies reach their maximum potential at an energy price of 550 NOK.

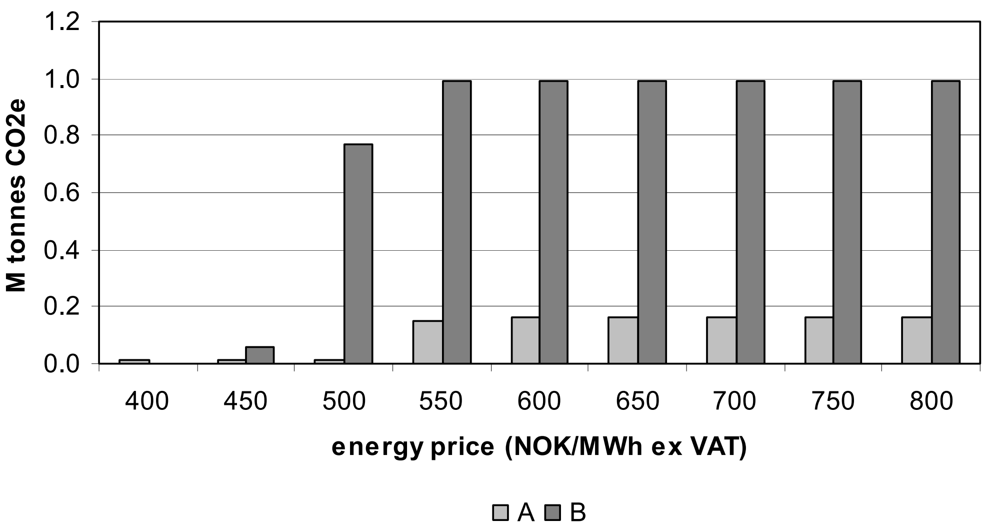


Figure 4.4: Projected quantities of avoided GHG emissions (M tonnes CO_2e) in year 2015 for varying energy prices (NOK/MWh ex VAT). A = existing buildings with water borne heating (no investments) B = existing buildings with water borne heating (change from fossil fuel to wood fuel). Rate of interest 7 % p.a. No subsidies.

4.2.2 Effectiveness of subsidies to increase bioenergy production

In figure 4.5 the projected total bioenergy production is showed, varying with the energy price and the support level for district heating installations. Above an energy price of 550

NOK/MWh, there is hardly any difference in production between different support levels, as the investments are profitable even without support (Trømborg *et al. forthcoming)*.

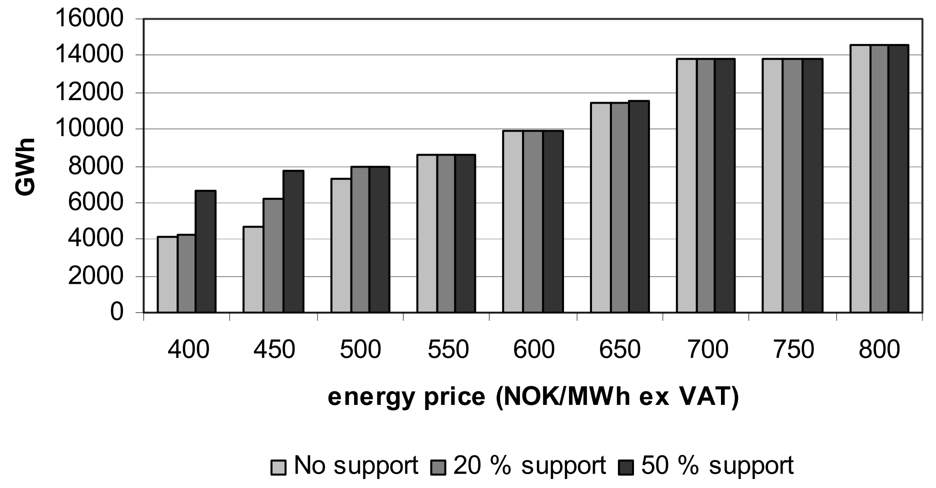


Figure 4.5: Projected total bioenergy production (GWh) in 2015 with varying energy prices (NOK/MWh ex VAT) and support level. Rate of interest 7 % p.a.

The share of the bioenergy production in figure 4.5 taking place in district heating installations is shown in figure 4.6. The production level in the 20 % support scenario is equal to the production level with no support above an energy price of 550 NOK/MWh. The reasons why not all production levels above this energy price are identical (as they are in figure 4.5) is a twist in the bioenergy production at 50 % support level and energy prices above 650 NOK/MWh, from central heating to district heating installations.

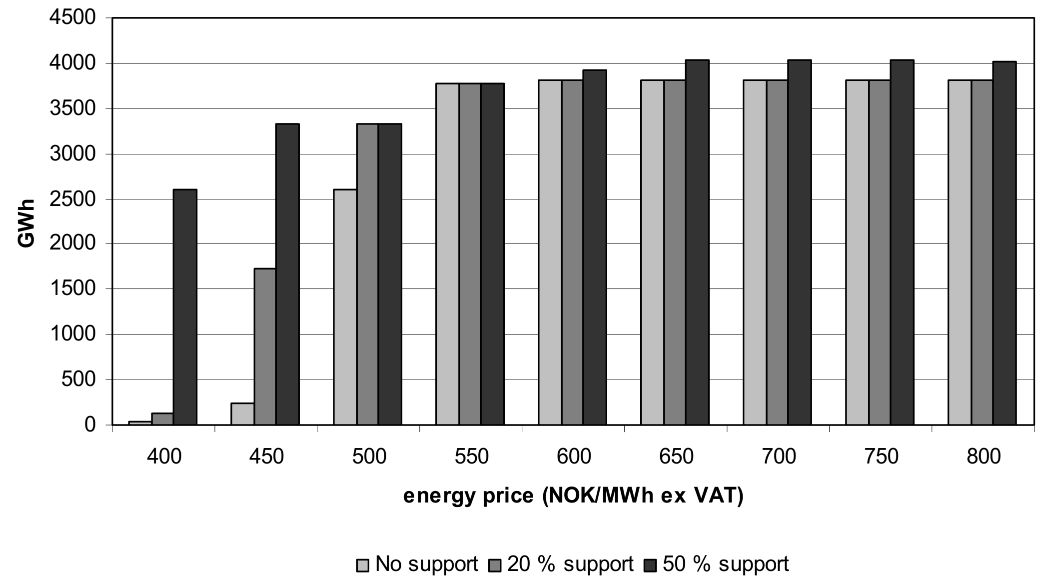


Figure 4.6: Projected bioenergy production (GWh) in year 2015 in district heating installations according to the energy price (NOK/MWh ex VAT) and support level. Rate of interest 7 % p.a.

The subsidies do not have any effect on the bioenergy production in existing buildings with water borne heating (technology B) above an energy price of 550 NOK/MWh, as shown in figure 4.7.

