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Energy Requirements for Norwegian Commercial Buildings

An assessment of the major social costs and benefits associated with stricter energy requirements in the Technical Building Regulation.

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ABSTRACT

The focus of this thesis is the energy requirements in the Norwegian technical Building Regulation. In 2015, these energy requirements are expected to be tightened. The purpose of this thesis is to evaluate whether this planned tightening of the energy requirements is likely to be positive for the society as a whole. This will be the case if the increased social benefits associated with the stricter energy requirements exceed the increased social costs related to these requirements. In order to evaluate whether this will be the case, a cost-benefit analysis was conducted. In this cost-benefit analysis, some of the major costs and benefits associated with the tightening of the energy requirements were assessed. The energy requirements in TEK10 represented the current requirements, and the energy requirements in the Passive House Standard represented the stricter energy requirements. Hence, the costs and benefits associated with a building that meets the energy requirements in TEK10 and a building with the Passive House Standard were estimated and compared. This was done for four different building types; a sports building, a kindergarten, a school building, and an office building. In order to evaluate whether the tightening of the energy requirements is likely to be positive for the society as a whole, the net social benefits were calculated for each building type. These net social benefits were then discounted in order to find the net present value. The net present value turned out to be positive for all building types. It is therefore expected that the increased benefits associated with stricter energy requirements will exceed the increased costs. Hence, the tightening of the energy requirements is expected to be positive for the society as a whole. A tightening of the energy requirements in the Technical Building Regulation can therefore be recommended.

PREFACE

This thesis was written as part of my Master's degree with the major "Energy, Natural Resources and the Environment". It marks the end of my studies within "Economics and Business Administration" at the Norwegian School of Economics (NHH). Writing this thesis has been a very interesting process and a great learning experience. However, it has also been challenging and demanding at times.

I am very grateful to all those who have contributed with valuable information and feedback on this thesis. First, I would like to thank my supervisor Stein Ivar Steinshamn for his guidance, feedback and advice during this writing process. I would also like to express my gratitude to Rune Stokstad (NCC) and Øyvind Jensen (Norconsult Informasjonssystemer) for valuable information and access to ISY Calcus. Furthermore, I would like to thank Helle Grønli (Enova) for comments and advice, and Isabel S. Pettersen (NASDAQ OMX) for guidance with respect to the financial market for Nordic electricity. Last, but not least, I would like to thank my family and friends for their support and advice along the way.

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ABBREVIATIONS

CBA	Cost-benefit analysis
CO_2	Carbon dioxide
CO_2e	CO_2-equivialents
COP	Coefficient of performance
CS	Consumer surplus
EU ETS	EU Emission Trading System
EUR	Euros
GHG	Greenhouse gas
GO	Guarantee of Origin
GRA	Gross area
GS	Government surplus
IEA	International Energy Agency
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hours
m^2	Square meter
MC	Marginal costs
MPC	Marginal private cost
MSB	Marginal social benefits
MSC	Marginal social cost
MWh	Megawatt hours
MWTP	Marginal willingness to pay
NOK	Norwegian kroner
NPV	Net present value
NSB	Net social benefits
P	Price
PHS	Passive House Standard
PS	Producer surplus
Q	Quantity
SDR	Social discount rate
t CO_2e.	Tonnes of CO_2-equivalents
TEK10	The 2010 version of the Technical Building Regulation
TEK15	The 2015 version of the Technical Building Regulation
TS	Total surplus
TWh	Terawatt hours
UFA	Usable floor area
UNFCCC	United Nations Framework Convention on Climate Change
WTP	Willingness to pay
ZEB	Research Centre on Zero Emission Buildings

1. INTRODUCTION

The world is currently faced with two major challenges related to the use of energy; climate change and security in the supply of energy. Both challenges stress the need to reduce the world's consumption of energy. As buildings consume a lot of energy, there is a large potential for reducing the world's energy consumption by reducing buildings' energy consumption. Energy efficiency measures are said to be one of the easiest and most cost-effective ways to reduce buildings' need for energy. By making it possible to use energy more efficiently, energy efficiency measures may therefore contribute to solving both challenges. A reduction in buildings' energy consumption may both reduce the global emissions of greenhouse gases and contribute to a more secure and stable supply of energy. Based on this, the Norwegian Government has clear ambitions towards making buildings more energy efficient. The energy requirements in the Norwegian building code, known as the Technical Building Regulation, have therefore been gradually tightened over the recent years. The latest review of these regulations took place in 2010. This version of the regulation is referred to as TEK10, and it represents the current regulation. The next revision is set to 2015 and is referred to as TEK15. It is expected that the energy requirements in TEK15 will represent a tightening and be based on the energy requirements in the Passive House Standard.

1.1. OBJECTIVE, SCOPE AND METHOD

The purpose of this thesis is to evaluate whether the planned tightening of the energy requirements in the Technical Building Regulation is expected to be positive for the society as a whole. This will be the case if the increased social benefits associated with the stricter energy requirements are expected to exceed the increased social costs related to these requirements. More specifically, the focus of this thesis is the energy requirements related to the construction of new commercial buildings. In order to assess whether the social benefits of stricter energy requirements are likely to exceed the costs, a cost-benefit analysis will be conducted. In this cost-benefit analysis, some of the major costs and benefits associated with the tightening of the energy requirements will be assessed. Hence, the difference in some of the costs and benefits associated with a building meeting the energy requirements in TEK10 and a building with the tightened energy requirements will be evaluated and compared. This thesis will therefore focus on the energy requirements of TEK10 and TEK15. The specific energy requirements of TEK15 are, however, not yet decided upon. The energy requirements in the Passive House Standard, which the energy requirements in TEK15 are expected to be based on, will therefore represent the expected energy requirements of TEK15 in this thesis.

It is important to note that the cost-benefit analysis performed in this thesis will differ somewhat from a traditional cost-benefit analysis of social investments. A traditional cost-benefit analysis will measure the costs and benefits of a specific public investment, like the construction of a bridge. The cost-benefits analysis in this thesis, however, will be based on a comparison of some of the costs and benefits associated with the energy requirements of two building codes. Hence, the cost-benefit analysis of this thesis does not concern a specific project. The methodological aspects of this cost-benefit analysis will, however, be identical to that of a traditional cost-benefit analysis.

1.2. RESEARCH QUESTION

Based on the above, this thesis aims to answer the following research question:

How large are the increased social costs and benefits related to stricter energy requirements for Norwegian commercial buildings expected to be, and will these increased benefits exceed the increased costs?

The research objectives of this thesis are therefore to identify and measure the changes in some of the major social costs and benefits associated with the tightening of the energy requirements in the Norwegian Technical Building Regulation.

1.3. PREVIOUS STUDIES

The private construction and building industry has, in the recent years, experienced a tightening of the energy requirements in buildings and a greater focus on energy efficiency measures. This has created a demand for analyses with respect to the costs and benefits associated with such energy requirements and energy efficiency measures. As a result, several studies have discussed the social and private costs and benefits associated with energy requirements and energy efficiency measures. Among these are the studies from the World Green Building Council (2013), the Norwegian Ministry of Local Government and Regional development (2010), and the study by Zhang (2006). In addition, the Low-Energy Programme (n.d.). has presented some of the costs and benefits of buildings with the Passive House Standard. These studies point out the additional construction costs as the major cost associated with strict energy requirements and energy efficient buildings. This is due to the fact that the fulfilment of stricter energy requirements and the construction of energy efficient buildings often require better building components, more material, new technology, and more planning. With respect to the benefits of stricter energy requirements and energy efficient buildings, these studies point out the reduction in a building's energy costs and emission due to reduced energy consumption. In addition, it is pointed out that stricter energy requirements may result in an improved indoor quality due to stricter requirements and better ventilation. This may improve the comfort, health and well-being of the occupants in the building, and thereby reduce employee health costs. Buildings that meet stricter energy requirements are also often thought of as buildings with a higher quality. This may result in an increased value of the building. It is also believed that energy efficient buildings tend to attract tenants more easily and may therefore make it possible to charge higher rents or achieve higher sales prices. Some of these benefits are fairly predictable, while others are very difficult to predict. As a result, although many of these benefits have been identified through qualitative research, some of them have never been measured in monetary terms.

Quite a few studies also focus on the assessment of such costs and benefits through a cost-benefit analysis. For example, studies by Clinch and Healy (2000), Zhang (2006) and Nilsen (2011) have all conducted cost-benefit analyses based on the costs and benefits associated with energy efficient buildings. It is, however, often difficult to compare such studies due to differences in the energy requirements and regulations in various countries. Also, these studies may differ with respect to which building types they focus on, and whether they focus on one separate building, many buildings, or one building type in general. While Clinch and Healy (2000) focused on domestic buildings in Ireland, Zhang (2006) evaluated LEED-certifications in American buildings, and Nilsen (2011) evaluated the costs and benefits of a specific building in Norway. As this thesis will focus on the tightening of the energy requirements in the Norwegian Technical Building Regulation, and not energy efficiency in general, I will not go any further into these previous studies. I will rather focus on some previous studies that focus on both TEK10 and the Passive House Standard. As these regulations are quite new, there are not many studies on this specific subject. There are, however, some Norwegian studies that include the evaluation of the additional costs and the reduced energy need associated with the construction of buildings with a Passive House Standard relative to the current regulation (TEK10).

In a study by the Norwegian Ministry of Local Government and Regional Development (2010) the additional costs of a building with the Passive House Standard are estimated to about 1000-2000 Norwegian kroner (NOK) per square meter (m^2). This study does, however, point out that these additional costs are expected to decrease over time due to more experience with the Passive House Standard. This expectancy of lower additional costs over time may be said to correspond with the estimates of a more recent study by Multiconsult and Sintef (2012). This study included estimations of the additional costs associated with the construction of various building types with the Passive House Standard compared to buildings that meet the requirements in TEK10. These additional costs for office buildings were estimated to 610 NOK/m^2. A third Norwegian study, performed by Rambøll (2013), estimated additional costs of 5-10% relative to the costs of buildings that meet the requirements in TEK10. However, in their analysis, the additional costs were based on the estimated costs from Multiconsult and Sintef (2012) and additional costs retrieved from historical projects. The latter were estimated to about 900 NOK/m^2.

The study by Multiconsult and Sintef also estimated buildings' net energy need in kilowatt hours (kWh). The net energy need of buildings that meet the requirements in TEK10 and buildings with the Passive House Standard were estimated to 118 kWh/m^2/year and 56 kWh/m^2/year respectively. Hence, the reduced net energy need of a building with the Passive House Standard relative to a building meeting the requirements in TEK10 were 62 kWh/m^2/year. Based on this, and the additional costs, this study calculated the private profitability of constructing a building with the Passive House Standard instead of a building meeting the requirements in TEK10. Parts of this study can therefore be said to relate to the analysis in this thesis. The analysis of this thesis will, however, differ from this study by including both social and private costs and benefits. Also, while the study by Multiconsult and Sintef evaluates the profitability of residential buildings, apartments and office buildings, this thesis will focus on commercial buildings. More specifically, this thesis will evaluate the costs and benefits of four different types of commercial buildings. In addition, while the study by Multiconsult and Sintef used a payback method in order to evaluate the profitability, this thesis will evaluate the costs and benefits using a cost-benefit analysis. The analysis of this thesis will also differ in the way the additional costs and the reduced energy consumption are estimated. In the study by Multiconsult and Sintef the additional costs were estimated based on numbers from a calculation tool from Holte and construction costs of completed buildings with the Passive House Standard. In this thesis a programme called ISY Calcus will be used in order to estimate these additional costs. With respect to the reduced energy consumption, Multiconsult and Sintef used a program called SIMIEN in their estimations. In this thesis, however, the reduced energy consumption will be based on the Technical Building Regulation's set limits for buildings' net energy need.

1.4. STRUCTURE

The remainder of this thesis has been organized into five sections. In order to establish the importance of the topic at hand, this thesis starts off with an introduction of two major energy challenges (Section 2). Some important subjects regarding energy consumption in buildings will then be presented (Section 3). This section is followed by a review of the relevant theoretical background, in order to understand the basics of how markets work and the need for and use of a cost-benefit analysis (Section 4). The cost-benefits analysis, conducted with respect to the changes in some of the major costs and benefits associated with the tightening of the energy requirements in the Technical Building Regulation, is then performed (Section 5). Lastly, the main points of the thesis will be summarized in a conclusion (Section 6).

2. ENERGY CHALLENGES

2.1. CLIMATE CHANGE

Research has shown that the global climate has changed noticeably over the past century. It is estimated that the average global temperature has risen by about 0.8 degrees Celsius since the start of the industrial revolution (Norwegian Ministry of Climate and Environment, 2012). Furthermore, the Intergovernmental Panel on Climate Change (IPCC) states that the average global temperature will continue to rise by an additional 1-3 degrees Celsius in this century. Such changes in the global climate may result in more extreme weather events and other impacts that may have significant social and economic consequences. Some known negative consequences of rising temperatures are extreme draught, rising sea levels, flooding, changes in agricultural activity, melting glaciers, and increased insect-borne disease (Kolstad, 2011). Climate change is therefore seen as one of today's major global challenges (Norwegian Ministry of Climate and Environment, 2012).

Reports issued by the IPCC indicate that there is, for the most part, a consensus in the scientific community with regards to the nature and scope of climate change. It has been shown that the global climate is changing, and it is generally accepted that this is mainly due to man-made emissions of greenhouse gases (GHGs) (Kolstad, 2011). This conclusion is drawn based on the observed relationship between the changes in the global climate and the increased atmospheric concentration of GHGs in the years following the industrial revolution (Norwegian Ministry of Climate and Environment, 2012). The six main GHGs in relation to climate change are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and the three fluorinated gases PFC, HFC and SF_6. The largest contribution to climate change comes from the emissions of CO_2. In 2010, for example, CO_2 represented about 84% of the total GHG emissions while CH_4, N_2O and the three fluorinated GHGs represented about 8%, 6% and 2% respectively (Norwegian Ministry of Climate and Environment, 2012). As these GHGs have different atmospheric effects, they are often converted into CO_2-equivialents (CO_2e) based on their warming effects relative to that of CO_2. This is done by using the Global Warming Potential Scale, and it makes it possible to compare the various GHGs' impact on climate change (Norwegian Ministry of Climate and Environment, 2012). These GHGs exist naturally in the atmosphere and they are responsible for the warming process called the greenhouse effect. By trapping radiation in the form of heat in the atmosphere these gases ensure an average global temperature of about 15 degrees Celsius. GHGs are therefore vital for life on earth as we know it. However, if the atmospheric concentration of these gases increases, more heat will be trapped in the atmosphere and result in higher global temperatures (University of California, 2014). Man-made emissions of GHGs, mainly due to the combustion of fossil fuels like coal and oil, are therefore thought to have intensified the natural greenhouse effect by increasing the concentration of GHGs in the atmosphere (Norwegian Ministry of Climate and Environment, 2012).

Emissions of GHGs are transboundary, in the sense that they will have the same impact on the atmosphere and the global climate irrespective of where in the world they are emitted. Hence, emissions in one part of the world create negative environmental externalities for people all over the world. Climate change is therefore considered a global problem and it is in all countries' interest to reduce the global emissions of GHGs (Kolstad, 2011). The awareness of the potential disastrous consequences of climate change has resulted in a broad political and scientific consensus concerning the need to reduce the global emissions of GHGs (Norwegian Ministry of Climate and Environment, 2012). In 1992, the main international treaty on climate change was adopted. This is referred to as the United Nations Framework Convention on Climate Change (UNFCCC), and its objective is to stabilize the atmospheric concentration of GHGs at a level that will prevent "undesirable anthropogenic interference with the climate system" (NOU 2012: 16, 2012, p. 129). In 1997, negotiations between the parties of the UNFCCC resulted in the adoption of the Kyoto Protocol. As the first international agreement with binding restrictions on the emission of GHGs the Kyoto Protocol entered into force in 2005. This agreement requires all developed countries (Annex I countries) to stay within a given number of emission allowances, which allow them to emit a given number of tonnes of CO_2e (t CO_2e). In a later negotiation between the parties of the UNFCCC the two-degree target was agreed upon (NOU 2012: 16, 2012). This target aims at limiting the increase in the global temperature to two degrees Celsius. It was first proposed by the IPCC. They stated that it will be necessary to reduce GHG emissions by 50-85 % (compared to the 2000-level) by 2050 in order to keep the global average temperature from rising with more than 2 degrees Celsius compared to pre-industrial levels (Norwegian Ministry of Climate and Environment, 2012). This may be achieved through investments in renewable energy, carbon capture and storage, and energy efficiency measures. There are other ways to reduce the global emissions of GHGs, but the above have been pointed out by the IPCC as some of the most effective measures (Cicero, n.d.).

The Kyoto Protocol and the two-degree target are very central in both the Norwegian and the European Union's climate policy (Norwegian Ministry of Climate and Environment, 2012). In addition to the Kyoto Protocol's emission commitment on a national level, Norway is part of the European Union Emissions Trading System for businesses (EU ETS). This trading system was established in 2005 and it requires all businesses in the "allowance requirement sector" to hand over one allowance for each tonne of CO_2 they emit (or the equivalent amount of N_2O or PFC). In Norway, these allowances are collected by the Norwegian authorities and used to meet the national requirements in the Kyoto Protocol. The EU ETS is a cap-and-trade system. Hence, a cap is set with respect to how much all the participating businesses can emit. Allowances for this level of emissions are then auctioned or allocated for free. As these allowances are tradable, businesses can buy and sell allowances in order to cover their emissions. As a result, a market for emissions has been created and it is possible to set a price on these emissions (NOU 2012: 16, 2012).