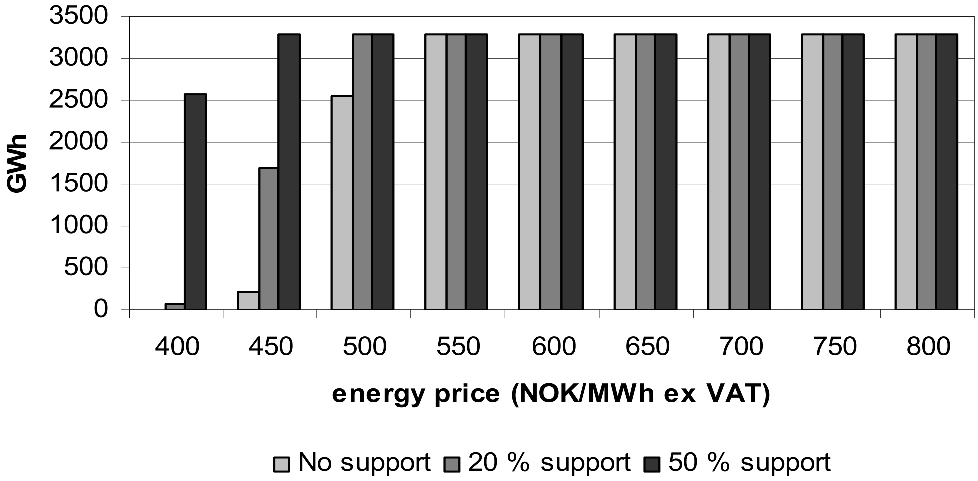


Figure 4.7: Projected bioenergy production (GWh) in year 2015 in technology B (existing buildings with water borne heating) with varying energy price (NOK/MWH ex VAT) and subsidy level. Rate of interest 7 % p.a.

Figure 4.8 shows that with no subsidies or with subsidies of 20 % of the investment, no bioenergy production will take place in new buildings. The subsidies have to be 50 % and energy price 600 NOK/MWh before any production takes place.

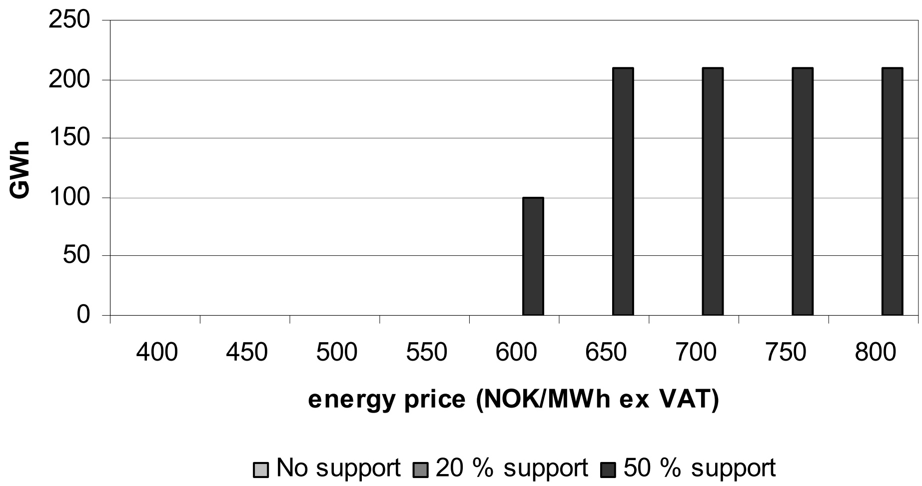


Figure 4.8: Projected bioenergy production (GWh) in year 2015 in technology C (new buildings) with varying energy price (NOK/MWh ex VAT) and subsidy level. Rate of interest 7 % p.a.

4.2.3 The efficiency of subsidies to increase the bioenergy production

Figure 4.9 shows the efficiency of the subsidies to increase the energy production, reported in NOK/GWh increased yearly production, i.e. the support to the investments paid by the society in proportion to the yearly increased quantity of bioenergy production. The support is paid once, at the construction time, and gives a return to the society every year there is a production. The support only covers the investment costs, and not the entire capital costs, so the costs of interest are not included in the calculated efficiency. The graphs are not represented on the entire energy price scale, because the production does not increase with increasing subsidies for all energy prices and for some energy prices, there is no production in this technology. There is no bioenergy production in new buildings (technology C) at a support level of 20 %.

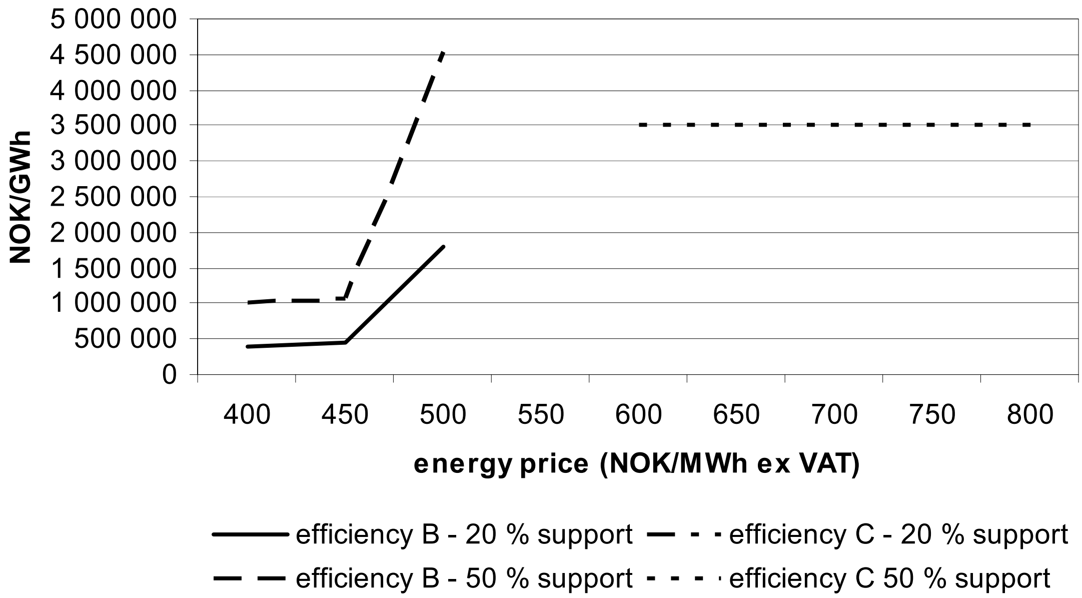


Figure 4.9: Projected efficiency of the support to increase the bioenergy production (NOK/GWh yearly increased production) with varying energy prices (NOK/MWh ex VAT) and support levels for technologies B (existing buildings with water borne heating) and C (new buildings). Rate of interest 7 % p.a.

4.2.4 The effectiveness of subsidies to reduce the GHG emissions

The development of the net effect of substitution in all technologies according to the energy price and the support level is displayed in figure 4.10. The effect of the subsidies above an energy price of 550 NOK/MWh is negligible.