2.2. ENERGY SUPPLY

In addition to the threat of climate change, it is expected that population growth and improved standards of living will result in a shortage in the supply of energy. As energy is essential for today's modern society, shortages in the energy supply may cause serious problems (NOU 2012: 9, 2012). One can just imagine how today's hospitals depend on energy. Looking back, the world's total energy consumption increased by about 2% yearly between 1970 and 2005. The International Energy Agency (IEA) is expecting a continuation of this trend, with an increase in the energy demand of about 55% towards 2030. If this growth continues, the world's energy consumption is likely to be doubled by 2042 and tripled by 2062 (Confederation of Norwegian Enterprise, 2009). If this happens, the world's energy supply will have to increase in order to avoid major problems associated with shortages in the supply of energy. This need for more energy may conflict with the need to reduce emissions of GHGs. There will be a need for more energy at the same time as there is a need to reduce the use of emitting sources of energy. The focus on reducing the emissions of GHGs has caused a rise in the investments in renewable resources, and the hope is that renewable energy will replace some of the emitting sources of energy. However, if the growth in the world's energy demand equals or surpasses the growth in renewable energy, the renewable energy will only be added to the total energy supply. Hence, emitting energy sources like fossil fuels will not be replaced by renewable energy, and the emissions of GHGs will not be reduced. An increase in the energy demand may also cause a need to produce more energy based on emitting energy sources like fossil fuels. As a result, emissions from the world's energy supply may remain the same or even increase (Norwegian Environment Agency, 2013). This problem emphasizes the importance of energy efficiency measures. By learning how to use energy more efficiently it might be possible to meet both energy challenges. A reduction in the energy demand due to energy efficiency measures may both result in a more secure energy supply and contribute to a reduction of the global emissions of GHGs. Energy efficiency measures are also said to be one of the easiest and most cost-effective ways to reduce energy consumption (Norwegian Ministry of Local Government and Regional Development, 2010).

3. ENERGY CONSUMPTION IN BUILDINGS

3.1. BUILDINGS' EFFECT ON THE ENVIRONMENT

Buildings consume a lot of energy, both in production and during their lifetime. In production, the consumption of energy is connected to the production of materials, the use of machines and the building process in general (UngEnergi, 2013). Energy consumption during a building's lifetime, however, includes energy used for space heating and cooling, lighting, ventilation, water heating, and different appliances and equipment (International Energy Agency, 2013a). The focus of this thesis will be on buildings' energy consumption during their lifetime. In Norway, buildings represent about 40% of the total domestic energy consumption (International Energy Agency, 2013a). This can be backed up with numbers from Statistics Norway (2013). In 2012, the total energy consumption in Norwegian buildings amounted to about 79 Terawatt hours (TWh). This number includes energy consumption in both households and commercial buildings (private and public services). The former represented about 60% of the total energy consumption in buildings while the latter, which is the focus of this thesis, represented about 40%. In total, the energy consumption in Norwegian buildings represented about 33% of that year's total energy consumption (237 TWh). Energy used to produce new energy products is often excluded from such calculations. With this exclusion, the total energy consumption in 2012 was about 217 TWh. Based on this, buildings' energy consumption represented about 37 % of the total energy consumption. The corresponding numbers for 2010, 2011, and the average for these three years are shown in Table 1.

Table 1: Energy consumption in Norwegian buildings

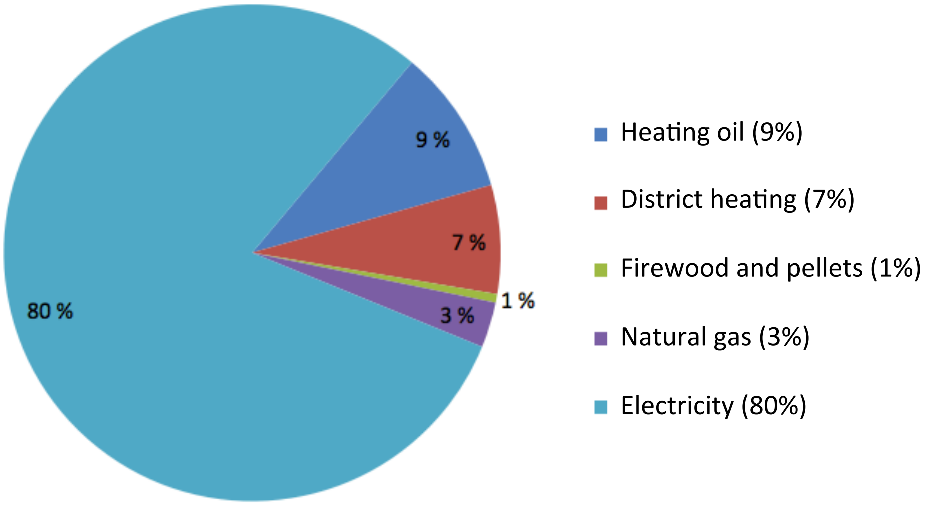
	2010	2011	2012	AVERAGE
Energy consumption in households (TWh)	51	46	47	48
Energy consumption in commercial buildings (TWh)	34	31	32	32
Total energy consumption in buildings (TWh)	85	77	79	81
Total energy consumption (TWh)	246	238	237	240
Total energy consumption* (TWh)	224	216	217	219
Buildings' proportion of the total energy consumption	**35 %**	**32 %**	**33 %**	**34 %**
Buildings' proportion of the total energy consumption*	**38 %**	**36 %**	**37 %**	**37 %**

* Total energy consumption without energy used to produce new energy products.

Based on numbers from 2009, about 80% of the energy used in Norwegian commercial buildings derives from electricity (see Figure 1). The remaining 20% derives from heating oil

(9%), district heating (7%), natural gas (3%) and firewood and pellets (1%) (Norwegian Water Resources and Energy Directorate, 2011). As electricity is the main source of energy in buildings, this thesis will focus on the use of electricity to cover buildings' net energy need.[1]

Figure 1: Energy sources in Norwegian buildings



Source: Norwegian Water Resources and Energy Directorate (2011)

In Norway, the use of electricity is often thought of as an emission free source of energy. This is due to the fact that about 98% of the electricity produced in Norway comes from renewable hydropower (Norwegian Water Resources and Energy Directorate, 2013). This is, however, a highly debated subject due to the fact that Norway is part of an integrated Nordic electricity system (see Figure 2). This electricity system is, in turn, connected to the Baltic countries and other European electricity markets (Norwegian Ministry of Petroleum and Energy, 2013). There is currently one direct connection from Norway to Europe (The Netherlands) through the NorNed cable and several interconnectors between other Nordic countries and the European market. In addition to the existing interconnectors in and between the Nordic countries, the Baltics, and the rest of the European continent, new interconnectors are planned in order to increase the transmission capacity in Europe. It is, for example, very likely that the Norwegian electricity system will be directly connected to Germany through the NordLink interconnector by 2018 and to the UK through the NSN interconnector by 2020. The goal is to strengthen the European electricity market, increase the security of supply and support the introduction of renewable energy (Statnett, 2013).

[1] This assumption was also made in in a study by Rambøll (2013, p. 111).

Figure 2: The Nordic electricity system

Source: Nord Pool (2014)

While most of the electricity produced in Norway is based on hydropower, other countries use nuclear power, wind power, solar power, biomass and waste, natural gas, coal, and oil in addition to hydropower in the production of electricity (Nord Pool, n.d.). Hence, while the Norwegian electricity can be said to have close to no environmental effect, the production of electricity in many European countries result in emissions due to the use of less environmental friendly technologies. However, as interconnectors make it possible to transfer electricity between countries, it can be said that electricity produced with different technologies is being mixed. After the generating companies have supplied their electricity to the transmission network, it will not be possible to tell whether the electricity was produced using hydropower or a less environmental friendly technology. As a result, the environmental impact of 1 kWh of electricity (CO_2e/kWh) can vary a lot (Norwegian Ministry of Petroleum and Energy, 2007).

As Norway exports or imports electricity based on whether the domestic production is high or low, one cannot know whether the consumption of electricity in Norway is covered by hydropower or less environmental friendly electricity. This complicates the notion of the environmental impact of Norwegian buildings' energy consumption. Some will argue that it should be possible to consider the Norwegian electricity consumption close to emission free due to the fact that the Norwegian production of hydropower is large enough to cover the Norwegian consumption. On the other hand, many are of the opinion that the emissions associated with electricity should equal the average emission of electricity produced in the European market. This is due to the fact that Norway is both indirectly and directly connected to the European market. It is also likely that Norway will be fully integrated in a European electricity system over time (Statsbygg, 2011). This view is also supported by the idea that Norwegian hydropower may be used to replace electricity from less climate-friendly sources of energy in other countries. By using less energy in Norwegian buildings, it will be possible to export more clean power to other countries. As this may reduce global emissions, it can be said that the consumption of Norwegian electricity has an indirect environmental impact. Excess electricity produced with hydropower can also replace more emission intensive energy sources in other Norwegian sectors, and it may reduce the need for new power generation (Dokka, 2011). Another counterargument to electricity being emission free is based on the concept of Guarantees of Origin (GOs). GOs were established by the EU Renewable Directive and give consumers a possibility to choose between renewable and non-renewable energy. As the production hydropower is renewable, GOs are issued for Norwegian electricity based on hydropower. The majority of these GOs are, however, bought by consumers in other countries. Due to the integrated European market, electricity bought without GOs may be attributed a European attribute mix where only 20% of the electricity is considered renewable. It can therefore be argued that electricity bought without GOs is associated with emissions, even though the actual electricity used is likely to come from clean hydropower. Hence, the electricity in the outlet may be based on hydropower but the environmental value of this electricity may have been exported to other countries through GOs (Norwegian Water Resources and Energy Directorate, 2013). Electricity will, in this thesis, be defined to have emissions (see Section 5.3.4. for more on the emission factors of electricity).

3.2. ENERGY EFFICIENCY MEASURES

The fact that the world is facing two major energy challenges stresses the need to use less energy. As buildings consume a lot of energy, there is a large potential for reducing the world's energy consumption through a reduction in buildings' energy consumption. One way to reduce buildings' energy consumption is by turning off lights or turning down the heat. This is called energy conservation, and it implies that one has to reduce or go without a service (light, heat, etc.) to reduce the energy consumption. A problem with this approach is that it can be hard to implement, as many are reluctant to lowering the comfort level in buildings. An alternative way to reduce buildings' energy consumption is through the implementation of energy efficiency measures. Energy efficiency can be defined as "using less energy to provide the same service" (Environmental Energy Technologies Division, 2014). Hence, a building can be said to be more energy efficient if it can provide the same services as before, but by using less energy. For example, instead of turning down the heat in order to save energy, one can improve a building's insulation and invest in highly insulated windows. By reducing the heat loss through walls and windows, this may make it possible to maintain the same temperature as before by using less energy. One can also make buildings more energy efficient by installing an energy efficient heating system like a heat pump, installing a heat recovery ventilation system, or by investing in energy efficient appliances and control systems for light and heating (UngEnergi, 2013). It may also be easier to reduce the energy consumption in buildings through energy efficiency measures, because such measures can be made mandatory (Norwegian Ministry of Local Government and Regional Development, 2010). Energy efficiency measures in buildings can therefore be seen as a good way to reduce a country's energy consumption and environmental impact.

Several international studies have shown that energy efficiency measures in buildings have a large potential. Energy efficiency measures are also said to be one of the easiest and cost-effective ways to reduce buildings' energy consumption. This is partly due to the fact that a lot of the technology needed for such measures already exists. Energy efficiency measures may therefore contribute to solving the two energy-related challenges mentioned in Section 2 (Norwegian Ministry of Local Government and Regional Development, 2010). In fact, according to the IEA, energy efficiency measures are among the most important initiatives when it comes to reaching the two-degree target. This is based on the fact that such measures reduce the need for new energy production and the ensuing emissions (Confederation of Norwegian Enterprise, 2009). As mentioned in Section 3.1., the energy saved through energy efficiency measures in buildings can also replace more emission intensive energy sources in other Norwegian sectors or be exported to replace less environmental friendly electricity in other countries. An increase in the Norwegian export of hydropower can also aid the development of more renewable energy in Europe. As electricity systems depend on matching the supply and demand of electricity, it is essential to ensure a continuous and stable supply of electricity. In order to achieve this, there are often various base load and peak load power plants. Base load power plants generate electricity at a constant rate 24 hours a day. Examples of such plants are nuclear, geothermal, hydropower, and coal-fired plants. Peak load power plants, on the other hand, provide electricity when the demand exceeds the base load. Hence, peak load power plants need to be very responsive in order to be able to handle sudden fluctuations in the energy demand. Many renewable sources of energy do not have this trait. Solar- and wind power, for example, are not easily controlled. As a result, countries using solar- and wind power may find it necessary to have emitting power plants up and running in case their renewable energy sources are unable to cover the peak load demand. The production of electricity at hydropower plants, on the other hand, can be turned on at a very short notice. Hence, hydropower provides flexibility, which is valuable when it comes to meeting sudden fluctuations in the demand. Hydropower from Norway could therefore serve as a back up in cases when the renewable energy in other countries is unable to cover a sudden increase in the demand. This would be more environmental friendly than having emitting power plants up and running. It is therefore often referred to as Norway being Europe's "green battery". This would also make it possible for many countries to invest in and rely more on renewable energy without having to worry about not being able to cover fluctuations in the demand (Eurelectric, 2011). In addition to these social benefits, energy efficiency measures often pay for themselves over time as a reduced energy consumption will result in lower energy costs (Environmental Energy Technologies Division, 2014). In sum, improving the energy efficiency of buildings is seen as a cost-effective and environmental friendly way to contribute to a reduction in the emissions of GHGs and a more secure energy supply. After all, the cleanest energy is the one that does not have to be produced (Norwegian Ministry of Local Government and Regional Development, 2010).

3.3. NORWEGIAN BUILDING REGULATIONS

As energy efficient buildings can contribute to a reduction in the energy demand and the emission of GHGs, the Norwegian government has clear ambitions towards making buildings more energy efficient (Norwegian Building Authority, 2013). Many existing technologies can be used to make buildings more energy efficient, but there are quite a few barriers for investing in energy efficiency measures. The main barrier is thought to be the expected increase in the construction costs of more energy efficient buildings. In addition, there are problems with customer indifference and the lack of the awareness of the benefits of energy efficiency measures. There are also incentive problems related to energy efficiency measures, as the owners of buildings are not always the ones receiving the monetary benefits of the reduced energy consumption. Due to such barriers, unleashing the potential of energy efficiency measures in buildings often require the use of informational programmes, economic incentives, and regulatory instruments such as building codes (International Energy Agency, 2013b). Based on this, a Norwegian energy agency called Enova was established in 2001. Its mission is to promote a more environmental friendly consumption and generation of energy and to increase the amount of energy efficiency investments. This is done through informational programmes and economic incentive schemes (Enova, n.d.-a). In addition to the information, support and incentives from Enova, a labelling scheme referred to as the Energy Labelling Regulation ("Energimerkeordningen") was introduced in 2010. It requires all buildings that are to be sold or rented out to have an energy label. This label is made up by a letter grade (A to E) describing the building's net energy need and a colour code (green to red) describing the amount of renewable energy use in the building. It also requires all commercial buildings larger than 1000 m^2 to have an updated energy certificate available at all times. By increasing the awareness of buildings' energy consumption, this regulation is meant to increase the focus on energy efficiency in buildings and the incentives to build more energy efficient buildings (Rambøll, 2013). Both Enova and the Energy Labelling Regulation are shown to increase the awareness of and investment in energy efficiency measures. The best effect, however, is believed to come from the Norwegian building code (Karlstrøm, Ryghaug, & Sørensen, n.d.). This building code is the focus of this thesis.

Building codes contain requirements with respect to various aspects of a building, and they are developed to ensure that certain standards for health, safety, energy and the environment are considered and met. The Norwegian building code is referred to as the Regulations on technical requirements for buildings ("Forskrift om tekniske krav til byggverk"). It is also known as the Technical Building Regulation ("Byggteknisk forskrift"), and the abbreviation TEK is often used. The first TEK was introduced in 1969, and is commonly referred to as TEK69. The requirements of this building code were tightened in 1987 (TEK87). The main focus of TEK69 and TEK87 was the thermal insulation of buildings. They did not pay any specific attention to energy and environmental concerns. In 1997, however, a new Technical Building Regulation with a greater emphasis on energy and the environment was introduced (TEK97). These requirements were, once again, tightened in 2007 (TEK07), with the intention of reducing building's energy consumption with 25% compared to the requirements in TEK97. This was to be achieved through increased insulation, heat recovery ventilation, better windows, and other measures to reduce the heat loss of buildings. It also required that about 40% of the heating should be covered by other energy sources than electricity and fossil fuels. The latest review of the Technical Building Regulation took place in 2010. This version of the Technical Building Regulation is commonly referred to as TEK10, and it represents the current regulation. The next revision of this regulation is set to 2015 (TEK15). The government has notified that this revision will include a tightening of the energy requirements, and that these requirements will most likely be based on the requirements in the Passive House Standard. It is also very likely that there will be another tightening to a nearly zero-energy standard in 2020 (Norwegian Ministry of Climate and Environment, 2012). This corresponds to the requirements in the EU's Energy Performance of Buildings Directive, and it is said to be an important piece in the work towards reaching the set energy targets (Rambøll, 2013). This planned tightening of the requirements might seem very strict but, due to the long lifetime of buildings, it is important to increase the energy efficiency standards in new buildings as quickly as possible (NOU 2012: 9, 2012). The average energy consumption of existing buildings is about 280 kWh/m^2, and it is expected that one will start to really see the effect of the new energy requirements towards 2040. By then, about 37% of Norwegian buildings are expected to have been built in the period 2010-2040 (with today´s building and demolition rate) (Norwegian Ministry of Local Government and Regional Development, 2010). This shows the long-term aspect of investments in energy efficiency measures.