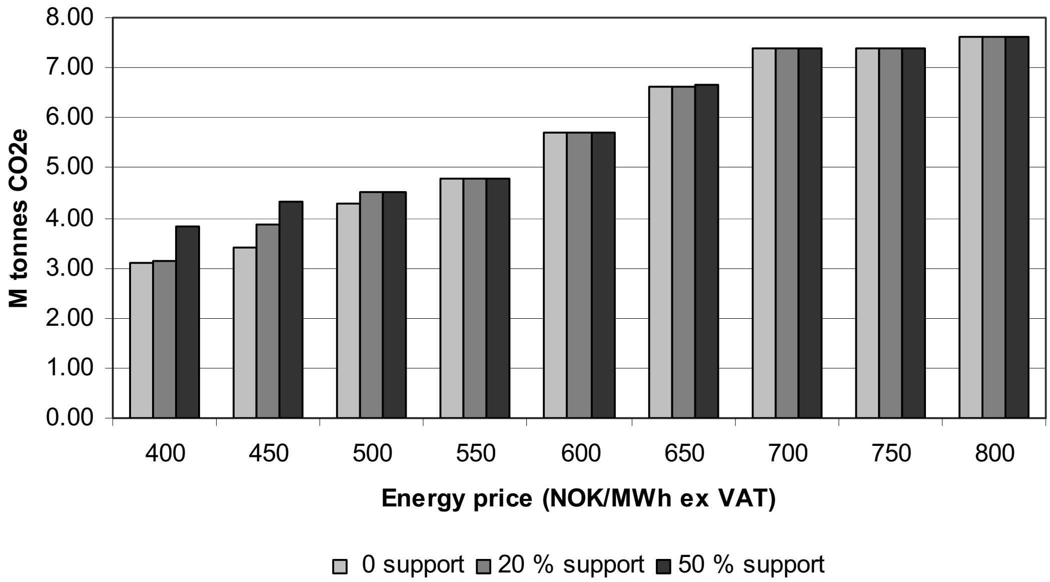


Figure 4.10: Projected net effect of substitution (M tonnes CO_2e) in year 2015 in all technologies with varying energy prices (NOK/MWh ex VAT) and support level. Rate of interest 7 % p.a.

Up to an energy price of 500 NOK/MWh, both 20 % and 50 % subsidies may contribute to the reduction of GHG emissions, stemming from district heating installations. Above this level, only 50 % subsides shows a difference from no subsidies, as seen in figure 4.11.

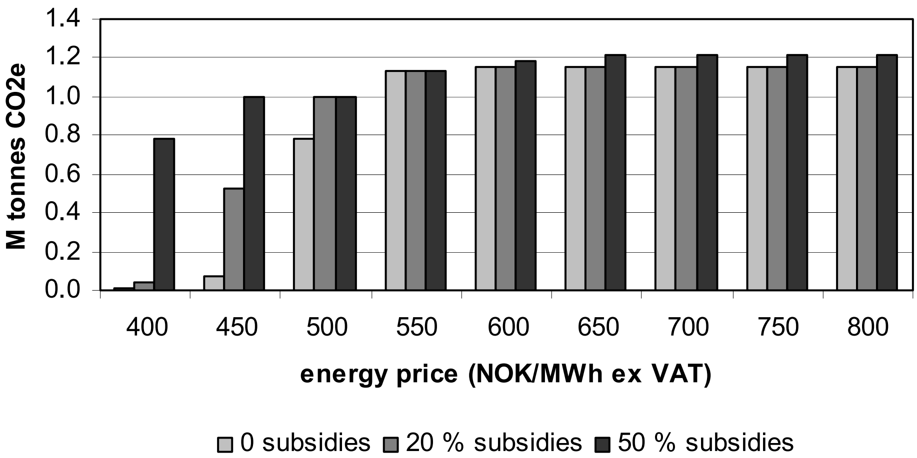


Figure 4.11: Projected net effect of substitution (M tonnes CO_2e) in year 2015 in district heating installations according to the energy price (NOK/MWh ex VAT) and the support level. Rate of interest 7 % p.a.

All increase of avoided GHG emissions in existing buildings with water borne heating (technology B) thanks to subsidies take place at energy prices below 550 NOK, as shown in figure 4.12.

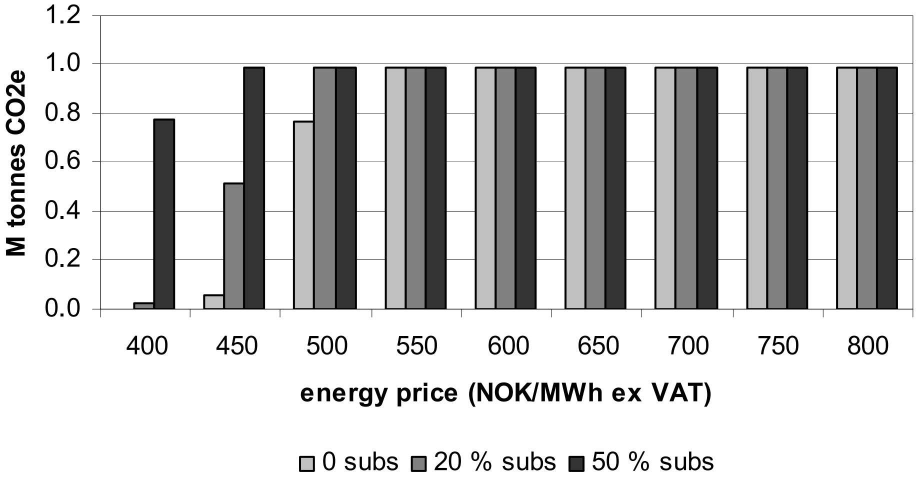


Figure 4.12: Projected net effect of substitution (M tonnes CO_2e) in year 2015 in bioenergy technology B (existing buildings with water borne heating) according to the energy price (NOK/MWh ex VAT) and support level. Rate of interest 7 % p.a.

It may be seen from figure 4.13 that in new buildings (technology C), 50 % subsidies have only an effect at energy prices above 600 NOK, and 20 % subsidies do not have any effect at all in this technology.

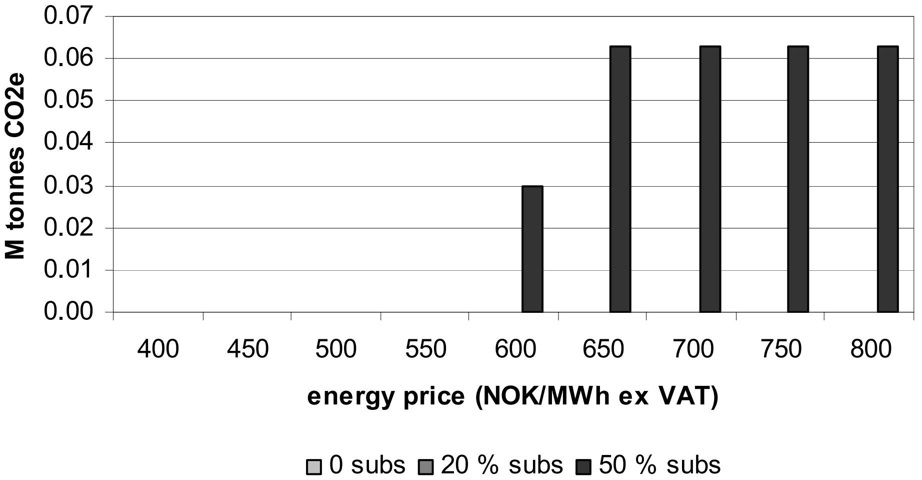


Figure 4.13: Projected net effect of substitution (M tonnes CO_2e) in year 2015 in bioenergy technology C (new buildings) according to the energy price (NOK/MWh ex VAT) and support level. Rate of interest 7 % p.a.

4.2.5 The efficiency of subsidies to reduce the GHG emissions

How efficient the subsidies are to reduce the GHG emissions varies with the energy price and the support level, as shown in figure 4.14. As for figure 4.9, the graphs are represented on only a part on the energy scale, either because of lack of production or because there is no change in production level. But unlike figure 4.9, the efficiency of the reduction of GHG emissions is reported in NOK/tonne CO_2e, i.e. the costs for every tonne reduced GHG emissions, and not as the investment costs in proportion to the return as yearly result.