This thesis will focus on the planned tightening of the energy requirements in the Technical Building Regulation. Hence, the focus will be on the current and the upcoming version of the Technical Building Regulation, TEK10 and TEK15. While the energy requirements of TEK10 are available online (Norwegian Building Authority, n.d.; Norwegian Building Authority, 2010), the design and formulation of the energy requirements of TEK15 are not yet decided upon. However, as mentioned, the Passive House Standard is expected to create the basis for the energy requirements in TEK15. The energy requirements in the Passive House Standard will therefore represent the expected energy requirements in TEK15. In the analysis of this thesis, the focus will therefore be on TEK10 and the Passive House Standard. TEK10 and the Passive House Standard will therefore be presented in the following. I will, however, not go into the technical aspects of these building codes, as that is beyond the scope of this thesis.

3.3.1. TEK10

TEK10 was introduced in 2010 but, due to a transition period of 1 year, all buildings constructed after July 1, 2011 have to meet the requirements in this building code. This regulation puts forward requirements with respect to different aspects concerning the technical quality of new buildings. For example, chapter 5 concerns the degree of area utilization and chapter 11 covers the requirements concerning fire safety in buildings. The focus of this thesis is chapter 14, which contains the requirements concerning buildings' energy consumption (see Appendix A). These energy requirements are meant to ensure that buildings are constructed in a way that result in a low energy demand and an environmental friendly energy consumption. They make sure that energy performance is considered throughout the planning and construction process (Norwegian Building Authority, n.d.). In broad terms, the energy requirements in chapter 14 cover buildings' energy efficiency (§ 14-2 to § 14-6) and energy supply (§ 14-7 to § 14-8).

The energy efficiency requirements can be met in two ways. One can choose to either (1) satisfy a number of individual energy characteristics put forward in § 14-3 or (2) make sure that the building's net energy need does not exceed the limits stated in § 14-4 (Norwegian Building Authority, 2010). If the first method is chosen, one needs to make sure that the U-values of different building components (floor, walls, roof, windows, etc.) do not exceed the set limits. These U-values measure the heat loss in the various building components, and a low value indicates less heat loss. Low U-values are therefore often associated with high levels of insulation (International Energy Agency, 2013a). By fulfilling these individual requirement one does not have to estimate the expected net energy need of the building. If the second method is chosen, however, the expected net energy need of the building's usable floor area (UFA) have to be estimated. A building's UFA ("Bruksareal"; BRA) is a measurement of the building's area within its external walls. This can be found by considering a building's gross area (GRA) ("Bruttoareal"; BTA) and the area occupied by its outer walls. In order to meet the energy efficiency requirements in this manner, one will therefore have to show that the expected total net energy need of the building does not exceed the set upper limit for the specific building type. For example, the net energy need for a school building have to be 120 kWh/m^2 or lower. By using this method, one can more freely decide how to make sure that the net energy need is sufficiently low. However, regardless of whether the first or the second method is chosen, the minimum requirements in § 14-5 have to be met. This is to make sure that new buildings meet a certain standard (Rambøll, 2013).

The energy supply requirements, on the other hand, do not offer any options with regards to how the requirements should be met. In § 14-7 the installation of boilers for fossil fuels are prohibited. § 14-7 also require buildings with a UFA of more than 500 m^2 to cover at least 60% of its net energy need for space- and water heating by the use of energy conversion systems that do not use direct acting electricity or fossil fuels. For buildings with a UFA of less than 500 m^2 the requirement is a minimum of 40%. Energy conversion systems convert fuels and energy into heat and work, and systems that use direct acting electricity includes electric boilers, heaters and radiators. Electricity supplied to heat pumps is not considered direct acting electricity. In addition, § 14-8 require new buildings to have heating systems that allow for the use of district heating if they are in areas where it is mandatory to be connected to a district heating system (Norwegian Building Authority, n.d.).

3.3.2. The Passive House Standard

The Passive House Standard refers to a German concept where the main idea is to reduce buildings' energy consumption through passive measures like insulation, highly insulated windows and doors, and ventilation systems with a high degree of heat recovery (Enova, n.d.-b). Due to differences in climate, construction design and building traditions, this standard has been adapted to Norwegian conditions. In 2012, a Passive House Standard for non-residential (commercial) buildings was published[2]. This standard consists of requirements concerning buildings' heat loss, the need for energy for heating, cooling and lighting, energy supply, and a set of minimum requirements for building components and systems (Standard Norge, 2012). These requirements are adjusted with respect to the building's size, the mean temperature in the area where the building is located, and the building type (Lexow, 2012). Buildings with the Passive House Standard are becoming quite common, even though it is currently a voluntary standard. This may be due to the fact that such buildings are often acknowledged as environmentally friendly and of higher quality (Standard Norge, 2012). This trend can be illustrated with the fact that Enova stopped the financial support to the construction of buildings with this standard in November 2013. This decision was based on the belief that the construction of buildings with the Passive House Standard will continue without their financial support (Lie, 2013).

[2] This standard is for sale at http://www.standard.no/en/webshop/Search/?search=NS+3701.

The Passive House Standard has many similarities with TEK10. However, as most of the requirements in the Passive House Standard are stricter, the heat loss in in buildings with the Passive House Standard is reduced. This makes it possible for buildings with this standard to use about half the energy as a building that meet the energy requirements in TEK10. The passive measures needed in order to achieve this are related to the building itself. The construction of buildings with the Passive House Standard will therefore require more effort, precision, better building components and a well planned construction process (Enova, n.d.-b). As a result, the construction of buildings with the Passive House Standard is likely to be more expensive than that of buildings that meet the requirements in TEK10.

4. THEORETICAL BACKGROUND

The focus of this thesis is the consumption of electricity in buildings. Hence, the market related to this thesis is the market for electricity. For most goods and services, markets yield the socially optimal amount by matching producers' costs and consumers' demands. In the presence of market failure, however, this socially optimal amount will not be provided. (Kolstad, 2011). This is the case in the market for electricity. The production of electricity is often associated with emissions of GHGs, which impose indirect costs on the global community. If these external costs are not taken into account in the market, the electricity price will not reflect the true social cost of the production and consumption of electricity. As a result, the production of electricity will exceed the socially optimal amount. This creates a rationale for government intervention. In Norway, one of the measures introduced in order to reduce the consumption of electricity is the energy requirements in the Technical Building Regulation. As stricter energy requirements can contribute to a reduced energy need in buildings, and thereby a reduction in the demand for electricity, the Norwegian government has introduced stricter energy requirements over the years. As mentioned, a tightening of these energy requirements is planned to come into effect in 2015. In order to evaluate whether this tightening will represent an improvement for the society as a whole, a cost-benefit analysis (CBA) can be conducted.

In order to understand the basics of how markets work and the need for and use of CBAs, this chapter will introduce some concepts from microeconomic theory and the conceptual and technical concepts of CBAs. First, in Section 4.1., the theory of competitive markets will be introduced. This involves an introduction to the concepts of supply and demand, consumer and producer surplus, allocative efficiency, Pareto efficiency, and the two theorems of welfare. This Section will create a foundation for understanding how the market for electricity would have worked if it was competitive. It will also serve as a foundation for some of the concepts in CBAs. For example, the concepts of consumer surplus, producer surplus, and Pareto efficiency are important concepts in the CBA framework. The concept of market failure and government intervention will then be presented in Section 4.2.. This includes a presentation of the conditions for a perfectly competitive market, an introduction to externalities, and a presentation of various ways governments can intervene in order to remove or reduce negative externalities. Hence, this section will explain why there is a need for government intervention in the market for electricity and how the government can intervene. Lastly, the concepts and theories behind CBAs will be presented in Section 4.3.. This includes an introduction to the concepts of net social benefits and Pareto efficiency, an introduction of the conceptually correct way to measure the impacts in CBAs, the idea of discounting, a recipe for conducting CBAs, and some problems and limitations with CBAs.

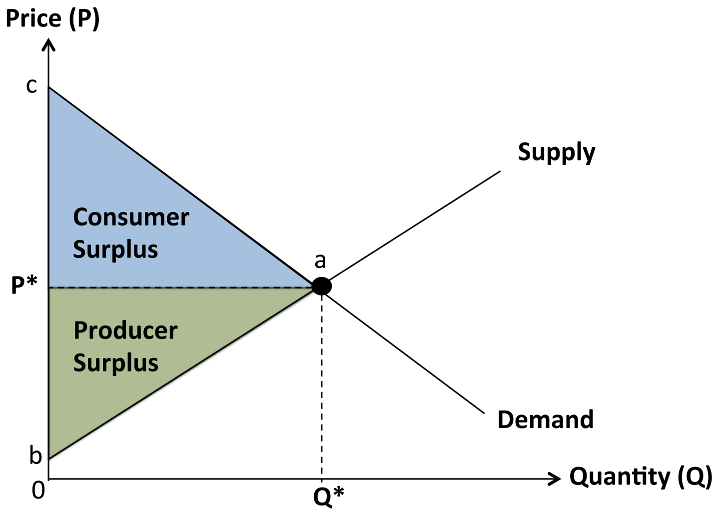
4.1. COMPETITIVE MARKETS

4.1.1. Supply and demand

The concepts of supply and demand, and the market they form, are among the major building blocks in microeconomic theory. Producers' individual supply curves are based on their marginal costs of production (MC) and show how much they are willing to sell at certain prices. The market supply curve is found by summing the individual supply curves of all the producers in the market. Hence, the market supply curve represents the amount that will be produced in the market at the various prices. The demand curve represents the consumers in the market, and individual demand curves indicate how much consumers are willing to buy at various prices (Pindyck & Rubinfeld, 2009). The basis for an individual demand curve is therefore the consumer's marginal willingness to pay (MWTP) for a good. The MWTP indicates the highest price a consumer is willing to pay for the next unit (Kolstad, 2011). In principle, a consumer's MWTP for a good should only depend on the price of the good. Hence, the demand curve should only incorporate the substitution effect of a price change, which refers to the change in the consumption of a good due to a change in its price relative to other goods. This is represented by a compensated, or Hicksian, demand curve. Hence, a compensated demand curve shows the relationship between the price of a good and the quantity demanded when the consumer's level of utility and the price of other goods remain constant. However, changes in the price of a good, and thereby the demand curve, will also result in an income effect. This effect refers to the change in the consumption of a good due to a change in the purchasing power (Pindyck & Rubinfeld, 2009). The two separate effects and the difficulty of holding the utility constant makes it hard to directly estimate a compensated demand curve. The Marshallian demand curve, which combines both effects, is therefore generally used as an approximation. Hence, the market demand curve is found by adding the individual Marshallian demand curves, and it represents the total demanded quantity of the good at various prices (Boardman, Greenberg, Vining, & Weimer, 2011).

When the supply and demand curves interact in the market, the intersection represents the market equilibrium. This equilibrium, illustrated by point "a" in Figure 3, is found where the quantity supplied equals the quantity demanded. This point determines the market price (P*) and the total quantity produced in the market (Q*). This tendency for the price to change until the market clears is known as the market mechanism (Boardman et al., 2011).

Figure 3: Supply, demand, and the market equilibrium



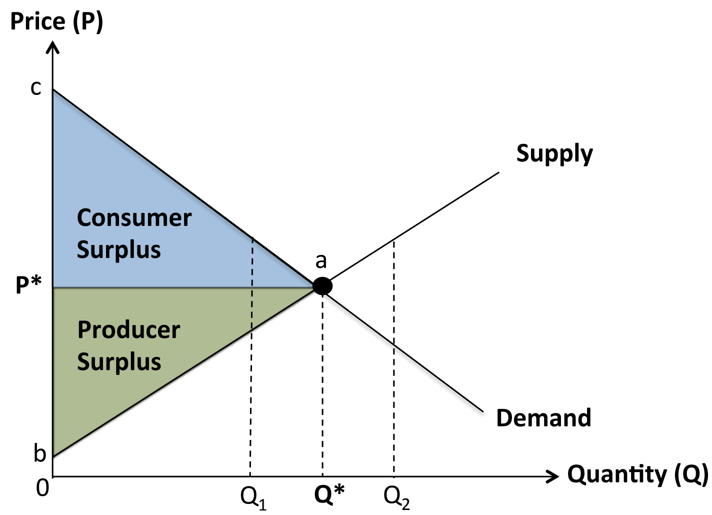
4.1.2. Consumer and producer surplus

As mentioned, the demand curve represents the consumers' MWTP for a good. The consumers' total willingness to pay (WTP) is therefore represented by the area under the demand curve as it represents the sum of all the MWTP. The WTP for a good can be seen as a measure of the benefits of a good. In figure 3, the total benefits to the consumers from consuming Q* units at the price P* are therefore represented by the area under the demand curve up to Q* (area caQ*0). However, as consumers have to pay the market price P*, the area below P* represents the consumers' expenditures (area P*aQ*0). By subtracting these expenditures from the total benefits, the consumers' net benefits are found. This is referred to as the consumer surplus (CS) (Boardman et al., 2011). Hence, the CS measures the difference between the amount consumers are willing to pay for a good and the amount they actually have to pay. It can therefore be interpreted as the value consumers get from the good above what they have to pay for it. In Figure 3, the CS is represented by the area below the demand curve but above the market price (area caP*). The supply-side equivalent to CS is the producer surplus (PS), which measures the net benefit going to firms. It is the difference between the revenue producers receive from selling a good (area P*aQ*0) and their costs of producing the good (area baQ*0). In Figure 3, the PS is represented by the area above the supply curve but below the market price (area P*ab). The sum of the CS and PS is known as the total surplus (TS) and is often referred to as the social welfare (Kolstad, 2011).

4.1.3. Allocative efficiency

If a market is perfectly competitive, the market equilibrium will be efficient. Such equilibriums are also referred to as allocatively efficient outcomes as they result in socially optimal allocations of society's resources (Boardman et al., 2011). This is one of the fundamental results of microeconomic analysis, and it illustrates Adam Smith's theory of "the invisible hand" of competition. This theory states that, by letting markets operate without government intervention, the actions of self-interested producers and consumers will lead to socially optimal allocations of resources (Pindyck & Rubinfeld, 2009). This can be illustrated by considering the CS and PS of the equilibrium and other quantities in Figure 4.

Figure 4: Allocative efficiency

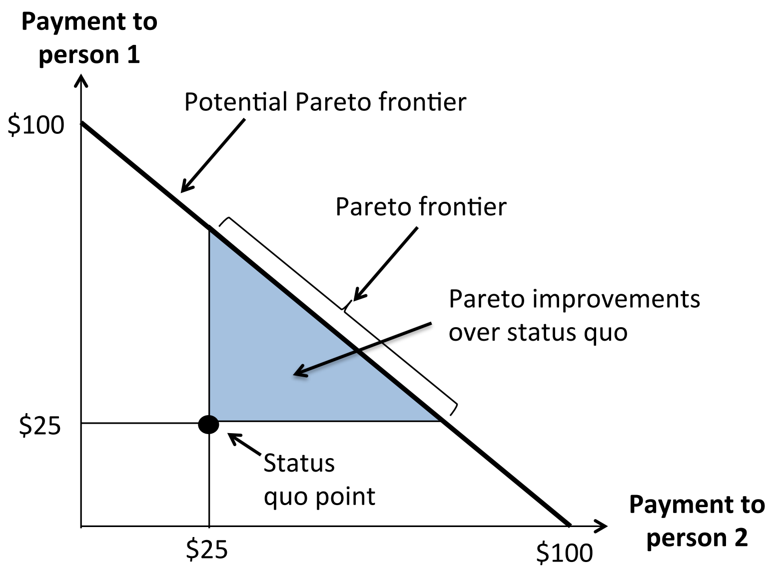


In a perfectly competitive market the equilibrium (Q*, P*) will result in a maximization of the TS as it maximizes the welfare of both producers and consumers. By supplying less than what is optimal (Q_1), it can be seen that the MC of supplying additional units (the supply curve) is lower than the MWTP for the additional units (the demand curve). An increase in the supply between Q_1 and Q* will therefore result in an improvement of the social welfare (TS). On the other hand, by supplying more than what is optimal (Q_2), the additional units are worth less to consumers than what it costs to produce them. Reducing the quantity between Q_2 and Q* will therefore result in an improvement in the TS. As a result, one can see that the market equilibrium Q*, P* is allocatively efficient (Pindyck & Rubinfeld, 2009).

4.1.4. Pareto efficiency

By allocating resources in a socially efficient manner there will be no "waste" of resources. This will be the case if there are no other allocations that will make someone better off without making anyone else worse off (Sandmo, 2003). Allocative efficiency is therefore often defined using the idea of Pareto efficiency. "An allocation of goods is Pareto efficient if no alternative allocation can make at least one person better off without making anyone else worse off." (Boardman et al., 2011, p. 27). This concept is illustrated in Figure 5 using a simple situation where 100 dollars are to be allocated between two individuals.

Figure 5: Pareto efficiency



In the extreme cases, one person gets 100 dollars while the other person gets nothing. The potential Pareto frontier is found by drawing a line between these two cases. This line represents all the possible ways one can split 100 dollars between the two. However, if they do not manage to agree on how to split the money, they will receive 25 dollars each. The point where they both receive 25 dollars is therefore called the status quo point. Based on this, the Pareto frontier is found by identifying the segment of the potential Pareto frontier that gives both individuals at least 25 dollars. As a result, the shaded area represents all possible allocations that will make at least one of the two better off than the status quo without making the other worse off. This possibility for one person to be better off without making the other one worse off means that the status quo is not Pareto efficient. Moving from the status quo to an allocation within the shaded area is therefore a Pareto improvement. Such improvements are possible until the allocation is on the Pareto frontier (Boardman et al., 2011).