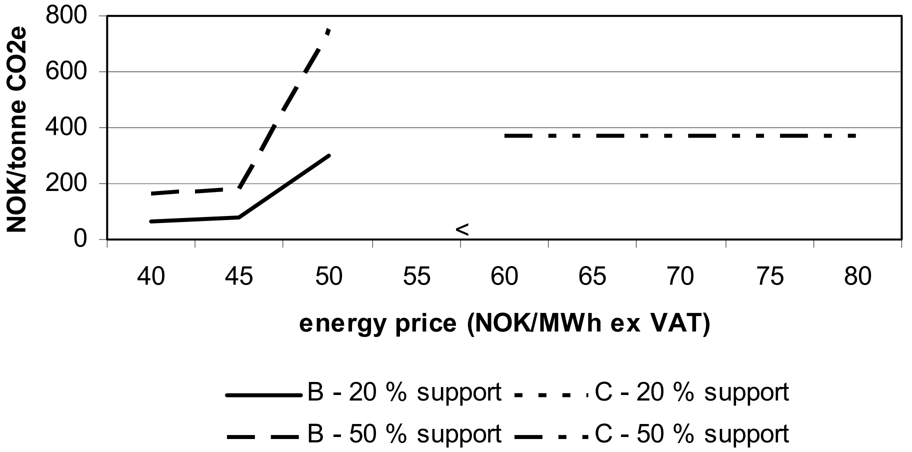


Figure 4.14: Projected efficiency of the support to reduce the GHG emissions (NOK/tonne CO2e) in year 2015 with varying energy prices (NOK/MWh ex VAT) and support levels for technologies B (existing buildings with water borne heating) and C (new buildings). Rate of interest 7 % p.a.

4.2.6 The rate of interest and quantities of avoided GHG emissions

Figures 4.15 and 4.16 show the impact the rate of interest has on the quantities of avoided GHG emissions in existing water borne heating systems where the heating plant and the feeding system are replaced (technology B). The first figure shows that when no subsidies are assumed, the production decreases with increasing rate of interest at energy prices below 600 NOK/MWh. Above this level, the interest rate does not have any effect on the investment pace.

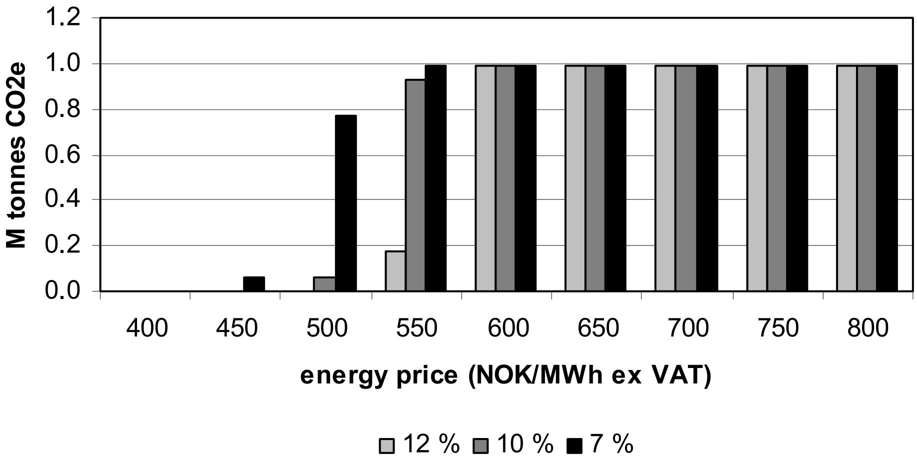


Figure 4.15: Projected net effect of substitution (M tonnes CO_2e) in year 2015 in district heating installations B (existing water borne heating systems) varying with energy price (NOK/MWh ex VAT) and rate of interest. No subsidies.

In figure 4.16 the same trend as in figure 4.15 is seen, the investments decrease with higher rate of interest. 50 % support is here assumed, which makes the effect of higher interest level disappear at an energy price of 500 NOK/MWh.

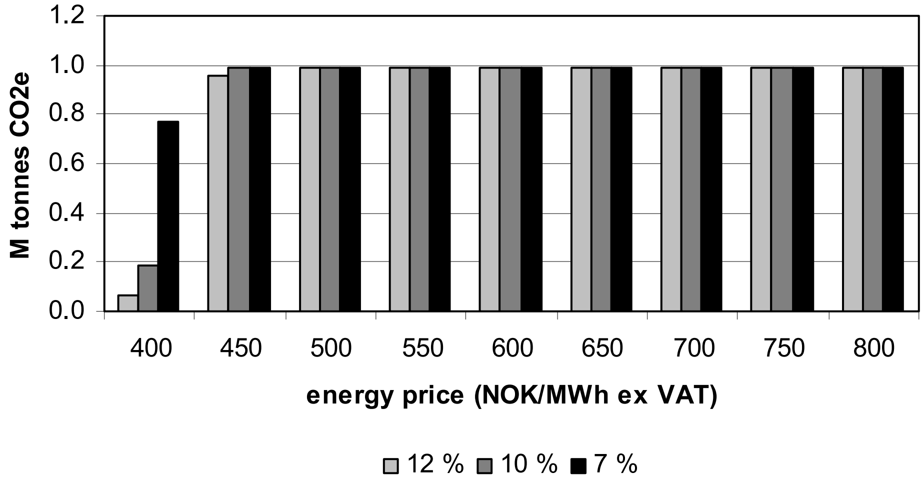


Figure 4.16: Projected net effect of substitution (M tonnes CO_2e) in year 2015 in district heating installations B (existing water borne heating systems) varying with energy price (NOK/MWh ex VAT) and rate of interest. 50 % subsidies.

Figure 4.17 shows the development of the net effect of substitution taking place in new buildings (technology C), varying with the energy price and the rate of interest, assuming 50 % support. At a rate of interest of 7 %, the production may start at an energy price of 600 NOK/MWh, while an interest rate of 12 % may delay the production until an energy price of 700 NOK/MWh.

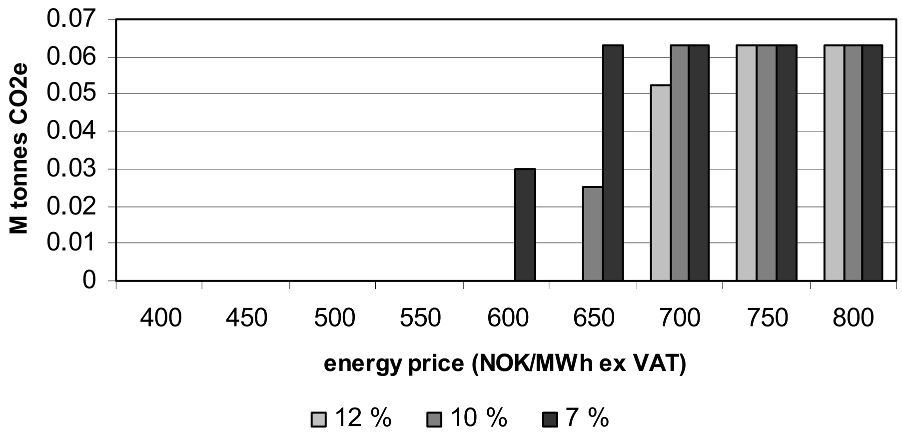


Figure 4.17: Projected net effect of substitution (M tonnes CO_2e) in year 2015 in district heating installations C (new buildings) varying with energy price (NOK/MWh ex VAT) and rate of interest. 50 % subsidies.