4.1.5. Theorems of welfare

Welfare economics is the study of how decisions regarding the production, consumption and distribution of goods and services affect the well-being of people and the society as a whole. The efficiency of a competitive market and the idea of Pareto efficiency are two of the main principles within this study. They are therefore expressed in the two theorems of welfare. The first theorem states that the market equilibrium in a competitive market is Pareto efficient (Kolstad, 2011). This establishes that a competitive equilibrium will result in a socially optimal allocation of resources (Baujard, 2013). Hence, it states that the TS is maximized at the market equilibrium. The second theorem of welfare stretches the first theorem. It states that any Pareto efficient allocation can be achieved in a competitive market if the resources are "appropriately distributed before the market is allowed to operate" (Kolstad, 2011, p. 81). In other words, this theorem establishes that it is possible to achieve the preferred social optimum by using a redistribution policy to establish the initial allocations (Baujard, 2013).

4.2. MARKET FAILURE AND GOVERNMENT INTERVENTION

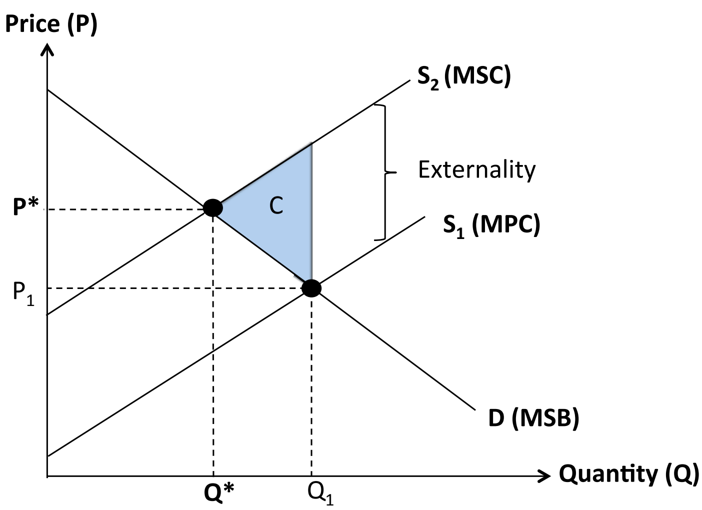
4.2.1. Conditions for a perfectly competitive market

Based on the two theorems of welfare, markets are better left alone if the objective is to achieve an efficient allocation of resources. However, these theorems only hold for perfectly competitive markets. Hence, the conditions for a perfectly competitive market need to be met in order for the TS to be maximized at the market equilibrium. First, for a market to be perfectly competitive, all consumers and producers have to be price takers. Hence, the market needs to consist of many small consumers and producers so that they cannot individually affect the market price. In a perfectly competitive market, producers maximize their profits and consumers maximize their utility, taking the price as given. In addition, for a market to be perfectly competitive the market should consist of homogenous products, there should be no transaction costs, and there should be no entry or exit barriers. Also, for the allocation to be efficient, all consumers and producers need to have access to perfect information about the price of the good, and there should be no externalities (Boardman et al., 2011; Kolstad, 2011; Pindyck & Rubinfeld, 2009). The theorems break down if one or more of these conditions are violated. If this happens, the prices will fail to give correct signals to consumers and producers regarding the full costs and benefits of a good. As a result, the affected market will fail to achieve an efficient allocation and the TS will not be maximized. This is referred to as market failure, and it is often associated with imperfect competition, externalities, imperfect information, and public goods (Pindyck & Rubinfeld, 2009). The focus of this thesis is market failure due to externalities.

4.2.2. Externalities

Externalities arise when the production or consumption of a good has an indirect effect on people that are not involved in the actual production or consumption of the good (third-parties). Hence, externalities arise when the producers and consumers of a good do not bear all the costs or capture all the benefits associated with the production or consumption of a good (Boardman et al., 2011). A positive externality will produce benefits and a negative externality will impose costs on third-parties. The focus of this thesis is negative externalities. Pollution is a classical example of a negative externality, as it represents a cost to society but not necessarily to the one that causes it (Wangensteen, 2005). For example, the production of electricity may result in a cost to society through emissions of GHGs. In the presence of a negative externality the marginal social cost (MSC) of production or consumption will exceed the marginal private cost (MPC) of production or consumption (Boardman et al., 2011). This is illustrated in Figure 6, where the production of a good results in a negative externality.

Figure 6: Negative externality in production



In Figure 6, S_1 is the original supply curve considered in the previous sections. This supply curve represents the MPC of production. S_2, on the other hand, is a supply curve that represents the MSC of production. This supply curve includes both the MPC incurred by the producers and the external costs inflicted on third-parties. Hence, the external cost (the externality) is represented by the gap between S_1 and S_2. In this market, the efficient allocation is represented by the intersection of the demand curve (D) and S_2. This equilibrium results in a supply of Q* units at the price P*. With this equilibrium, the negative external costs are taken into account. If the market in Figure 6 is left to its own device, however, the producers will only consider their MPCs, represented by S_1. In other words, the producers will decide on how much to produce without taking the negative external effects into account. This is due to the fact that, without government intervention, producers will have no incentives to consider these external costs inflicted on third parties. Hence, the point where the demand curve (D) and S_1 intersects will serve as the markets equilibrium and result in a supply of Q_1 units at the price P_1. This price will be too low and the quantity supplied will be too high relative to the efficient equilibrium (Boardman et al., 2011). In the presence of externalities, the producers' individual incentives will therefore no longer result in an efficient allocation of resources (Sandmo, 2003). Hence, it will result in an inefficient allocation from a social point of view. This is due to the fact that, for the production that exceeds the optimal quantity (Q*) the MSC (represented by S_2) will outweigh the marginal social benefits (MSB) (represented by D). Hence, the market will supply more than what is optimal and create what is referred to as a deadweight loss. With the production of Q_1 units, the deadweight loss is represented by the shaded area labelled C (Boardman et al., 2011).

4.2.3. Government intervention

In order to correct for a market failure caused by a negative externality the external costs have to be considered by the producers or consumers responsible for creating them. As governments can impose taxes and regulations on both producers and consumers, they have the power to force markets to consider these external costs (DeNyse, 2000). Negative externalities can therefore be removed, or at least reduced, through government intervention. Governments have many instruments at hand, but the ones most frequently used to address negative externalities are Pigouvian taxes, tradable permits, and technology- and performance standards.

A Pigouvian tax internalizes the external costs by imposing a tax on each unit equal to the marginal external cost (the difference between the MSC and the MSB). As this will result in the producers having to pay for each unit they produce, it will be in their best interest to reduce their production (Kolstad, 2011). Hence, the introduction of a Pigouvian tax will include the external costs in the production costs and result in a shift in the market supply curve from S_1 to S_2 (see Figure 6). This will result in an efficient market equilibrium with a supply of Q* units at the price P*. A Pigouvian tax is, according to economic theory, the first-best regulation when it comes to addressing negative externalities. This is partly due to the fact that it manipulates the market and uses the market mechanism to reduce the supplied quantity. It can, however, be difficult to assess the actual economic consequences of an externality, which is necessary in order to decide upon the correct tax level (Wangensteen, 2005). Tradable permits are fairly similar to a Pigouvian tax, in the sense that both inflict costs on the units produced. However, instead of having to pay for each unit they produce tradable permits make it possible for producers to buy and sell permits that allow them to emit and thereby produce. Hence, it is possible for producers to reduce their production and the associated emissions or pay to produce and cause emissions. Alternatively, if producers are given a certain amount of tradable permits, they will be able to sell their permits if they reduce their emissions. As a result, emissions will be given a price tag. Pigouvian taxes and tradable permits are both market-based instruments that aim at changing producers' or consumers' behaviour by affecting their costs. They give producers and consumers economic incentives that make them willing to produce or consume less. Standards, on the other hand, are known as regulatory instruments or command-and-control regulations because they limit producers' or consumers' production or consumption through restrictions. In other words, standards force producers or consumers to produce less. This might seem very straight forward, but it can be difficult to decide upon the stringency of the restriction. If the requirements in the standard are too strict, the costs of implementing a standard may be higher than the benefits it produces. If this happens, the government intervention will not be considered efficient (Kolstad, 2011).

4.3. COST-BENEFIT ANALYSIS

Negative externalities and other sources of market failure give a rationale for government intervention. By correcting for, or reducing, market failure, government interventions are expected to contribute to a more efficient allocation of resources. Hence, government interventions are meant to increase the social welfare. However, intervening in a market is not necessarily better than letting the market operate on its own. If, for example, the costs of an intervention exceed the associated benefits, the intervention will not represent an improvement in the social welfare. For an intervention to be an improvement compared to the current situation (status quo), it is necessary to demonstrate that it will result in an increase in the social welfare. Hence, an intervention will have to increase the social welfare in order to be justified. This may be assessed by conducting a CBA where the social costs and benefits associated with an intervention are evaluated (Boardman et al., 2011). A CBA is, in fact, one of the primary tools used to evaluate government interventions (Kolstad, 2011). It can be used to compare and evaluate an intervention relative to the status quo or alternative interventions. In other words, it can be used to determine whether an intervention can be justified or provide a basis for the comparison of alternative interventions (Norwegian Water Resources and Energy Directorate, 2003).

4.3.1. Net social benefits and Pareto efficiency

The objective of a CBA is to aid social decision making by identifying and measuring the positive and negative consequences of Government interventions (NOU 2012: 16, 2012). Simply put, a CBA is therefore conducted by measuring all the expected social costs and benefits associated with an intervention. Based on this, an intervention can be defined as socially efficient if the expected benefits exceed the expected costs. In order to evaluate this, an intervention's net social benefits (NSB) are found by subtracting the total costs from the total benefits. If the NSB are positive, an intervention's benefits will exceed its costs. Hence, a government intervention is considered socially efficient if its NSB are positive. The basic decision rule in CBA is therefore based on what is known as the NSB criterion stating that one should only accept a government intervention if it yields positive NSB. Hence, for an intervention to be justified, its NSB will have to be positive, and for an intervention to be seen as an improvement relative to the status quo its NSB need to be higher than the NSB of the status quo. If alternative interventions that are mutually exclusive are being compared, the intervention that yields the largest (positive) NSB is preferred, as it will yield the highest return to society and maximize the efficiency (Ward, 2006).

In CBAs, the goal of allocative efficiency is based on the concept of Pareto efficiency (see Section 4.1.4.). Hence, the concept of Pareto efficiency forms the conceptual basis of CBAs.

The link between the NSB criterion and Pareto efficiency can be explained by considering the following. If a government intervention results in positive NSB, the benefits associated with the intervention exceed the costs. As a result, it will be possible for the ones reaping the benefits from the intervention to compensate those who bear the costs, and still be better off. The possibility for such transfers or side-payments will make at least one person better off without making anyone else worse off. Hence, as an intervention with positive NSB indicates the possibility to compensate those who bear the costs, it will be Pareto improving as it can improve the economic efficiency (Boardman et al., 2011). The Pareto efficiency principle is very appealing. However, actually compensating the ones bearing the costs would be very demanding (see Boardman et al., 2011, p. 31). A *potential* Pareto efficiency rule is therefore applied in practice. Potential Pareto efficiency is based on the Kaldor-Hicks criterion, which states that one can justify a government intervention if those who will gain from the intervention *could* compensate those who bear the costs and still be better off. In other words, for an intervention to be justified it is not necessary to actually compensate those who bear the costs. It is sufficient to show that it would be possible to compensate them. Hence, the goal of a CBA is to determine whether an intervention has the potential to be Pareto improving. This is the case if the NSB of an intervention are positive, as it implies that it is possible to compensate the people that bear the costs so that some people are made better off without making someone worse off (Boardman et al., 2011).

4.3.2. Measuring costs and benefits

For most government interventions some people will like the consequences and be willing to pay for them, while others will dislike the consequences and be willing to pay to avoid them. The former will see the consequences as benefits, while the latter will see them as costs[3], or negative benefits. For example, if an intervention results in a decrease in the price of a good, the consumers of the good will most likely see this as a benefit. The producers, on the other hand, will see this as a negative benefit. By adding all positive and negative benefits one will get to know how the society value the intervention. In addition to these positive and negative benefits, a government intervention will normally require some resources in order to implement it. These resources can, for most interventions, be divided into the broad categories of capital, materials, and labour. In order to evaluate whether the NSB of an intervention are

[3] In order to avoid confusion between these costs and the costs associated with the implementation of an intervention, these costs are often referred to as negative benefits.

positive or not, all costs and benefits have to be measured in monetary terms. In CBAs, the concepts of opportunity cost and WTP (willingness to pay) are used as the guiding principles for measuring these costs and benefits (Boardman et al., 2011).

4.3.2.1. Willingness to pay and opportunity costs

The basis for the valuation of the consequences of an intervention should be what the society would be willing to pay to obtain or avoid the changes caused by the intervention (Norwegian Government Agency for Financial Management, 2010). The notion of willingness to pay (WTP) is therefore considered the conceptually correct measure of the consequences of an intervention. A person's WTP expresses the subjective valuation of a good or service. Hence, it reflects the maximum amount of money a person would be willing to pay to obtain a good or a service. If, on the other hand, people are willing to pay to avoid the consequence, the term willingness to accept is used. This is often converted into a negative WTP. The WTP of all affected individuals, both positive and negative, are then summed up in order to find the total WTP for an intervention. The WTP for a good or service can therefore be found by considering the demand curve in the appropriate market. This will, however, be challenging if the market does not work well or if there is no market for the good or service. The WTP for such goods and services can be estimated through various nonmarket valuation methods. The two main nonmarket valuation methods are the revealed preference method (infer peoples' WTP from their behaviour) and the stated preference method (ask people what they would be willing to pay). Obtaining estimates through such methods can be quite time consuming, especially when it comes to valuing environmental impacts. As a result, most CBAs draw upon previous research and studies on the WTP for the goods they want to include in their analysis (Boardman et al., 2011). I will not go any further into these valuation methods as they are beyond the scope of this thesis.

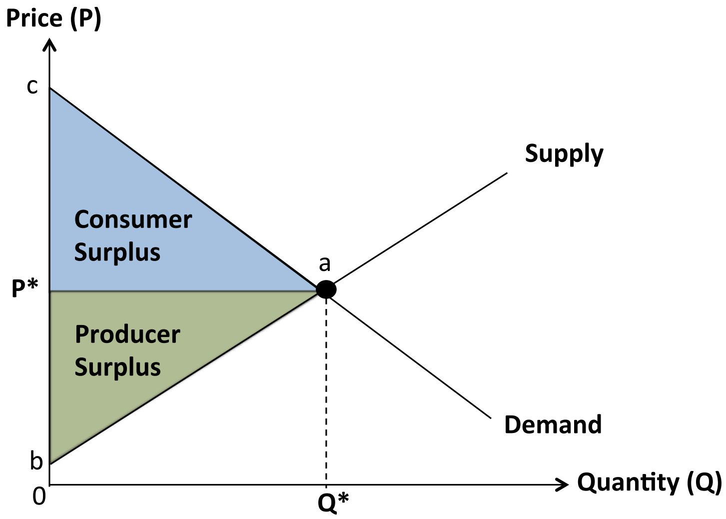
When it comes to the value of the resources needed to implement an intervention, opportunity costs are considered the conceptually correct measure. This is due to the fact that these resources could, potentially, have been used to produce other goods or services. An opportunity cost reflects the value the society needs to refrain from by using a resource in a specific government intervention instead of in its next best use. Hence, an opportunity cost represents the marginal social cost associated with an intervention, which is represented by the area under the supply curve. In a perfectly competitive market, the market price will reflect the opportunity cost of the use of a resource. Hence, when the market for a resource is efficient, the opportunity cost can be found by looking at the market price of the resource. The market price is, in fact, often seen as the most natural way to measure the cost of using resources. However, if the market for a resource is distorted, for example due to market failure or government intervention, the market price may overstate or understate the opportunity cost. In such cases, the market price will have to be corrected for market failure or adjusted in order to reflect the true opportunity cost. For example, if a market is distorted due to a negative externality like pollution, it is necessary to consider both the market price and the external cost of pollution (Norwegian Water Resources and Energy Directorate, 2003). For capital and materials, the market price is normally identical to the opportunity cost due to the existence of efficient markets. For labour, however, the opportunity cost may differ due to varying labour market conditions. Under perfect competition, market wages will serve as the opportunity cost of labour. If there is unemployment, however, the opportunity cost of labour will not equal the wage because the next best "use" of a worker will be represented by unemployment. With unemployment, the opportunity cost is therefore often set to zero due to the fact that it can be argued that unemployed workers would not have been employed in a productive way if it were not for the intervention.

The use of WTP and opportunity cost can be illustrated by imagining that an intervention affects three people. Person 1 and 2 see the outcome of the intervention as desirable while person 3 sees the outcome as undesirable. Person 1 and 2 would therefore be willing to pay for the intervention while person 2 would be willing to pay to avoid it. More specifically, person 1 is indifferent between the current situation and having to pay 100 dollars to see the government intervention come into effect. For person 2 the value that result in such an indifference is 200 dollars. Hence, person 1 and person 2 have a total WTP for the government intervention of 300 dollars. Person 3, on the other hand, is indifferent between the current situation and the government intervention if he receives 250 dollars if the intervention is implemented. This amount represents person 3's willingness to accept, or negative WTP. The total benefit of this government intervention can be found by adding these individual valuations of the intervention's consequences. Hence, the total benefits of this intervention are 50 dollars (100 + 200 + (-250)). To obtain the net benefits of this intervention, the opportunity cost of the resources used are then subtracted from these benefits. If the opportunity costs were estimated to 20 dollars, the intervention would therefore generate a net benefit of 30 dollars (Boardman et al., 2011).