5. DISCUSSION

5.1 Discussion of methods and materials

5.1.1 Use of the NTM II

The NTM II is a projection model, made to compare scenarios with varying economic frames. It is most suitable to compare the differences in results rather than the absolute numbers. Consequently, the results of differences in avoided GHG emissions of different subsidy regimes are more reliable than just the projected avoided GHG emissions.

Integration of other wood products makes the model adequate to model development in the bioenergy sector. Since the main raw material for bioenergy in Norway is wood fibre, which is a raw material for other purposes as well, an integrated modelling of the entire forest industry sector is necessary to project well probable developments of the bioenergy production.

The model is built upon economic theory, so the results are consistent in this regard. But to what degree the results are directly applicable depends on the consistency between the model's assumptions and the actual conditions in the bioenergy sector.

Competitive behaviour where marginal revenue is defined by the product price is assumed in the model. With few actors, this assumption might be too strong. Capacity constraints and transport costs may also lead to imperfect competition. In addition, there are some inertia in the system which is not taken into account in the model. In the model, a replacement is supposed to take place as soon as it is economic profitable. But since it is some work to change the heating system, a minimum profit is demanded to do it. And the fact that it might be much cheaper to change the heating system while constructing or renovate a building may result in a second inertia. Even if it is profitable to change the system now, it might be more profitable to wait for renovation of the building. The uncertainty of future energy prices is also an important factor which increases the risk in investments and therefore reduces the replacement pace. People may also have preferences which make them choose differently from the economic rational choice, and these preferences are consequently not taken into consideration in the model.

The base year in the NTM II is 2003, and all numbers for production and consumption are from 2003. But since the prediction is in year 2015, the differences in production and consumption in the model's base year and the actual use today is less important as long as the economic conditions are quite similar. Since Norway has known a construction boom the last years, today's potential of district heating in new buildings is probably underestimated. The construction costs might of same reason also be a little underestimated. This lack of coincidence might continue to year 2015, but that depends on further economic development.

Today, the support level to district heating installations amounts to 20 % of the investment, the same as analysed in this study. But it is not sure that the real support level and the support level studied are directly comparable. The real support level is an average, but the support in the analysis is given to all investments of this type. But on the other side, the average cost structure of district heating installations in the analysis should reflect the real cost structure, making the study's results consistent.

The energy price is exogenously defined in the model analysis through demand functions with infinite elasticity, which makes it uninfluenced by the supply. It might be unusual that the analysed product is exogenously decided. But in this case it is probably best to keep the energy price constant. The reason is that the bioenergy market is a part of a bigger heat market. This market is dominated by electricity and oil products, while bioenergy has a market share of about 18 % (Enova 2007a). Electricity and oil are also major components in other, huge markets, as electricity and transport fuels, and pricing of these goods is very complex. Forest – based bioenergy is very little used in these other markets. If the energy price should have been endogenous, a general equilibrium model ought to be used, alternatively a partial model that include the entire energy market. For a partial model as the NTM II, it makes more sense that the energy price is exogenously defined.

The results show that when there is production in a bioenergy technology, the maximum potential is reached quite fast with higher energy price. This is especially true for district heating and pellets stove. The potentials are probably reached faster in the model than the actual development. This gap may be due to rough modelling or lack of precise data. The ceiling of bioenergy production in district heating might also be too low. The potentials of district heating installations are based on the numbers of service sector buildings and multi – dwellings in urban areas and their consumptions of domestic heating oil. 90 % of this fossil fuel is assumed replaceable. This potential is probably not very far from the actual potential of replacement. But since new housing estates are not taken into account, this potential in new buildings might be some higher. Another reason that the production maybe reaches the potential too fast might be that the cost structures modelled of the technologies do not reflect well enough how the costs change with varying conditions. This is probably more true for district heating installations than for pellets stoves, since the former are much bigger and more complex installations.

5.1.2 Calculation of unit avoided emissions

To combine the model's output with the unit avoided emissions, some assumptions about the wood and fossil fuels have to be made. Usually, each bioenergy technology may be based upon several wood fuels. But it is supposed that the each technology only burns one type of wood fuel, for example that district heating installations would only burn chips, even if pellets actually may also be used. The wood fuel assumed used in each technology is seen as the most relevant one, of economic or practical reasons. This is a simplification of the real use, but of very little consequence. Firstly, all three wood fuels which are produced in quantities are modelled. (Briquettes are not included, but it is very similar to pellets both in use and unit emissions.) So even if some of the chips use modelled in the district heating installations should have been replaced by pellets, and vice versa in central heating systems, the total quantity of chips and of pellets may be more correct than the amounts used in each system. Secondly, which is the most important reason; chips and pellets in all technologies have unit emissions in the same magnitude.

A similar simplification is done for the fossil fuels. There are many types of fossil fuels used for heating, but only a few are analysed here. And only one fossil fuel is analysed for each technology to avoid complicating. This may be done because of the small quantities consumed of many fossil fuels. Except for coal and gas, the others fossil fuels are oil products, for which the emissions are in the same size. Coal is via electricity included in the analysis, and the Norwegian consumption of gas is negligible (Statistics Norway 2007f).

But the assumption about what the electricity is produced of is important. It certainly makes a great difference if it stems from hydroelectric power or coal power. As explained in the first chapter, almost the entire Norwegian electricity production is based on hydroelectric power. But Norway is also trading electricity from Sweden and Denmark, and the Nordic electricity market is partly common. The electricity production is based on hydroelectric power and nuclear in Sweden and mainly on coal in Denmark. The marginal costs of coal power production are higher than the marginal costs in both hydroelectric power and nuclear production, so it can be reasonably assumed that if the demand for electricity decreases, the coal production is the first to be substituted. In addition, it does not matter where the GHG emissions take place, in the regard of global warming. But on the other side, a country's GHG emissions account for the UNFCCC includes only emissions that take place in the respective country, and not emissions in another country stemming from the production process for imported goods. And because of capacity limits on the grids between the countries, parts of the electricity which might be substituted by fire wood are not coal-based. It might be argued that if it is hydroelectric power which is substituted, this may again substitute coal – based electricity later. But this assumption is neither clear, again because of capacity constraints. In 2006, there were binding capacity limits between the electricity markets of Oslo and Copenhagen in 40 % of the year's hours. The constraints vary with the time on day, week, month and year, due to consumption and production factors. In 2006, the capacity constraints were least binding (i.e. the coal – based electricity is most probable to be directly replaced) during winter (November to February) and summer (June – July). If regarding the time on day, the limits were least binding during evening (8 p.m. – 11 p.m.) (Nordpool *s.a.*). Since fire wood is most probable to be used during winter and evening (this latter since the consumption take place in households), this facts indicates that fire wood actually might replace coal – based electricity to a certain extent. Nevertheless, the dynamic and the complexity in the electricity system make that the answer to which extent the substituted electricity should be assumed hydro – based and coal – based is not clear.

Given that the electricity is coal-based, the efficiency used is also of considerable importance. The Danish coal plants are usually combined heat and power plants (CHP), which may have a rather high efficiency. But the marginal production of electricity, which occurs during periods of shortages, is often pure electricity, because it might be difficult to sell the heat during these periods. Since it is the mostly the marginal production which may be substituted by more use of bioenergy in Norway, it is reasonable to use efficiency according to only electricity production. Still, analyses of this part of the electricity market are necessary to predict the exact efficiency in the replaced coal – based electricity.