4.3.2.2. Net social benefits and total surplus

As was seen in Section 4.1.2., the CS represents the total benefit consumers get from the consumption of a good beyond what they have to pay for it. Under most circumstances, changes in the CS can therefore be used as an approximation of peoples' WTP to obtain or avoid the consequences of an intervention[4]. Change in the CS resulting from an intervention can therefore be used to measure an intervention's positive and negative benefits to consumers. The PS is the equivalent measure for producers. Hence, changes in the PS can be used to measure an intervention's impact on producers. The changes in the TS in the relevant markets, found by summing the changes in CS and the PS, can therefore be used to measure the impacts an intervention has on both consumers and producers (Boardman et al., 2011). Under most circumstances, the TS is therefore equivalent to the NSB. This can be illustrated by considering Figure 7.

Figure 7: Net social benefits and total surplus



With a market equilibrium where Q* units of the good are supplied at the price P*, the CS and the PS are represented by the areas "caP*" and "P*ab" in Figure 7 respectively. Hence, the TS is represented by the area "cab". By looking at the same figure, the total benefits are represented by the area "caQ*0" and the total costs are expressed by the area "baQ*0". The NSB, found by subtracting the costs from the benefits, are therefore represented by the area "cab". Hence, the TS equals the NSB (Boardman et al., 2011). The maximization of the TS (aggregate CS and PS) will therefore result in a potential Pareto efficient allocation of

[4] For more on this, see Appendix 3A in Boardman et al. (2011).

resources (Kolstad, 2011). In addition, many CBAs consider an intervention's effect on the government. This effect can be both positive, in the sense of a tax income, and negative, due to expenditures. The net impact on a government is called the government surplus (GS). The total costs and benefits associated with an intervention are therefore often determined by considering the resulting changes in both the TS and the GS (Boardman et al., 2011). When both the TS and the GS are considered, it is important to remember that the use of taxes will cancel out. This is due to the fact that taxes will be seen as a cost to producers and consumers (the TS) and a benefit for the government (the GS).

In principle, it would be quite straightforward to estimate the changes in CS, PS and GS resulting from an intervention. In practice, however, the measures used to evaluate the benefits and costs associated with an intervention often differ somewhat from the conceptually correct measures of costs and benefits. This is mainly due to practical problems associated with deriving the relevant supply and demand curves (Boardman et al., 2011). The actual costs and observed prices associated with an intervention are therefore often included in CBAs. If the market is affected by externalities, however, these costs might differ from the opportunity costs. In such cases, the externality can be considered in the analysis by adding an external cost separately. This approach is recommended in the valuation of costs and benefits by the Norwegian Government Agency for Financial Management (2010). Hence, the conceptually correct measures are not always used in practice. It is, however, valuable to be familiar with these measures as they can serve as a benchmark for the measures used in practice (Boardman et al., 2011).

4.3.3. Discounting of costs and benefits

The costs and benefits associated with government interventions often arise in multiple time periods. For example, if a government spends money on an intervention meant to reduce future emissions of CO_2, the benefits will most likely arise in the future. In order to evaluate and compare government interventions, all costs and benefits have to be expressed in cash-equivalent values of a particular time. This is done by discounting the costs and benefits from different time periods to a chosen reference year (NOU 2012: 16, 2012). The most common approach to discounting is to convert all future costs (C) and benefits (B) into present values (PV) by applying a discount rate (*i*) for each year (*t*) over the analytical time horizon (*n*). This is done using Equations 1 and 2, showing the present value of benefits and costs respectively.

$$PV(B) = \sum_{t=0}^{n} \frac{B_t}{(1+i)^t} \tag{1}$$

$$PV(C) = \sum_{t=0}^{n} \frac{C_t}{(1+i)^t} \tag{2}$$

After having found the present value of the benefits, PV(B), and the costs, PV(C), the net present value (NPV) can be found by subtracting the PV(C) from the PV(B). Alternatively, the NPV can be found directly by discounting the NSB using Equation 3 or 4. Hence, the NSB in year t can be converted to its present value by dividing it by $(1+i)^t$ or by multiplying it with the discount factor (DF) $1/(1+i)^t$ (Boardman et al., 2011).

$$NPV = \sum_{t=0}^{n} \frac{NSB_t}{(1+i)^t} = \sum_{t=0}^{n} \frac{(B-C)_t}{(1+i)^t} \tag{3}$$

$$NPV = \sum_{t=0}^{n} DF_t \cdot NSB_t \tag{4}$$

By looking at these equations it can be seen that the NPV of an intervention is the same as the present value of the NSB. Hence, if the NPV of an intervention is positive, the present value of the NSB is positive (Boardman et al., 2011). The NSB criterion (see Section 4.3.1.) can therefore be rewritten to a NPV criterion stating that an intervention can be justified if the NPV is positive. This is due to the fact that a positive NPV indicates that an intervention will be positive for the society as a whole. As for the NSB criterion, if two or more interventions are being compared, the intervention with the highest NPV should be chosen if there are multiple alternatives that are mutually exclusive (Ward, 2006).

4.3.3.1. The rationale for discounting

The need to discount future values arises from the generally accepted idea that a given amount (for example 100 NOK) in the future is worth less than the equivalent amount today. As a result, costs and benefits that arise in multiple time periods are not directly comparable. The difference in the value of current and future resources is based on two ideas. First, there is an opportunity cost connected to the use of resources (Boardman et al., 2011). This is due to the fact that, by using a resource today, all other alternative uses of that specific resource are ruled out. For example, instead of using a given amount of money on a government intervention, it could have been deposited in a bank. The amount would then have increased over time due to a positive interest rate. The opportunity cost is then reflected by the highest alternative rate of return one could have received on the invested money (NOU 2012: 16, 2012). Second, people tend to prefer consumption today rather than in the future. For example, people will generally value 100 NOK today more than 100 NOK in a year. This is referred to as time preference and it is reflected by peoples' decisions with respect to investments and savings (Boardman et al., 2011). The ideas of opportunity cost and time preference are conceptually different, but they both result in a higher valuation of present costs and benefits relative to future costs and benefits. This trade-off between different periods can be taken into account by applying a discount rate that represents the weight given to cash flows or, in the case of CBA, future costs and benefits (Kolstad, 2011). In addition, future cash flows or costs and benefits are subject to uncertainty. This is due to uncertainties in the development in the economy and the outcome of interventions. This is a contributing factor to why one cannot place the same weight on present and future benefits. The discount rate should therefore consist of a risk-free rate reflecting the trade-off between different periods (the opportunity cost and time preference) and a risk premium reflecting the uncertainty with respect to the future (NOU 2012: 16, 2012).

4.3.3.2. Private and Social discount rate

This approach to NPV and the reasoning behind discounting is used in the evaluation of both private and social investments. While a CBA compares the social costs and benefits of a government intervention (i.e., a social investment), individuals and companies evaluate the private costs and profits (cash flows) of their investments. As the costs and profits associated with private investments also often occur at different points in time, companies calculate the present value of investments' future cash flows. What separates the evaluation of private investments and government interventions is the discount rate, i (Pindyck & Rubinfeld, 2009). In the evaluation of private investments, i represents the private discount rate, which is also referred to as the market discount rate. The focus of this discount rate is individuals' or firms' opportunity costs and time preference, and it is normally set by considering the market interest rate. In the evaluation of social investments like government interventions, however, i represents the social discount rate (SDR). This discount rate reflects the society's opportunity cost and time preference, as the outcomes of government interventions will affect the society as a whole. In CBAs, the SDR is therefore applied in order to find the present values of all future social costs and benefits (Pindyck & Rubinfeld, 2009).

4.3.3.3. The social discount rate

The SDR is a very important aspect of CBAs because it can have significant impacts on the desirability of government interventions. As the SDR represents the rate at which future costs and benefits are discounted, it will affect the weight given to future costs and benefits. The SDR will therefore determine the value of future costs and benefits relative to the current costs and benefits. Hence, the SDR will affect the present value of the net benefits. This is especially important if the costs and benefits occur over longer periods. While a low rate will result in future values being valued relatively high compared to the current, a higher rate will value effects today higher than effects in the future. Hence, future costs and benefits will not matter very much if the discount rate is relatively high. A larger SDR will therefore weaken the case for interventions where most of the benefits occur in the future (Boardman et al., 2011). The choice of the SDR in a CBA is therefore a very debated topic. As the choice of the SDR can be subject to many value judgements, there are many different opinions as to what the appropriate SDR should be. There is, however, a general consensus that it should be lower than the private discount rate. This is partly due to the fact that it is argued that the SDR should be based on ethical judgments in addition to the market process. This argument is based on the fact that government interventions affect the society as a whole and often result in benefits far into the future. As a high SDR will result in a very low value for benefits that lie far into the future, a relatively low SDR is necessary in order to apply sufficient weights to benefits in the future and for future generation (Kolstad, 2011). For example, with a SDR of 5%, one can only justify spending about 0.76 NOK today to avoid a damage of 100 NOK occurring in 100 years from now. With a SDR of 1%, however, one can justify spending about 37 NOK in order to avoid the damage of 100 NOK in 100 years.

There are two main approaches used in order to find an appropriate SDR. First, it is possible to find a SDR by considering alternative investments in the financial markets. This is referred to as a market based SDR. The problem with this approach is that one cannot find information about financial investments for more than 35 to 40 years. Hence, problems may arise if the government intervention being considered has impacts beyond 40 years (Hagen, 2012). The second approach is based on Ramsey's optimal saving model. This model includes the time preference, the expected economic growth, and the marginal utility of consumption. As a result, it combines the preference for the present and how much more important the current generation is compared to future generations due to the fact that we are relatively poorer. The problem with this approach is that the three values in the model have to be estimated. This SDR will therefore most likely be based on many subjective evaluations[5] (Kolstad, 2011). In Norway, the Ramsey model was used to find the SDR from 1967 to 1999. Today, however, the main rule is that one should use market-based estimates for the SDR with a risk-free rate and a risk premium (NOU 2012: 16, 2012).

In practice, many government agencies specify or recommend a SDR that should be used in CBAs of government interventions (Boardman et al., 2011). In Norway, a real risk-adjusted SDR of 4% is recommended for the discounting of costs and benefits associated with government interventions that arise within 40 years of the implementation. This rate can be divided into a risk-free rate of 2.5% and a risk premium of 1.5%. The risk-free rate is based on the assumption that one can secure a risk-free real interest rate of 2.5% by investing money in the financial market (the opportunity cost). More specifically, it is based on the expected return on the Government Pension Fund. As mentioned, one cannot find information about financial investments for more than 35 to 40 years. As a result, for impacts beyond 40 years the SDR should be determined based on a certainty-equivalent rate. This has resulted in a recommendation of a real risk-adjusted SDR of 3% for impacts that arise in year 41 until year 75 and a real risk-adjusted SDR of 2% for all years after year 75 (NOU 2012: 16, 2012). These recommendations are outlined in Table 2.

Table 2: The social discount rate for Norwegian cost-benefit analyses

	YEARS 0-40	YEARS 41-75	AFTER YEAR 75
Risk-free rate	2.5%	2 %	2 %
Risk premium	1.5%	1 %	0 %
Real risk-adjusted SDR	**4 %**	**3 %**	**2 %**

Based on Table 5.2. in NOU 2012: 16 (2012).

Hence, for interventions that do not have impacts beyond 40 years, a constant SDR is suggested to be appropriate. For interventions with costs and benefits beyond 40 years, however, a time-declining SDR is recommended. This corresponds with the recommendations

[5] For more information about these methods, see Pindyck & Rubinfeld (2009, p. 667), Kolstad (2011, p. 121), and NOU 2012: 16 (2012).

from Boardman et al. (2011). With a time-declining SDR, effects in the far future will be given more weight than what they would have been given with a constant SDR (Boardman et al., 2011). When a time-declining SDR is used it is important to remember that values in a specific period have to be discounted at the same SDR. For example, an impact in year 50 will have to be discounted from year 50 to year 40 by applying a SDR of 3% and from year 40 to year 0 by applying a SDR of 4% (NOU 2012: 16, 2012, p. 71).

4.3.4. Recipe

In order to ease the process of conducting a CBA, it can be broken down to the following nine steps (Boardman et al., 2011).

1. Specify the projects, policies or regulations the analysis will focus on.
2. Decide whose costs and benefits the analysis will take into account.
3. Identify the impacts (costs and benefits) and decide upon how they will be measured.
4. Predict the costs and benefits over time.
5. Attach a monetary value to the costs and benefits.
6. Discount the costs and benefits to obtain present values.
7. Calculate the NPV.
8. Perform a sensitivity analysis.
9. Make a recommendation based on the NPV of the original- and the sensitivity analysis.

4.3.5. Problems and limitations

One of the major limitations of CBAs is related to the difficulty associated with the valuation of costs and benefits. It is often hard to quantify the WTP for a benefit as demand and supply curves may be hard to find. Sometimes, it is even impossible to value a benefit in monetary terms. In such cases, benefits are often mentioned and discussed without being given a monetary value (Kolstad, 2011). For example, if the NPV of a CBA turns out to be slightly negative, an omitted benefit might be discussed in order to argue that the NPV could have been positive if this benefit was monetized. Another limitation is related to the NPV criterion of a CBA. As the recommendation based on the NPV criterion only applies to the alternatives evaluated in the CBA, it will not necessarily result in the most efficient allocation. It will result in a more efficient allocation, but in order to find the most efficient allocation all alternatives need to be evaluated. Hence, an intervention with a positive NPV is said to be Pareto improving, not Pareto efficient (Boardman et al., 2011). A third problem with CBAs is related to the fact that such analyses do not take into account who bears the costs and who reaps the benefits (Kolstad, 2011). A CBA measures the net effect on society's welfare. Hence, the NPV criterion makes it possible to make a trade-off between a person's costs and another person's benefits. As a result, inflicting a cost on someone can be justified if the benefits received by someone else exceed these costs. As seen earlier, this is justified through the idea of Pareto efficiency, where the beneficiaries may compensate the ones who bear the costs. Some people argue that it should not be possible to make such trade-offs (NOU 2012: 16, 2012). Despite these problems, the CBA framework represents an important contribution to the evaluation of government intervention.

5. COST-BENEFIT ANALYSIS

As was mentioned in Section 3.3, a tightening of the energy requirements in the Technical Building Regulation is planned to come into effect in 2015. In order to assess whether this tightening is likely to be positive for the society as a whole, a CBA was conducted with respect to some of the social costs and benefits associated with these stricter energy requirements. More specifically, this CBA consisted of an evaluation of the difference between the costs and benefits associated with a building that meet the energy requirements in TEK10 and a building with the Passive House Standard. This was done in order to find out how stricter energy requirements are expected to affect these costs and benefits. The goal of this CBA was to evaluate whether the increased benefits associated with this tightening are likely to exceed the increased costs related to the tightening.

This CBA was based on the steps in the recipe in Section 4.3.4.. For the sake of clarity, however, many of these steps were combined. The assumptions, estimations and results of the analysis will be presented in the following sections. In Section 5.1., the first and the second step of the recipe will be presented. Hence, it will include a presentation of the regulations and projects that were the focus of this CBA and a presentation of whose costs and benefits it took into account. Section 5.2., will include step 3 as it will identify the impacts that were the focus of the analysis and explain how they were measured. Moving on, Section 5.3. will cover steps 4, 5, 6, and 7. This section includes the estimation of all input values and the calculation of the costs, benefits, NSB and NPVs of each project. Combining these steps is expected to clarify the CBA as it makes it possible to present all calculations in one model. Section 5.4. will then include step 8. Hence, it will explain how a sensitivity analysis was conducted in order to test the assumptions and results of the original analysis. Lastly, Section 5.5. will go through step 9, which consist of the recommendation based on the NPVs of the original analysis and the sensitivity analysis.

All the estimations and calculations in this CBA were based on a number of assumptions. First, the analysis was based on the idea that two buildings of each building type were to be constructed in 2014 and be made operational in 2015. These buildings were thought to be identical, except for the fact that one would meet the energy requirements in TEK10 while the other would comply with the energy requirements in the Passive House Standard. Second, the analysis was based on a time horizon of 60 years. This seems like a reasonable time horizon as buildings are expected to have a long lifetime. Hence, the costs and benefits that are expected to arise within 60 years after the buildings are made operational were assessed in this CBA. A third assumption is related to the monetary value given to the various costs and benefits. It was decided that all costs and benefits should be measured in constant 2013 prices. Also, as this is a social CBA, no taxes were included in the valuation of the costs and benefits. This assumption was based on the fact that, the effect of taxes would cancel out as they will be positive for some parts and negative for other parts.

5.1. THE FOCUS OF THE ANALYSIS

The first step of a CBA involves the specification of the alternative projects, policies or regulations the analysis will focus on. As mentioned previously, the focus of this thesis is the tightening of the Norwegian Technical Building Regulation. Hence, the focus of this CBA was the energy requirements in the current and the upcoming Norwegian Technical Building Regulation, TEK10 and TEK15. The exact requirements of TEK15 are not yet decided upon, but they will most likely be based on the requirements set forward in the Passive House Standard. In this CBA, the energy requirements in the Passive House Standard were therefore expected to represent the tightened energy requirements in TEK15. Hence, in the analysis of this thesis, the calculations were based on buildings built according to the energy requirements in TEK10 and the Passive House Standard. In the following, a building that meet the energy requirements in TEK10 will be referred to as a TEK10 building, and a building that meet the energy requirements in the Passive House Standard will be referred to as a PHS building.