LCA is a method which is now increasingly used to compare the environmental impacts of a product. It might provide useful information about the impacts from the entire value chain, but there might also be some problems in comparing different LCA. The reason is that the extension of LCA may differ from one analysis to another, and it is not always clear how far – reaching the analysis is, i.e. which impacts are included. For example, most LCA include emissions from exploitation, transport and refining, while others also include emissions stemming from construction, running and demolition of buildings and machines. In this analysis, results from a LCA of coal – based power production in the United States are applied for the coal power production in Denmark, because of shortage of LCA of coal used in Denmark. The numbers may differ a bit from the real emissions from the coal used in Denmark, but the difference is probably so small that it only has minor impacts on the results. The LCA of oil products do only include the CO_2 – gas, and not other GHG. This may result in slightly lower net effect of substitution than the real effect, but the magnitude of error is probably quite small. Another problem with the LCA is that even if the analyses' content is known, it is not sure that they really represent the actual value chains for the products, since for most products, the input factors may vary greatly. Despite uncertainties about these analyses' results, LCA is one of the best tools we have today to compare products' entire environmental footprints. And even if the details are unsure, a LCA may give a good overview about the impacts.

Despite all these different uncertainties, on should keep in mind which uncertainties are the most important ones. The fact that it is not sure which type of wood fuel may be used as substitute is not very important, since the results do not differ very much between different wood fuels. Which type of fossil fuel is substituted, if it is coal, oil products or gas, has a much greater influence on the results. And especially the origin of electricity is a decisive factor of the net effect of substitute electricity with bioenergy. Further, if the electricity is based on coal, the assumption about the plants' efficiency (i.e. if it is combined heat and power or only power plants) is also of importance for the result of the substitution's net effect.

Another aspect is the quantities of GHG that would be emitted if the wood had undergone decomposition instead of being burned. In a long perspective, wood fuels might be assumed to be carbon neutral, since the CO_2 emitted by the wood fuel during combustion would anyway have been emitted in some time (in contrast to fossil fuels), and when a tree is harvested, another tree may take its place and start sequester. But the quantities of other GHG emitted during decomposition, as CH_4 and N_2O, might be more debatable. The amounts emitted of these gases depend on the natural conditions during the decomposition. In this analysis, all emissions of CH_4 and N_2O from combustion are counted. This might be an overestimation, if wood which undergo decomposition usually emit some amounts of these gases. I have not found any studies investigating these emissions from decomposition.

The emissions of oil calculated in the LCA used here (Raymer 2006) are in same magnitude as what Hektor (1998) found, 318 tonnes CO_2/GWh. The unit emissions for coal found in Hektor (1998), 489 tonnes CO_2/GWh, are much lower than the equivalent emissions found by

Raymer (2006), indicating that the former assumed a higher efficiency. The results in his analysis of the LCA emissions of wood fuels, combustion not included, are less than in Raymer (2006), 2 and 4 tonnes CO_2/GWh for respectively sawdust and pellets. A Finnish study of GHG emissions from the entire life cycle of harvest chip production (Wihersaari 2005), found that the total emissions from harvest, chipping and transport were between 4.3 and 7.5 tonnes CO_2e/GWh, while the emissions of other GHG than CO_2 from the combustion process are maximum 2 tonnes CO_2e/GWh. The emissions from combustion showed in the Finnish study to be less than in Raymer (2006), but the plant investigated was a combined heat and power plant, which may have a higher efficiency.

The net effect of substitution is in accordance with the number in a Finnish study (Korpilahti 1998), where the net effect of substitute oil with wood fuel from logging residues is estimated to be 294 kg CO_2/MWh. The same effect for coal was estimated to 331 kg CO_2/MWh, implying that a rather high efficiency for the coal production is assumed.

5.2 Discussion of results of total avoided GHG emissions

5.2.1 Energy prices and quantities of avoided GHG emissions

In figure 4.2 it is seen that fire wood is the major wood fuel to decrease the GHG emissions from heating. At low energy prices, it is nearly the only wood fuel with significant production. Pellets in pellets stoves enter the market at an energy price of 650 NOK/MWh, and reaches soon its potential. District heating has a minor production up to 450 NOK/MWh. After, the production increases up to 550 NOK/MWh, where it reaches its economic potential to reduce the GHG emissions. The quantities of all wood fuels, and consequently the avoided quantities of GHG emissions, do heavily depend upon the energy price. Without any governmental intervention, a doubled energy price may increase the GHG effect of substitution by 150 %.

The main part of the avoided GHG emissions stems from fire wood, which is assumed to substitute coal-based electricity. But if the electricity is assumed hydro-based, the count looks rather different. Then there is a negative net effect of substitution, since the hydropower is free for emissions (at least if not construction is considered), and the fire wood is not. As discussed in section 5.1.2, it is not clear whether the electricity substituted always might be considered to be coal – based because of trading limits between the Nordic countries. To be able to make a certain answer on this question, modelling of the Nordic energy market has to be done. A modelling would probably show that the electricity substituted is partly coal – based and partly based on hydroelectric power.

5.2.2 Effectiveness of subsidies to increase bioenergy production

The production development of wood fuels in district heating installations, shown in figure 4.6, sees two trends with increased energy price and support level. The first is the rapid augmentation thanks to subsidies until a level of 500 - 550 NOK/MWh. At an energy price of 450 NOK/MWh, a support level of 20 % might increase the yearly bioenergy production by 1 500 GWh, while a 50 % increase might cause an increased yearly production of 3 000 GWh. After, there is a small increase from 600 NOK/MWh. The first increase of production takes place in existing buildings with water borne heating (figure 4.7), while the second is in new buildings (figure 4.8). This latter need not only high energy prices, but also high support level, to become profitable. The total bioenergy production does not increase with higher support level from 550 NOK/MWh, which is in accordance with the results in Trømborg *et al.* (*forthcoming*). This is due to the fact that district heating and central heating may be competitors in urban areas.

5.2.3 The efficiency of subsidies to augment bioenergy production

At energy prices of 400 and 450 NOK/MWh, the subsidies start to have an effect. At this level, their efficiency is similar to the given support per GWh. 20 % support costs about 400 000 NOK/GWh yearly increased production, while 50 % support costs circa 1 000 000 NOK/GWh yearly increased production. The costs of support occur only once, while the increased production takes place every year during the installation's lifetime. When the efficiency is equivalent to the given support, all support is used for increasing the bioenergy production, and the social economic loss from the subsidies is minimized. But with increasing energy price, the subsidies become less efficient, as seen in figure 4.9. This is due to the fact that with increasing energy price, the production would increase anyway. Even if the subsidies make the production increase more, some of the production is also profitable without subsidies. But profitable or not, they all receive the same support. The more the energy price increase, the more subsidies have to be paid out. But at the same time, the additional bioenergy production is decreasing. Mathematically, the efficiency (NOK/GWh) goes toward infinite, as the increased production thanks to subsidies approaches 0. Subsidies for new buildings (technology C) do not meet this problem, since without subsidies there is no production at all.