More specifically, the focus of this analysis was the energy requirements for commercial buildings. In the Technical Building Regulation, 11 building types are listed as commercial buildings; office buildings, hotels, hospitals, universities, office buildings, school buildings, cultural buildings, kindergartens, nursing homes, sports buildings and workshops. Hence, commercial buildings include building used for all kinds of employments, both public and private (Norwegian Building Authority, n.d.). The size and the net energy need of these buildings vary. In order to evaluate how stricter energy requirements are expected to affect buildings of various sizes and various net energy needs, four of these building types were included in the analysis. Hence, the costs and benefits related to a sports building, a school building, a kindergarten, and an office building were included in the analysis. The size and upper limits for the net energy need of these buildings are listed in Table 3.

Table 3: The size and net energy need of the four building types

	SIZE (m^2 GRA)	NET ENERGY NEED TEK10 ($kWh/m^2/year$)	NET ENERGY NEED PHS ($kWh/m^2/year$)
Sports building	2130	170	100
School building	6800	120	75
Kindergarten	800	140	65
Office building	5000	150	75

After having specified the alternative projects, policies or regulations, one has to decide whose costs and benefits the analysis will take into account (standing). Governments often focus on the national costs and benefits. However, many critics argue that the global costs and benefits should be analysed, especially when environmental issues are included in the analysis. This is due to the fact that such projects, policies and regulations are likely to affect people beyond borders (Boardman et al., 2011). In the analysis of this thesis, the costs and benefits were assessed from a global perspective. This decision was based on the fact that the regulation might affect the global emission of GHGs due to the transboundary state of GHGs and the common European electricity market.

5.2. THE COSTS AND BENEFITS INCLUDED IN THE ANALYSIS

The third step of a CBA deals with the identification of the impacts of the alternative projects, policies or regulations in terms of costs and benefits. In this analysis, it is important to note that the costs and benefits were based on the difference in the costs and benefits of a TEK10 building and a PHS building. Hence, the costs and benefits in this CBA measure the impacts associated with the tightening of the energy requirements in the Technical Building Regulation. The main objective of the energy requirements in the Technical Building Regulation, and the tightening of these requirements, is to contribute to a reduced net energy need and a more environmental friendly energy supply in buildings. This alone may result in many benefits, both private and social. The reduction in a building's energy consumption may, for example, result in lower energy costs, reduced risk with respect to higher energy prices, and it may reduce the emission of GHGs. The energy requirements in the Technical Building Regulation may also result in improved indoor quality due to stricter requirements with respect to ventilation. This may result in an increased productivity and health benefits for employees in such buildings. By fulfilling stricter energy requirements, the value of a building may also increase due to the fact that it may be thought to be of higher quality. On the other side, the fulfilment of stricter energy requirements is likely to increase the costs associated with the construction of buildings. Increased costs could, again, lead to a reduction in the construction of new buildings, and thereby hurt the building sector (Low-Energy Programme, n.d.; World Green Building Council, 2013). Some of these costs and benefits are fairly predictable, while others are quite difficult to predict. Due to the limited time frame of this thesis, the CBA focused on the following three impacts.

5.2.1. Increased construction costs

Stricter energy requirements in the Technical Building Regulation are likely to require more planning, better building components, more materials, and the use of new technologies. This is expected to increase the total construction costs of the various building types. In this analysis, the expected increase in the construction costs were measured by the difference between the costs per m^2 (NOK/m^2) related to the construction of a PHS building and a TEK10 building. Hence, the expected increase in the construction costs associated with stricter energy requirements for a building was measured using Equation 5.

$$Increased\ costs = Costs\ PHS\ building - Costs\ TEK10\ building \tag{5}$$

These increased costs will only appear once for each building as they are related to the construction of the building. They were therefore assigned to one year (year 0) in the analysis. Section 5.3.1. explains how these costs were estimated for the purpose of this analysis and presents the increased construction costs for each building type.

5.2.2. Reduced energy costs

Stricter energy requirements in the Technical Building Regulation will most likely result in a reduction in buildings' energy consumption, and thereby its need for supplied energy. This will result in reduced energy costs for those who own or rent the building. This private benefit of a building's reduced energy costs will, in the following, be referred to as an energy benefit. In the analysis, this benefit was measured based on two factors; (1) the difference in the expected level of supplied energy to TEK10 buildings and PHS buildings and (2) the expected future electricity prices. The energy benefits for each year (t) were measured using Equation 6, where the difference in the supplied energy of the two buildings for year t is multiplied with the expected electricity price for that year.

$$Energy\ benefit_t = Difference\ in\ the\ level\ of\ supplied\ energy_t \cdot Electricity\ price_t \quad (6)$$

The expected level of supplied energy in the various buildings was expressed as kWh per m^2, while the yearly electricity prices were expressed as NOK per kWh. As a result, the energy benefit was measured as NOK per m^2. Section 5.3.2. and 5.3.3. explain how these values were estimated and present the expected level of supplied energy to the various building types and the expected future electricity prices.

5.2.3. Reduced emissions

In addition to a reduction in energy costs, a reduction in buildings' energy consumption may result in a reduction in the emissions of GHGs. Also, the Technical Building Regulation's focus on environmental friendly energy supply in buildings may contribute to a reduction in the emission of GHGs. This social benefit of a building's reduced emissions will, in the following, be referred to as an environmental benefit. In the analysis, this benefit was measured based on three factors; (1) the difference in the expected level of supplied energy to TEK10 buildings and PHS buildings, (2) the expected future emission factors for electricity, and (3) the expected future emission prices. The environmental benefits for each year (t) were measured using Equation 7. Hence, the reduction in yearly emissions was first found by multiplying the difference in the supplied energy with the future emission factor for electricity. The value of this reduction was then found by multiplying the yearly reduction in emissions with the expected emission prices.

$$Environmental\ benefit_t = Difference\ in\ the\ level\ of\ supplied\ energy_t \cdot Emission\ factor_t \cdot Emission\ price_t \quad (7)$$

The expected level of supplied energy was measured as kWh per m^2, the future emission factors of electricity were specified in t CO_2e per kWh of electricity, and the future emission prices were stated as NOK per t CO_2e. As a result, the environmental benefit was also measured as NOK per m^2. Section 5.3.2., 5.3.4., and 5.3.5. explain how these values were estimated and present the expected level of supplied energy to the various building types, the expected future emission factor for electricity, and the expected future emission prices.

5.3. INPUT VALUES AND CALCULATIONS

As seen in Section 5.2., the values needed in order to measure the three impacts associated with stricter energy requirements are:

- The difference in the construction costs of TEK10- and PHS buildings (NOK/m^2)
- The difference in the level of supplied energy to TEK10- and PHS buildings (kWh/m^2)
- Future electricity prices (NOK/kWh)
- Future emission factors of electricity (t CO_2e/kWh)
- Future emission prices (NOK/t CO_2e)

Hence, in order to predict and attach a monetary value to the costs and benefits associated with stricter energy requirements, it was necessary to estimate these values. In the following, the assumptions and methods used to estimate these values over the lifetime of the various building types will be presented (Sections 5.3.1. – 5.3.5.). The SDR used to calculate the NPVs of the various building types will also be introduced (Section 5.3.6.). The estimated values, the SDR and the discount factors will then be summed up in two tables (Section 5.3.7.). Lastly, the costs and benefits, the NSB, and the NPVs for each building type, estimated based on these input values, will be presented (Section 5.3.8.).

5.3.1. Construction costs

The expected construction costs of TEK10 and PHS buildings were estimated using a program called ISY Calcus. This is a calculation tool used to estimate the costs associated with the construction of various building types[6]. Users are given the possibility to either develop an individual project or to use one of the 40 predefined building projects (Norconsult Informasjonssystemer, n.d.). In this analysis, the estimated construction costs were based on 8

[6] ISY Calcus was developed by Norconsult Informasjonssystemer in cooperation with AS Bygganalyse. Norconsult is a Norwegian company that provides IT solutions for the design, construction and management of infrastructure and property and AS Bygganalyse is a Norwegian company that provides products and services within building economics.

predefined building projects; one TEK10 building and one PHS building for each of the 4 different building types. The estimated costs in ISY Calcus for these building types are based on predictions about the hours of work needed (labour), the use of materials and equipment, and predefined databases with updated standard costs of labour, materials, and equipment. These costs are likely to coincide with the opportunity costs of the construction of a building under the assumption that the materials and equipment used in the construction are not scarce resources, and that there is no unemployment.

In ISY Calcus, the estimated construction costs are split into 10 categories; (1) overhead costs, (2) costs related to the building structure, (3) costs connected to the heating, ventilation and sanitary installations, (4) costs related to the electrical power system, (5) costs related to telecommunication and automation installations, (6) costs of other installations, (7) costs of outdoor structure and facilities, (8) general costs, (9) special costs, and (10) contingency costs. (See Appendix B for a more specific overview over what these categories include.) In this analysis, the value added tax was not included. This is due to the fact that taxes cancel out in social CBAs, as they turn up as a negative post for the constructor and a positive post for the government. In addition, most of the estimates in ISY Calcus do not consider the financial costs and the costs of outdoor structure and facilities. The value added tax and the financial costs make up category 9, and the outdoor structure and facilities make up category 7. Categories 7 and 9 were therefore not included in the cost estimations.

After having estimated the construction costs for all buildings (one TEK10 building and one PHS building for each of the four building types), the difference between the various TEK10 and PHS buildings were found. For example, the difference between the costs of the TEK10 sports building and the costs of the PHS sports building were found by subtracting the former from the latter (see Equation 5). This difference was positive for all building types, indicating that the tightening of the energy requirements are expected to result in increased costs for all building types. These increased cost were then divided on the building's UFA in order to find the difference in these construction costs per m^2. A building's GRA, the total floor area of all stories, could also have been used as a basis for the m^2. However, as the upper limits for buildings' net energy need in TEK10 and the Passive house are stated in kWh per m^2 UFA, the UFA was used as the measure of a building's m^2 in order to ensure consistency. A challenge associated with the use of UFA as a measurement for m^2 was the fact that buildings constructed with TEK10 and the Passive House Standard have different UFAs. This is due to the fact that PHS buildings have thicker walls. Hence, the UFAs of the PHS buildings will be smaller than for TEK10 buildings. This analysis was based on the UFAs of the PHS buildings, which will result in the highest costs per m^2. These UFAs were chosen as it is seen as better to overestimate the costs than to underestimate them. The UFAs of the sports building, the school building, the kindergarten and the office building with the Passive House Standard are 1938 m^2 (GRA · 0.91), 6392 m^2 (GRA · 0.94), 728 m^2 (GRA · 0.91), and 4700 m^2 (GRA · 0.94) respectively. Table 4 shows the difference in the expected construction costs per m^2, both for the different categories and in total. Negative numbers represent a cost reduction, while positive numbers represent additional costs associated with the building of a PHS building. All prices are given in constant 2013 terms.

Table 4: Difference in the construction costs of TEK10- and PHS-buildings

	SPORTS BUILDING	SCHOOL BUILDING	KINDERGARTEN	OFFICE BUILDING
Overhead costs	160	157	215	139
Building structure	550	386	867	218
Heating, ventilation and sanitary	-181	-293	-419	160
Electrical power system	0	0	0	0
Telecommunication and automation	0	0	0	0
Other installations	0	0	-279	0
General costs	0	65	45	54
Contingency	73	51	70	86
Total difference (NOK/m^2)	**601**	**366**	**498**	**657**

The specific costs for each building type, with both the TEK10 and the Passive House Standard, can be seen in Appendix C. Why and how these costs differ will, however, not be discussed further as that is beyond the scope of this thesis. It is important to note that these costs are not necessarily representable for all buildings. Buildings' design (size, height, etc.) will, to a large extent, determine their costs.

5.3.2. Level of supplied energy

A building's energy use can be expressed in several ways. The two most common are supplied energy and delivered energy. Supplied energy is the energy supplied to a building's energy conversion systems. This amount is to cover a building's energy need when gains and losses in the energy conversion systems are taken into account. Delivered energy, on the other hand, is the amount of energy delivered from a building's energy conversion systems. This amount does not include the gains and losses in the energy conversion systems, and is therefore also referred to as the net energy need. Hence, the difference between the supplied and delivered energy results from the fact that energy may be gained or lost in the conversion process (for example from electricity to heat). Such gains and losses are therefore based on the efficiency in the energy conversion systems. Examples of energy conversion systems are heat pumps and electrical boilers. Energy supplied to heat pumps will result in a gain because heat pumps use energy stored in our surroundings in addition to the supplied electricity. Energy supplied to electrical boilers, on the other hand, will result in a loss. The efficiency of an energy conversion system is often referred to as a coefficient of performance (COP). This coefficient indicates how effective the conversion process is. Hence, it describes the ratio between a building's delivered and supplied energy (Santamouris, 2005). The extra kWh "generated" in a heat pump will not be associated with any costs or emissions. Also, the extra kWh needed due to the "loss" in electrical boilers will be associated with costs and emissions. The costs and emissions associated with buildings' energy consumption are therefore related to the supplied energy.

Based on the above, a building's expected level of supplied energy depends on its estimated delivered energy, its energy conversion systems and the efficiencies of these energy conversion systems. In this analysis, the estimated amounts of delivered energy of the various TEK10- and PHS buildings were based on the upper limits for buildings' net energy need in TEK10 and the Passive House Standard. These limits were found using ISY Calcus, but they could also have been found in TEK10 and the Passive House Standard. The upper limits for the net energy need of the various buildings and standards, and the difference in the net energy need of TEK10 buildings and PHS buildings are listed in Table 5. Positive values for the difference in the net energy need represents a reduction in the energy need of PHS buildings relative to TEK10 buildings.

Table 5: The energy need of the four building types

	NET ENERGY NEED TEK10 (kWh/m^2/year)	**NET ENERGY NEED PHS** (kWh/m^2/year)	**DIFFERENCE** (kWh/m^2/year)
Sports building	170	100	**70**
School building	120	75	**45**
Kindergarten	140	65	**75**
Office building	150	75	**75**

A building's delivered energy is used to cover two main areas; space- and water heating and electricity-specific energy consumption. The latter includes electricity used for lighting and electrical appliances like computers and TVs (Norwegian Water Resources and Energy Directorate, 2011). The relative amounts of net energy needed for these two main areas were calculated based on numbers from Statsbygg (2012). These numbers were based on the energy need of TEK10 buildings as the energy saved by constructing a PHS building would, in theory, be the energy in the original TEK10 building. In a sports building, for example, 74% of the net energy need is used to cover space- and water heating, while 26% is used to cover the electricity-specific energy consumption. The corresponding percentages for the other building types are shown in Table 6.

Table 6: Energy needed for heating and electricity-spesific consumption

	ENERGY FOR SPACE- AND WATER HEATING	ELECTRICITY-SPECIFIC ENERGY CONSUMPTION
Sports buildings	74 %	26 %
School buildings	52 %	48 %
Kindergartens	66 %	34 %
Office buildings	45 %	55 %

The energy needed for space- and water heating may be covered by a number of energy conversion systems. For the purpose of this analysis, it was assumed that 60% of energy needed for space- and water heating will be covered by heat pumps, while electrical boilers will cover the remaining 40%. This assumption is related to the energy requirements in TEK10, where all new buildings of more than 500 m^2 are required to cover at least 60% of their energy need for space- and water heating with another energy supply than direct acting electricity or fossil fuels (see Section 3.3.1.). The amount of energy used for space- and water heating (see Table 6) will therefore be divided in two. For the sports building, for example, 60% of the 74% of energy used for space- and water heating will be covered by heat pumps and 40% of the 74% will be covered by electrical boilers. Hence, it was assumed that 44% (60% · 74%) of the total net energy will be delivered by a heat pump while 30% (40% · 74%) will be covered by an electrical boiler. The corresponding numbers for the school building, the kindergarten and the office building are listed in Table 7. In this table, the amount of energy needed for electricity-specific energy consumption is also shown. These values are, however, the same as in Table 6 because this electricity can only be provided in one way.

Table 7: Energy provided by electrical boilers and heat pumps

	ENERGY FOR SPACE- AND WATER HEATING PROVIDED BY:		ELECTRICITY-SPECIFIC ENERGY CONSUMPTION
	ELECTRICAL BOILERS (40%)	HEAT PUMPS (60%)	
Sports buildings	30 %	44 %	26 %
School buildings	21 %	31 %	48 %
Kindergartens	26 %	40 %	34 %
Office buildings	18 %	27 %	55 %

Electric boilers have a COP of about 0.86, while heat pumps have a COP of about 2.25 (Statsbygg, 2012). Hence, with an electrical boiler, the supplied energy will have to be higher than the delivered energy (net energy need). About 1.16 kWh (1/0.86) will have to be supplied into the energy conversion system in order to get 1 kWh of delivered energy. With a heat pump, on the other hand, the supplied energy will be lower than the delivered energy. It will be possible to have a supplied energy of about 0.44 kWh (1/2.25) in order to get 1 kWh of delivered energy from a heat pump. The electricity-specific energy, on the other hand has a COP of 1 because direct acting electricity does not go through any energy conversion systems in the buildings (Statsbygg, 2012).

Based on the above, the difference in the level of supplied energy to a building in year *t* was found using Equation 8. This equation includes the reduced net energy need (RNE), the coefficients of performance of the various energy conversion systems (COP), and the percentages of the total net energy needed for electricity-specific energy consumption (ESE), and for space- and water heating through electrical boilers (EEB) and heat pumps (EHP).

$$Difference\ in\ the\ level\ of\ supplied\ energy_t = \frac{(RNE \cdot \%EEB)}{COP_{EEB}} + \frac{(RNE \cdot \%EHP)}{COP_{EHP}} + \frac{(RNE \cdot \%ESE)}{COP_{ESE}} \quad (8)$$

For the sports building, for example, the difference in the level of supplied energy was calculated as follows:

$$Difference\ in\ the\ level\ of\ supplied\ energy_t = \frac{(70 \cdot 30\%)}{0.86} + \frac{(70 \cdot 44\%)}{2.25} + \frac{(70 \cdot 26\%)}{1} = 56{,}3$$

The reduction in the net energy need and the level of supplied energy for the various building types are shown in Table 8.

Table 8: Reduction in the net energy need and the supplied energy

	REDUCTION IN NET ENERGY NEED (kWh/m^2/year)	REDUCTION IN SUPPLIED ENERGY (kWh/m^2/year)
Sports buildings	70	56
School buildings	45	39
Kindergartens	75	62
Office buildings	75	66

5.3.3. Future electricity prices

The future prices for Nordic electricity will be affected by many factors. It is therefore hard to estimate the future electricity prices. Among the most important factors affecting the development in the future electricity prices are the future prices of emissions, the European goals for renewable energy production, and the development in the transmission capacity in and between the Nordic and European countries. A reduction in the amount of emission quotas will result in a higher price of emissions, and higher emission prices will result in a higher demand for electricity. Hence, a reduction in the amount of emission quotas is likely to increase the price of electricity. Growth in the production of renewable energy, on the other hand, is likely to result in a lower electricity price due to an increased supply of electricity. By increasing the possibility to export excess power to other countries, however, the electricity prices are likely to increase due to a higher demand (NOU 2012: 9, 2012).

As the Nordic countries' electricity systems are connected, the electricity price in Norway is based on the generation and consumption of electricity in the Nordic region. This price, determined by the supply and demand of electricity, is referred to as the system price, and it is determined at Nord Pool Spot AS. In addition, separate area prices are set based on the conditions in the transmission grids between different areas in the Nordic countries (Norwegian Ministry of Petroleum and Energy, 2013). In addition to the market for Nordic electricity at Nord Pool Spot AS, NASDAQ OMX offers financial contracts for Nordic electricity for 10 years ahead. The traders at NASDAQ OMX have therefore listed their expectations for the development in the system price for Nordic electricity and price differentials for the various areas for the next 10 years (NASDAQ OMX, 2014). These expectations can provide an indication as to what the market expects the Nordic electricity price to be for the next 10 years. These expectations were therefore used to estimate the future electricity prices for the years 2015 through 2024 in this analysis. At NASDAQ OMX, the yearly expectations of the system price of Nordic electricity for these years are represented by the closing prices (the “daily fix”) of the ENOYR-[XX] [7] values. In order to obtain the various area prices, a price differential represented by SY[YYY]YR-[XX][8] can be added to the system price. These price differentials are not listed for all 10 years. However, as these values are not expected to vary a lot from year to year, the value from the previous year can be used when no SY[YYY]YR-[XX] is listed. For the Norwegian areas, these price differentials are only listed for Oslo (OSL) and Tromsø (TRO). In this analysis, the future prices of Nordic electricity were therefore estimated based on an average between the area price for Oslo and Tromsø (Pettersen, 2014). Hence, the expected price for Nordic electricity in year 20[XX] was found using Equation 9.

$$Nordic\ electricity\ price_{[\mathrm{XX}]} = \frac{(ENOYR-[XX]+\ SYOSLYR-[XX])+\ (ENOYR-[XX]+\ SYTROYR-[XX])}{2} \quad (9)$$

The Nordic electricity prices from 2015 to 2024 were found using the expected values listed by NASDAQ OMX (2014) on April 29, 2014 (see Table 9). These prices were converted from Euros (EUR) per Megawatt hours (MWh) to NOK/kWh using the exchange rate listed at Norway’s central bank April 29, 2014[9] (Norges Bank, 2014).

Table 9: Future Nordic electricity prices

	DAILY FIX (EUR/MWh)			NORDIC ELECTRICITY PRICE	
	ENOYR-[XX]	SYOSLYR-[XX]	SYTROYR-[XX]	(EUR/MWh)	(NOK/kWh)
2015	30,35	0,50	0,10	30,65	**0,25**
2016	29,75	0,30	0,10	29,95	**0,25**
2017	28,40	0,30	0,10	28,60	**0,24**
2018	28,75	0,30	0,10	28,95	**0,24**
2019	29,68	0,30	0,10	29,88	**0,25**
2020	30,65	0,30	0,10	30,85	**0,26**
2021	33,25	0,30	0,10	33,45	**0,28**
2022	34,20	0,30	0,10	34,40	**0,28**
2023	35,20	0,30	0,10	35,40	**0,29**
2024	36,20	0,30	0,10	36,40	**0,30**

[7] ENOYR: Energy Nordic YeaR. [XX]: Year 20XX.
[8] [YYY]: The area, OSLo or TROmsø. [XX]: Year 20XX.
[9] 1 EUR=8,281 NOK

It is very difficult to estimate the future Nordic electricity prices beyond 2024. The price listed for year 2024 (0.30 NOK/kWh) was therefore used for the remaining years of the analysis (2025-2074). The price could have been forecasted based on the average percentage change during those 10 years, but there was no reason to assume this.

The prices of Nordic electricity listed at NASDAQ OMX do, however, not represent the total costs associated with the consumption of electricity. The total electricity bill for end users consists of several components. The price of Nordic electricity is the basic component, but consumers also have to pay a consumption tax, a value added tax, a premium to Enova, and a transmission tariff in order to support the operation, maintenance and development of the transmission grids. The latter consists of a fixed amount (NOK/year) and an amount that varies with the energy consumption (NOK/kWh) (Norwegian Ministry of Petroleum and Energy, 2013). In this analysis, the consumption tax, the value added tax, and the premium paid to Enova were not included in the total costs of electricity. As these costs are paid to the government, they would cancel out in a social CBA. A reduction in these taxes would be positive for the end users but negative for the government as they collect these taxes. Also, the fixed amount of the transmission tariff was not included in the costs of electricity in this analysis. This is due to fact that the fixed amount is independent of a building's energy consumption. The variable part was, however, included as it will be affected by a building's energy consumption. Hence, the expected future electricity prices related to Norwegian buildings' energy consumption were based on the expected price of Nordic electricity stated at NASDAQ OMX and a variable transmission tariff. The variable transmission tariff varies throughout the country, but the national average rate in 2014 is estimated to 0.267 NOK/kWh. In average, this transmission tariff varied by about 1.64% yearly from 2005 until 2014 (see Appendix D) (Norwegian Water Resources and Energy Directorate, 2014). However, as there was no specific pattern in the increase from year to year, there was no reason to expect a certain development in the variable transmission tariff. In this analysis, the variable transmission tariff was therefore assumed to equal the national average of the variable transmission tariff in 2014 (0.267 NOK/kWh). The resulting expectations for the electricity prices for the next 60 years are listed in Table 11.

5.3.4. Future emission factors of electricity

An emission factor indicates the amount of GHGs emitted per unit of energy produced or consumed (for example t CO_2e/kWh) (Rambøll, 2013). There is no official emission factor for electricity used in Norway, but a number of approaches have been suggested and discussed in various studies. First of all, it can be discussed whether one should look at the Norwegian, the Nordic or the European production of electricity in order to decide upon the environmental impact of Norwegian electricity consumption. Emission factors for electricity produced in Norway, and emission factors for the Nordic electricity mix and the European electricity mix can be estimated based on the composition of technologies used to generate the electricity in those areas. Electricity produced in Norway is mainly based on hydropower, and is therefore associated with very low emissions. The emission factor related to the Nordic electricity mix, however, is higher due to the use of fossil fuels in the production of electricity in some of the Nordic countries (International Energy Agency, 2013a). The European electricity mix has an even larger share of electricity generated with fossil fuels. Hence, the emission factor of electricity produced in all European countries is higher than the emissions from both the Norwegian electricity and the Nordic electricity mix. One of the recent estimations indicate emission factors for the Norwegian, Nordic and European mix of 50 g CO_2e/kWh, 200 g CO_2e/kWh, and 542 g CO_2e/kWh respectively (Klimaløftet, 2012). As was seen in Section 3.1., the Norwegian electricity system is fully integrated with the electricity systems in the other Nordic countries. This suggests that one should use the emission factor for the Nordic electricity mix instead of the Norwegian mix. However, the Nordic electricity system is, in turn, connected to the Baltic countries and other European electricity systems. It is also very likely that Norway will be part of a fully integrated European electricity system over time. For future emission factors, it could therefore be said that the focus should be on the European electricity mix. If the European electricity mix is seen as a basis for future emission, it is also possible to evaluate the emission factors of electricity with and without GOs (see Section 3.1.). Electricity bought with GOs will then be given a low emission factor, while electricity bought without GOs will be attributed a higher emission factor based on the European attribute mix (Norwegian Water Resources and Energy Directorate, 2013).

It is expected that the European electricity system will change in the coming years, both with respect to the electricity grid and the technologies used in the production of electricity. As the composition of technologies used to generate electricity is expected to change over time, the emission factors of the European electricity mix are likely to change over time. Hence, for an analysis with a long time horizon, the use of today's emission factor for the entire period will not be realistic. Also, uncertainty with respect to the development in the composition of technologies will also make it difficult to predict future emission factors (Klimaløftet, 2012). Emission factors may also vary depending on how they are estimated, and thereby make it harder to compare studies on the emissions associated with electricity consumption. Based on this concern, representatives from seven Norwegian companies, organizations and ministries[10] met and discussed a joint approach to the use of emission factors for electricity. The representatives agreed that the approach of the Research Centre on Zero Emission Buildings (ZEB) can be seen as a reasonable approach towards the prediction of future emission factors of electricity. This approach is based on the two-degree target (see Section 2.1.) and the European electricity system (Klimagassregnskap, 2012). The future emission factors of electricity in this analysis were based on this approach.

ZEB's approach to future emission factors for electricity is based on a simulation of the European electricity system towards 2050 where measures directed towards reducing emissions in line with the two-degree target are initiated. In order to fulfil the two-degree target, it is expected that the production of renewable electricity and the capacity of nuclear power will have to increase. In addition, an expected development towards a super grid with an increased transmission capacity is assumed to reduce the average emission factor of electricity. This is due to the fact that an increased transmission capacity is likely to make it possible to export more renewable energy to countries where it can offset less environmental friendly electricity production. As was mentioned in Section 3.2., increased transmission capacity may also enable a higher utilization of wind- and solar power and thereby reduce the emission factor of European electricity. An extrapolation of these trends serves as the basis for future emission factors beyond 2050. Based on these assumptions, the emission factor of the European electricity mix is expected to be 361 gCO_2e/kWh in 2010 and decrease over time. By assuming a linear development, the emission factor for electricity (K_{el}) in a given year (t_{yr}) after 2010 can be estimated using Equation 10. Based on this equation, the emission factor will be 0 in 2054, indicating that it is expected that the European electricity system will be fully decarbonized by then (Dokka, 2011).

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[10] Statsbygg, Futurebuilt, The Norwegian Ministry of Climate and Environment, the Norwegian Ministry of Local Government and Regional Development, The Norwegian Ministry of Petroleum and Energy, The Research Centre on Zero Emission Buildings (ZEB) and Civitas AS.

$$K_{el}(t_{yr}) = 361 - 8.3 \cdot [t_{yr} - 2010] \tag{10}$$

Equation 10 gives the yearly emission factors of electricity in grams of CO_2e per kWh of electricity. For the use in the analysis of this thesis, however, these emission factors had to be expressed in t CO_2e per kWh of electricity. The yearly emission factors were therefore converted from g CO_2e/kWh to t CO_2e/kWh (multiplied by 1 000 000). These emission factors, which were used as a basis for assessing the environmental impacts of the consumption of electricity in Norwegian buildings, are listed in Table 11.

5.3.5. Future emission prices

As mentioned in Section 2.1., the EU ETS has created a market for emissions, which makes it possible to set a price on emissions. There is, however, considerable uncertainty surrounding the development of these emission prices. The outcome of international climate negotiations, global economic developments, political signals, and the prices of oil, gas and coal are likely to affect the future emissions prices in the EU ETS. Ambitious targets with respect to the reduction of emissions may, for example, result in higher emission prices. This makes it challenging to estimate future emission prices. Also, the many possibilities result in a range of estimated values for the future emission prices. This may make it difficult to compare the results of CBAs where the value of emission reductions is assessed. An expert committee appointed in order to review the Norwegian cost-benefit analysis framework has therefore recommended the use of a joint emission price in Norwegian CBAs. The committee recommends that the market expectations of future emission prices in the EU ETS should be used as far as future prices are quoted, and gradually approach the expected emission prices based on the two-degree target. Emission prices based on the two-degree target are often referred to as the two-degree path, and they are meant to represent the costs associated with the measures needed to realize the two-degree target. This recommendation is based on the uncertainties associated with the estimation of future EU ETS emission prices far into the future. In addition, the committee thinks that it is realistic to believe that the emission prices in the EU ETS will approach the two-degree price path over time. This is partly based on the fact that the current policy suggests a linear reduction in the number of allowances of 1.74% each year after 2013. Fewer emissions indicate higher emission prices (NOU 2012: 16, 2012).

Based on these recommendations, the future emission prices in the analysis of this thesis were based on estimates for future EU ETS allowance prices until 2020, while emission prices based on the two-degree target were applied from 2021 to 2074. The future EU ETS emission prices until 2020 were based on the estimates from the Norwegian report *Climate Cure 2020*. This report was commissioned by the Norwegian Ministry of Climate and Environment. It was published in 2010 with the objective to aid the Government's evaluation of climate policies. In this report, three different scenarios for the development in the future emission price were reported (see Appendix E). In this analysis, the future emission prices from 2015 to 2020 were based on the middle scenarios of EUR 18 in 2012, EUR 26 in 2015 and EUR 40 in 2020 (Climate Cure 2020, 2010, p. 70). With respect to the emission prices for 2021 to 2077, many organizations and researchers have suggested emission price paths needed in order to realize the two-degree target. Some of these estimated price paths were summed up in the Italian research initiative International Centre for Climate Governance (see Appendix F). The committee recommends the use of these estimates in the valuation of emissions in Norwegian CBAs. In this analysis, the future emission prices from 2021 to 2074 were based on the mean of these price paths. Hence, emission prices of EUR 68 and EUR 235 were applied in 2030 and 2050 respectively (NOU 2012: 16, 2012, p. 137).

The estimated emission prices for 2015 and 2020 were originally measured in constant 2009 prices, while the estimates for 2030 and 2050 were measured in constant 2012 prices. These emission prices were therefore adjusted for inflation in order to be expressed in constant 2013 terms. This was done using the Norwegian Consumer Price Index and the inflation calculator available at Statistics Norway (2014). For the use in the analysis, these emission prices were also converted into NOK using the exchange rate listed at Norway's central bank on April 29, 2014 (Norges Bank, 2014). In order to find the emission prices for the years between 2015 and 2020, 2020 and 2030, 2030 and 2050, and in the years after 2050, a linear development was assumed. Hence, the development from year to year was found by dividing the total increase between two of the estimates on the number of years between those estimates. For example, the total change from 2020 to 2030 was expected to be EUR 28. By dividing this on 10, we get a yearly increase of EUR 2.8. Hence, the emission price in 2021 was found by adding EUR 2.8 to the price from 2020. The resulting emission prices are listed in Table 11.

5.3.6. The social discount rate

As mentioned in Section 4.3.3., the costs and benefits in a CBA have to be discounted to a chosen reference year. In the analysis of this thesis, it was assumed that all costs appear in year 2014 as they are related to the construction of the buildings. The benefits, however, are assumed to arise over time. 2014 was therefore chosen as the base year (year 0), and the benefits were discounted to 2014 using the SDR presented in Section 4.3.3.3. (see Table 2). Hence, the benefits that arise in the first 40 years (2015-2054) were discounted with a real risk-adjusted SDR of 4%, while the costs and benefits that arise in the next 20 years (2055-2074) were discounted with a real risk-adjusted SDR of 3%. As mentioned in Section 4.3.3.3., impacts in a specific period have to be discounted at the same SDR. All impacts beyond year 2054 were therefore discounted to 2054 (year 40) with a SDR of 3% first and then to 2014 (year 0) with a SDR of 4%. To ease these calculations, the discount factors for each year were calculated. For example, for 2040 and 2060 (years 26 and 46), the discount factors of 0.36 and 0.17 respectively were found using Equations 11 and 12. The SDRs and the resulting discount factors (DF) for the years of the analysis are listed in Table 11.

$$DF_{2040} = \frac{1}{(1+0.4)^{26}} \tag{11}$$

$$DF_{2060} = \frac{1}{(1+0.4)^{40} \cdot (1+0.3)^{6}} \tag{12}$$

5.3.7. The input values used in the analysis

Table 10 summarizes the input values that are specific for each of the four building types, while Table 11 summarizes the general input values that are identical for all building types.