5.2.4 The effectiveness of subsidies to reduce the GHG emissions

Equivalent to the results of bioenergy production, the subsidies do not have any effect to reduce the GHG emissions from all technologies above an energy price of 550 NOK/MWh, as shown in figure 4.10. The avoided emissions from district heating increase, but since the subsidies at this level cause a twist in the use of bioenergy from central heating to district heating installations, the increased effect is zero. The subsidies are maximum effective at an energy price of 450 NOK/MWh. At this level, a 20 % support might reduce the national GHG emissions by 0.45 M tonnes CO_2e, while a 50 % support might reduce the emissions by 0.93 M tonnes CO_2e. In comparison, the national emitted quantities of GHG were in 2004 about 55 M tonnes CO_2e. 20 % subsidies may reduce the national GHG emissions by almost 1 %, while 50 % subsidies cause a reduction of almost 2 %. About 1.8 M tonnes CO_2e of the national GHG emissions stem from heating and other stationary combustion. This means that the most ambitious subsidy policy may reduce the emissions from heating with 50 %. With a support level of 20 %, the emissions may be reduced with 25 %.

5.2.5 The efficiency of subsidies to reduce the GHG emissions

The development of the subsidies' efficiency to reduce the GHG, shown in figure 4.14, sees the same trend as the efficiency of bioenergy production. This is due to the same fact; with higher energy price, the support will also be given to projects which are profitable also without subsidies, making the efficiency decrease.

The results are in the same magnitude as the results of cost-effectiveness of substitution in district heating installations (Hektor 1998). The numbers are not directly comparable, because the domestic heating oil supposed substituted by the wood fuel (based on sawdust) also is in district heating installations. Included investments, the replacement costs in that analysis were calculated to circa 44 NOK/tonne CO_2. The main reason for lower replacements costs in that article than in this one is higher oil price.

The price for GHG, often expressed as the price for the CO_2, occurs in many sectors, as the CO_2 – tax for industry and consumption, the allowance price of CO_2, or the costs in R&D projects to reduce the emissions. Even if it is only the allowance which is tradable, all prices are the same good and might therefore be compared. According to environmental economics, all these emissions should be priced equivalently to minimize the costs (Perman *et al.* 2003). This is not the case, but the costs of reducing the GHG emissions by support investments in district heating might be compared to all these prices.

The most cost-effective subsidy analysed is 20 % support for existing buildings with already water borne heating. The price is in this case shown to be 66 NOK/tonne CO_2e, or about 8 € /tonne CO_2e. 50 % subsidies reduce the efficiency much, and the price increases to 166 NOK/tonne CO_2e (approximately 21 €/tonne CO_2).

Since the crash of the European market of CO_2 allowances in May 2006, the forward price for the first Kyoto agreement' s obligation period (2008 – 2012) provides better information about the evaluated value of CO_2 than the spot price. The forward price of CO_2 allowances for 2008 is about 17 € or circa 137 NOK/tonne CO_2 (Nordpool 2007). The Norwegian CO_2 – tax of gasoline is 345 NOK/tonne CO_2, while the industry of oil and gas exploitation pays between 255 and 342 NOK/tonne CO_2 (The Norwegian Ministry of Finance *s.a.*). The Norwegian government's project of capture of CO_2 from a gas heat and power plant at Mongstad, Norway, will probably have abatement costs of more than 500 NOK/tonne CO_2 (Norwegian Minister of Petroleum and Energy 2007). In accordance with environmental economics theory, the means for reducing the emissions should at first be imposed where the abatement costs are the lowest for maximizing the cost-effectiveness (Perman *et al.* 2003). Subsidies of 20 % to investments in district heating installation where the infrastructure already exists might therefore be a better way to reduce the GHG emissions than all these other means mentioned.

5.2.6 The rate of interest and quantities of avoided GHG emissions

A higher rate of interest demand higher energy price (all other factors constant) before the project will be realized. But how big the shifts are, depend on the support level. With 50 % support, only the production level in existing buildings at 400 NOK/MWh is reduced, together with a tiny reduction at an energy price of 450 NOK/MWh, shown in figure 4.16. If the support is decreased to 20 %, the energy price has to reach 550 NOK/MWh before the production levels are identical for higher rates of interest than 7 %. With no subsidies, the production levels for 10 and 12 % rates of interest catch up the 7 % - production level at 600 NOK/MWh. Increasing support decreases the effect of reduced production due to higher rates of interest. This effect is due to the fact that more support results in less investment costs, which are not that hard to make profitable even with a higher rate of interest.

5.3 General discussion

5.3.1 Economic aspects

Even if Enova's average subsidy level is 20 % to district heating installations, only projects which are dependent on financial support to be started up are entitled subsidies (Enova *s.a.*). If this condition is met, the problem with decreasing efficiency with higher energy price will disappear.

But use of subsidies creates (at least) two problems. The first is that all use of subsidies and taxes reduce the economic well-fare, because they change the price and volumes from the optimal levels. Even if the subsidies make the surpluses increase for both producers and consumers, the sum of their increased surpluses are less than the subsidies paid. Energy is probably a quite inelastic good, making the demand increase only a little with lower prices, and causes consequently rather small economic losses. Financial support to bioenergy provokes also a dilemma with the policy goal to reduce the energy consumption. Subsidies result in lower prices, and thereby increase the demand. Taxes on fossil energy sources may twist the consumption to bioenergy, but support to bioenergy may both cause a twist in consumption from fossil fuels as well as an additional increase in demand.

Another problem caused by taxes and subsidies is transaction costs. Both taxes and subsidies normally produce some transaction costs, but their sizes depend on how they are shaped, and on institutional frames. It is beyond the scope of this study to analyse the transaction costs related to subsidies to district heating installations, but it might nevertheless be an important factor, and cause big economic losses.

According to the study's results, district heating becomes profitable without subsidies at an energy price of 450 – 550 NOK/MWh. If the energy is electricity, this price is a sum of the electricity price, network charge and taxes. In 2006, this total electricity price was in average 750 NOK/MWh (Statistics Norway 2007b). The heat prices of district heating in Oslo were in 2006 600 NOK/MWh for multi – dwellings and 600 – 800 NOK/MWh for industrial buildings (Viken Fjernvarme *s.a.*) This implies that district heating should be competitive today, even without financial support. It is true that much district heating has been developed the last years, but many projects are dependent on subsidies. There might be several reasons for this lack of coincidence. Bioenergy in district heating may be less competitive than thought, either because of higher raw material prices or higher construction or operation costs than modelled. Or modification and installation of district heating plants and infrastructure may take such a long time that the results are not to be shown yet. Another aspect which might cause inertia in the investments is expectance that the support level will increase more in the years to come. The expectance of future energy prices might be at least as important for the decision of investment as the current price level. Even if the prices are high enough for profitable investments at the moment, investments might not be profitable if the prices decrease in future. When developing infrastructure for district heating, the constructions have to be build in a large scale and for many consumers to be profitable. This might be a challenge, and cause another inertia of the development.

5.3.2 Other environmental aspects than the GHG emissions

An environmental aspect which is not handled here is local pollution caused by fossil and wood fuels. Even if substitution of coal-based electricity with fire wood is a good measure to handle the global climate challenges, the local impacts are more ambiguous. There are two main components of local air pollution from fuel combustion, nitrogen oxides (NO_X) and suspended dust. The major emissions of NO_X stem from combustion of fossil fuels, but combustion of fire wood might be the main source of suspended dust locally (Soma Miljøkonsult *s.a.*). The emissions of suspended dust from combustion of fire wood might be 5 – 6 times higher in old stoves than in new ones. Despite this fact, about two thirds of the fire wood is burned in older stoves (Statistics Norway 2006h). The local consequences of suspended dust emissions vary greatly between urban and rural areas. According to Norsk Petroleumsinstitutt (1998) are particles emissions from wood fuels combusted in district heating installations at the same level as from oil.

Forest is actually the most important single factor in the Norwegian GHG account, absorbing half of the CO_2 emitted in 2004 (SFT 2006). This was achieved unintentionally, since Norwegian forest is not politically approved as a tool to reduce the atmospheric CO_2. In the Kyoto protocol, there is a possibility to include some directly human – induced changes in forest carbon stock taking place after 1990, as reforestation, afforestation and deforestation (United Nations 1998). But most carbon stock increase in Norwegian forests is not covered by this definition. And the small amount carbon possibly credited by Norwegian forest is decided by the government to not be taken into account. If decided to use forest as a tool for reduction of atmospheric CO_2, it might create new possibilities for forestry, but also some challenges, for example in regard to biodiversity. On the other side, use of forest to sequester CO_2 might somehow delay some of the greenhouse gas problem, since any planted tree will one day die and start to emit the CO_2 sequestrated if not harvested and used for purposes reducing the emission effect. But the delay may also provide opportunities to better handle the problem, and flexibility. This latter point is due to the fact that forest also has other applications, for which it may be used later, if the value of forest as a carbon sink is shown to be low (Econ 1999).

There are mainly two ways trees and tree products may contribute to the reduction of GHG in the atmosphere. One is by sequestrating atmospheric CO_2, the second is by substituting fossil fuels or goods that emit fossil fuels and thereby reduce the emissions. Naturally, there is a trade – off between the two approaches, since a tree can not be use for sequestration and for substitution at the same time. Several studies looking at this problem have been carried out. The time aspect in sequestration is very important, because of a tree's long lifetime, and the dynamic of CO_2 fluctuation due to the life cycle. Hoen and Solberg (1994) found that the flow of the net CO_2 fixations might be increased by 60 % with marginal costs below 60 NOK/tonne CO_2, with a 3 % real rate of interest. According to Hektor's results (1998), reduction of atmospheric CO_2 by plantation is as cost-effective as bioenergy substitution of fossil fuel in a short perspective (20 years), but the costs of keeping the plantation as a net sequester increase dramatically in long term.

It is also possible to avoid decomposition and consequently GHG emissions from trees in long term, if the trees are cut down and used in a way so they do not decay, for example for construction of buildings. According to The Norwegian Ministry of the Environment (2006), a medium increase of use of wood in construction may reduce the annual emissions by 0.3 M tonnes CO_2e, which is 20 – 30 % of the total emissions from production of new buildings in Norway. Concrete and steel are increasingly used for construction, with negative effects on the GHG account. Firstly, concrete processing emits large quantities of CO_2. Secondly, the possibility to store carbon in the building is loosed when concrete or steel is used in the place of wood. The Norwegian concrete industry does not pay CO_2 – tax, and have long term – accords of cheap electricity. Petersen and Solberg (2005) compared several studies of avoided GHG emissions by substituting steel and concrete with wood. They found that the net effect of substituting steel with wood in these studies varies from 36 to 530 kg CO_2e/m^3 timber, assumed 4 % discount rate, while the equivalent number for substituting concrete with wood is 93 – 1062 kg CO_2e/m^3 timber.

It might be queried if wood should be used either as substitute in construction or for energy purposes. The fact that wood quality varies greatly makes only a part of the harvested wood usable for construction. This high – quality timber has a much higher economic value than the rest, which is used for pulp and paper, particleboard and energy purposes. Consequently, since it is not technically possible to use all wood for construction, and it is not profitable to use all wood for energy purposes, the substitution should probably take place in both areas. While the high – quality timber only has one major application, construction, low-quality timber may be used for several purposes, as mentioned above. An improvement of economic frames for bioenergy may reduce the competitiveness of other industries; Bolkesjø *et al.* (2006) found that the particleboard industry is particular sensitive in Norway.

Since only one third of the annual increment in Norwegian forests is harvested (Statistics Norway 2006d, 2006e), there is no doubt a potential to increase the use of forest-based bioenergy. But if the harvest increases a lot, it might cause troubles with the protection of biodiversity. Bolkesjø *et al.* (2006) found that a high energy price might cause an increase in domestic harvest of pine pulpwood of one third, compared to a business-as-usual - scenario.

5.4 Implications and further research

The average level of financial support to investments in district heating installations is today 20 %. According to the analysis' results, it seems like an efficient level. But only two support levels are investigated in this study, so it is possible that other levels are even more efficient. The energy price is of highest importance for the efficiency of subsidies. Therefore, the governmental enterprise which distributes the support should extensively use models that predict future energy prices.

Results of analyses in general energy models would also be of interest to use as input in the NTM II. By such a combination, the NTM II could be used to predict the development for bioenergy and for forest industries in the most probable or relevant energy scenarios.

As discussed in several sections, the uncertainty about which type of electricity which is substituted by increasing use of bioenergy makes the net effect of substituting electricity ambiguous. More knowledge about the capacity constraint between Nordic countries is necessary to clarify this effect, together with more knowledge about how the marginal production of the coal – based electricity is divided on only power and combined heat and power production.

District heating installations is only one of several types of bioenergy technologies. Support to both pellets stoves and to replacement of old fire wood stoves with new ones have in periods been imposed. Even if the replacement of fire wood stoves is mostly done for local environmental concerns, new stoves also have a higher efficiency and are therefore interesting to study also in a context of energy consumption. There is a lack of studies regarding the local environmental impacts of these subsidies. These studies could be of interest for all bioenergy technologies.

District heating is a quite new form of heating in Norway, and it is still not very important in volume. Further research in how to implement district heating is important to increase the pace of development and to avoid pitfalls. The cost structure of installations also needs further investigation.

The only environmental aspect considered in this analysis is the global warming. But local environment is also of importance. Combining the challenges of global warming with the problems of local pollution and threat to biodiversity in forest, and analyse these problems in an economic context, would be of greatest interest.

5.5 Conclusion

The most important factor deciding the effectiveness and the efficiency of financial support to district heating is the energy price. If the energy is very cheap, huge subsidies are needed to develop district heating. At high energy prices, district heating will develop in the same degree independently of subsidies. Subsidies to replace fossil fuels with wood fuels in already existing system of district heating are shown to be most effective and efficient at energy price levels of 400 – 450 NOK/MWh. For a cost of 400 000 NOK/GWh, 1 500 GWh increase in yearly production might be obtained. 3 000 GWh yearly increased production might be realised to a cost of 1 000 000 NOK/GWh. Above an energy price of 550 NOK/MWh, subsidies to replacement in existing buildings might not have any effect. Subsidies to district heating installations in new buildings might only have an effect above energy prices of 600 NOK/MWh. At an energy price of 450 NOK/MWh, 50 % subsidies to existing district heating systems might reduce the national GHG emissions from heating by 50 %. 20 % subsidies may reduce the emissions by 25 % at the same energy price level. At energy price of 400

NOK/MWh, 20 % subsidies to existing district heating systems are shown to cost 66 NOK/tonne CO_2e, while the 50 % subsidies might cost 166 NOK/tonne CO_2e. The cost of 20 % subsidies might then be less than the forward price of CO_2 allowances for Kyoto protocol's first obligation period, and less than many CO_2 taxes in Norway, and might therefore be a very efficient policy measure to reduce the CO_2 emissions.

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