Table 10: The spesific input values

	INCREASED CONSTRUCTION COSTS (NOK/m^2)	REDUCTION IN SUPPLIED ENERGY (kWh/m^2/year)
Sports building	601	56
School building	366	39
Kindergarten	498	62
Office building	657	66

Table 11: The general input values

YEAR	ELECTRICITY PRICE (NOK/kWh)	EMISSION FACTOR (t CO_2e/kWh)	EMISSION PRICE (NOK/t CO_2e)	SOCIAL DISCOUNT RATE	DISCOUNT FACTOR
2014	-	-	-	4 %	1
2015	0,52	0,000320	230	4 %	0,96
2016	0,52	0,000311	255	4 %	0,92
2017	0,50	0,000303	279	4 %	0,89
2018	0,51	0,000295	304	4 %	0,85
2019	0,51	0,000286	329	4 %	0,82
2020	0,52	0,000278	354	4 %	0,79
2021	0,54	0,000270	376	4 %	0,76
2022	0,55	0,000261	398	4 %	0,73
2023	0,56	0,000253	420	4 %	0,70
2024	0,57	0,000245	442	4 %	0,68
2025	0,57	0,000237	464	4 %	0,65
2026	0,57	0,000228	487	4 %	0,62
2027	0,57	0,000220	509	4 %	0,60
2028	0,57	0,000212	531	4 %	0,58
2029	0,57	0,000203	553	4 %	0,56
2030	0,57	0,000195	575	4 %	0,53
2031	0,57	0,000187	646	4 %	0,51
2032	0,57	0,000178	716	4 %	0,49
2033	0,57	0,000170	787	4 %	0,47
2034	0,57	0,000162	858	4 %	0,46
2035	0,57	0,000154	928	4 %	0,44
2036	0,57	0,000145	999	4 %	0,42
2037	0,57	0,000137	1069	4 %	0,41
2038	0,57	0,000129	1140	4 %	0,39
2039	0,57	0,000120	1211	4 %	0,38
2040	0,57	0,000112	1281	4 %	0,36
2041	0,57	0,000104	1352	4 %	0,35
2042	0,57	0,000095	1423	4 %	0,33
2043	0,57	0,000087	1493	4 %	0,32
2044	0,57	0,000079	1564	4 %	0,31
2045	0,57	0,000071	1634	4 %	0,30
2046	0,57	0,000062	1705	4 %	0,29
2047	0,57	0,000054	1776	4 %	0,27
2048	0,57	0,000046	1846	4 %	0,26
2049	0,57	0,000037	1917	4 %	0,25
2050	0,57	0,000029	1987	4 %	0,24
2051	0,57	0,000021	2058	4 %	0,23
2052	0,57	0,000012	2129	4 %	0,23
2053	0,57	0,000004	2199	4 %	0,22
2054	0,57	0	2270	4 %	0,21
2055	0,57	0	2341	3 %	0,20
2056	0,57	0	2411	3 %	0,20
2057	0,57	0	2482	3 %	0,19
2058	0,57	0	2552	3 %	0,19
2059	0,57	0	2623	3 %	0,18
2060	0,57	0	2694	3 %	0,17
2061	0,57	0	2764	3 %	0,17
2062	0,57	0	2835	3 %	0,16
2063	0,57	0	2906	3 %	0,16
2064	0,57	0	2976	3 %	0,15
2065	0,57	0	3047	3 %	0,15
2066	0,57	0	3117	3 %	0,15
2067	0,57	0	3188	3 %	0,14
2068	0,57	0	3259	3 %	0,14
2069	0,57	0	3329	3 %	0,13
2070	0,57	0	3400	3 %	0,13
2071	0,57	0	3470	3 %	0,13
2072	0,57	0	3541	3 %	0,12
2073	0,57	0	3612	3 %	0,12
2074	0,57	0	3682	3 %	0,12

5.3.8. The results of the analysis

After having estimated the increased construction costs, the reduction in the level of supplied energy, future electricity prices, future emission factors, and the future emission prices, the three impacts associated with stricter energy requirements were calculated using Equations 5, 6 and 7 in Section 5.2. Hence, the three impacts for each building type were found as follows:

- The increased costs were found by considering the difference in the costs of the TEK10 building and the PHS building.
- The yearly energy benefits were found by combining the yearly difference in the level of supplied energy to the TEK10 building and the PHS building with that year's electricity price.
- The yearly environmental benefits were found by combining the yearly difference in the level of supplied energy to the TEK10 building and the PHS building with the emission factor and emission price of that year.

The yearly NSB were then found by summing the three impacts (benefits minus costs), and the yearly NPVs were found by multiplying each year's NSB with that year's discount factor (DF). Lastly, the total NPV - the basis for the final recommendation - was found by summing the yearly NPVs. Hence, the total NPV for each building type were found using Equation 13.

$$NPV = \sum_{t=2015}^{2074} DF_t \cdot NSB_t = \sum_{t=2015}^{2074} DF_t \cdot (B - C)_t \tag{13}$$

The yearly and total increased costs, energy benefits, environmental benefits, NSB and NPVs for the four building types are shown in Tables 12, 13, 14 and 15. Furthermore, a summary of the total increased costs, energy benefit, environmental benefit, NSB and NPV for the four building types are shown in Table 16. These results represent the main findings of this analysis. As can be seen in these tables, the total NPV of all the building types are positive. The NPVs amount to 226 NOK/m^2, 210 NOK/m^2, 418 NOK/m^2, and 318 NOK/m^2 for the sports building, the school building, the kindergarten, and the office building respectively. Hence, with a time horizon of 60 years and a declining discount rate, the benefits from stricter energy requirements are expected to surpass the costs related to the fulfilment of stricter energy requirements. The tightening of the energy requirements are therefore seen as positive for the society as a whole (see more on this in Section 5.5.). (For an overview of the full model in which these results were estimated, see Appendix G.)

Table 12: Sports building

YEAR	INCREASED COSTS (NOK/m^2)	ENERGY BENEFIT (NOK/m^2)	ENVIRONMENTAL BENEFIT (NOK/m^2)	NET SOCIAL BENEFITS (NOK/m^2)	NET PRESENT VALUE (NOK/m^2)
2014	601	0	0	-601	-601
2015	0	29	4	33	32
2016	0	29	4	33	31
2017	0	28	5	33	29
2018	0	28	5	33	29
2019	0	29	5	34	28
2020	0	29	6	35	27
2021	0	30	6	36	27
2022	0	31	6	37	27
2023	0	31	6	37	26
2024	0	32	6	38	26
2025	0	32	6	38	25
2026	0	32	6	38	24
2027	0	32	6	38	23
2028	0	32	6	38	22
2029	0	32	6	38	21
2030	0	32	6	38	20
2031	0	32	7	39	20
2032	0	32	7	39	19
2033	0	32	7	39	19
2034	0	32	8	40	18
2035	0	32	8	40	17
2036	0	32	8	40	17
2037	0	32	8	40	16
2038	0	32	8	40	16
2039	0	32	8	40	15
2040	0	32	8	40	14
2041	0	32	8	40	14
2042	0	32	8	39	13
2043	0	32	7	39	13
2044	0	32	7	39	12
2045	0	32	6	38	11
2046	0	32	6	38	11
2047	0	32	5	37	10
2048	0	32	5	37	10
2049	0	32	4	36	9
2050	0	32	3	35	9
2051	0	32	2	34	8
2052	0	32	1	33	8
2053	0	32	1	32	7
2054	0	32	0	32	7
2055	0	32	0	32	6
2056	0	32	0	32	6
2057	0	32	0	32	6
2058	0	32	0	32	6
2059	0	32	0	32	6
2060	0	32	0	32	6
2061	0	32	0	32	5
2062	0	32	0	32	5
2063	0	32	0	32	5
2064	0	32	0	32	5
2065	0	32	0	32	5
2066	0	32	0	32	5
2067	0	32	0	32	5
2068	0	32	0	32	4
2069	0	32	0	32	4
2070	0	32	0	32	4
2071	0	32	0	32	4
2072	0	32	0	32	4
2073	0	32	0	32	4
2074	0	32	0	32	4
TOTAL	**601**	**1889**	**232**	**1520**	**226**

Table 13: School building

YEAR	INCREASED COSTS (NOK/m²)	ENERGY BENEFIT (NOK/m²)	ENVIRONMENTAL BENEFIT (NOK/m²)	NET SOCIAL BENEFITS (NOK/m²)	NET PRESENT VALUE (NOK/m²)
2014	366	0	0	-366	-366
2015	0	20	3	23	22
2016	0	20	3	23	21
2017	0	20	3	23	20
2018	0	20	3	23	20
2019	0	20	4	24	20
2020	0	20	4	24	19
2021	0	21	4	25	19
2022	0	22	4	26	19
2023	0	22	4	26	18
2024	0	22	4	26	18
2025	0	22	4	26	17
2026	0	22	4	26	17
2027	0	22	4	27	16
2028	0	22	4	27	15
2029	0	22	4	27	15
2030	0	22	4	27	14
2031	0	22	5	27	14
2032	0	22	5	27	13
2033	0	22	5	27	13
2034	0	22	5	28	13
2035	0	22	6	28	12
2036	0	22	6	28	12
2037	0	22	6	28	11
2038	0	22	6	28	11
2039	0	22	6	28	10
2040	0	22	6	28	10
2041	0	22	5	28	10
2042	0	22	5	27	9
2043	0	22	5	27	9
2044	0	22	5	27	8
2045	0	22	4	27	8
2046	0	22	4	26	7
2047	0	22	4	26	7
2048	0	22	3	25	7
2049	0	22	3	25	6
2050	0	22	2	24	6
2051	0	22	2	24	6
2052	0	22	1	23	5
2053	0	22	0	23	5
2054	0	22	0	22	5
2055	0	22	0	22	4
2056	0	22	0	22	4
2057	0	22	0	22	4
2058	0	22	0	22	4
2059	0	22	0	22	4
2060	0	22	0	22	4
2061	0	22	0	22	4
2062	0	22	0	22	4
2063	0	22	0	22	4
2064	0	22	0	22	3
2065	0	22	0	22	3
2066	0	22	0	22	3
2067	0	22	0	22	3
2068	0	22	0	22	3
2069	0	22	0	22	3
2070	0	22	0	22	3
2071	0	22	0	22	3
2072	0	22	0	22	3
2073	0	22	0	22	3
2074	0	22	0	22	3
TOTAL	**366**	**1315**	**161**	**1111**	**210**

Table 14: Kindergarten

YEAR	INCREASED COSTS (NOK/m²)	ENERGY BENEFIT (NOK/m²)	ENVIRONMENTAL BENEFIT (NOK/m²)	NET SOCIAL BENEFITS (NOK/m²)	NET PRESENT VALUE (NOK/m²)
2014	498	0	0	-498	-498
2015	0	32	5	37	35
2016	0	32	5	37	34
2017	0	31	5	36	32
2018	0	31	6	37	32
2019	0	32	6	38	31
2020	0	32	6	38	30
2021	0	34	6	40	30
2022	0	34	6	41	30
2023	0	35	7	41	29
2024	0	35	7	42	28
2025	0	35	7	42	27
2026	0	35	7	42	26
2027	0	35	7	42	25
2028	0	35	7	42	24
2029	0	35	7	42	23
2030	0	35	7	42	23
2031	0	35	7	43	22
2032	0	35	8	43	21
2033	0	35	8	44	21
2034	0	35	9	44	20
2035	0	35	9	44	19
2036	0	35	9	44	19
2037	0	35	9	44	18
2038	0	35	9	44	17
2039	0	35	9	44	17
2040	0	35	9	44	16
2041	0	35	9	44	15
2042	0	35	8	44	15
2043	0	35	8	43	14
2044	0	35	8	43	13
2045	0	35	7	42	13
2046	0	35	7	42	12
2047	0	35	6	41	11
2048	0	35	5	40	11
2049	0	35	4	40	10
2050	0	35	4	39	9
2051	0	35	3	38	9
2052	0	35	2	37	8
2053	0	35	1	36	8
2054	0	35	0	35	7
2055	0	35	0	35	7
2056	0	35	0	35	7
2057	0	35	0	35	7
2058	0	35	0	35	7
2059	0	35	0	35	6
2060	0	35	0	35	6
2061	0	35	0	35	6
2062	0	35	0	35	6
2063	0	35	0	35	6
2064	0	35	0	35	5
2065	0	35	0	35	5
2066	0	35	0	35	5
2067	0	35	0	35	5
2068	0	35	0	35	5
2069	0	35	0	35	5
2070	0	35	0	35	5
2071	0	35	0	35	4
2072	0	35	0	35	4
2073	0	35	0	35	4
2074	0	35	0	35	4
TOTAL	**498**	**2091**	**256**	**1850**	**418**

Table 15: Office building

YEAR	INCREASED COSTS (NOK/m²)	ENERGY BENEFIT (NOK/m²)	ENVIRONMENTAL BENEFIT (NOK/m²)	NET SOCIAL BENEFITS (NOK/m²)	NET PRESENT VALUE (NOK/m²)
2014	657	0	0	-657	-657
2015	0	34	5	39	38
2016	0	34	5	39	36
2017	0	33	6	39	35
2018	0	33	6	39	34
2019	0	34	6	40	33
2020	0	34	6	41	32
2021	0	36	7	43	32
2022	0	36	7	43	32
2023	0	37	7	44	31
2024	0	38	7	45	30
2025	0	38	7	45	29
2026	0	38	7	45	28
2027	0	38	7	45	27
2028	0	38	7	45	26
2029	0	38	7	45	25
2030	0	38	7	45	24
2031	0	38	8	45	23
2032	0	38	8	46	23
2033	0	38	9	46	22
2034	0	38	9	47	21
2035	0	38	9	47	21
2036	0	38	10	47	20
2037	0	38	10	47	19
2038	0	38	10	47	18
2039	0	38	10	47	18
2040	0	38	9	47	17
2041	0	38	9	47	16
2042	0	38	9	46	15
2043	0	38	9	46	15
2044	0	38	8	46	14
2045	0	38	8	45	13
2046	0	38	7	45	13
2047	0	38	6	44	12
2048	0	38	6	43	11
2049	0	38	5	42	11
2050	0	38	4	41	10
2051	0	38	3	40	9
2052	0	38	2	39	9
2053	0	38	1	38	8
2054	0	38	0	38	8
2055	0	38	0	38	8
2056	0	38	0	38	7
2057	0	38	0	38	7
2058	0	38	0	38	7
2059	0	38	0	38	7
2060	0	38	0	38	7
2061	0	38	0	38	6
2062	0	38	0	38	6
2063	0	38	0	38	6
2064	0	38	0	38	6
2065	0	38	0	38	6
2066	0	38	0	38	5
2067	0	38	0	38	5
2068	0	38	0	38	5
2069	0	38	0	38	5
2070	0	38	0	38	5
2071	0	38	0	38	5
2072	0	38	0	38	5
2073	0	38	0	38	4
2074	0	38	0	38	4
TOTAL	**657**	**2226**	**273**	**1842**	**318**

Table 16: Summary of the results of the analysis

	INCREASED COSTS (NOK/m²)	ENERGY BENEFIT (NOK/m²)	ENVIRONMENTAL BENEFIT (NOK/m²)	NET SOCIAL BENEFITS (NOK/m²)	NET PRESENT (NOK/m²)
Sports building	601	1889	232	1520	**226**
School building	366	1315	161	1111	**210**
Kindergarten	498	2091	256	1850	**418**
Office building	657	2226	273	1842	**318**
Average	530,5	1880,3	230,5	1580,8	**293**

5.4. SENSITIVITY ANALYSIS

A CBA will always involve a degree of uncertainty due to the need for assumptions and estimated values. This should be taken into account by looking at how changes in assumptions and estimated values would affect the NPV of the analysis. This is referred to as a sensitivity analysis as it examines how sensitive the results are to changes in assumptions and estimated values. The most straightforward way to perform a sensitivity analysis is by varying the values associated with uncertainty and recalculate the NPV. More specifically, a sensitivity analysis is normally performed by varying the values of one of the uncertain values at a time, holding all other values constant. This is known as a partial sensitivity analysis as it isolates the partial effect on the NPV caused by changes in one value. If the NPV remains the same (either positive or negative) after having conducted a sensitivity analysis, the recommendation is said to be robust (Boardman et al., 2011). In the analysis of this thesis, the main uncertainty is related to the six values needed to measure and discount the three impacts; the difference in the construction costs, the difference in the level of supplied energy, future electricity prices, future emission factors of electricity, the future emission prices, and the social discount rate. A partial sensitivity analysis was therefore performed with respect to these values. These variations consisted of values that are both lower and higher than the base case values used in the original analysis (see Tables 10 and 11 in Section 5.3.7.). These "low" and "high" values are summarized in Tables 23 and 24 in Section 5.4.7.. The reasoning behind the variations that were made with respect to the various values will be explained and the resulting NPVs will be presented[11] in Sections 5.4.1. to 5.4.6..

[11] The calculations with these values will not be shown, but they were conducted in the same manner as in the analysis with the base case values.

In addition to the recalculation of the NPVs with these variations, the time horizon's effect on the NPV was assessed (see Section 5.4.8.). Furthermore, this sensitivity analysis included an assessment of how a 10% change in the estimated input values would affect the NPVs (see Section 5.4.9.). By finding the percentage changes in the NPVs as a result of a 10% change in the various values, it was possible to identify which of the input values the analysis is most sensitive to. This was done in order to identify the values one needs to pay close attention to in possible future analyses. The changes in the input values are listed in Appendix H. Unlike the variations in Sections 5.4.1. to 5.4.6., these changes were found by simply reducing and increasing the base case values in Tables 10 and 11 by 10%. The changes in the NPVs as a result of these changes will be presented in Section 5.4.9..

5.4.1. Construction costs

The actual construction costs of a building may differ from the estimated numbers. In order to evaluate how changes in the costs per m^2 would affect the NPV, the NPVs for the various building types were recalculated with a 10% decrease and increase in the increased costs relative to the base case. These "low" and "high" values for the various buildings are listed in Table 23 (see Section 5.4.7.), and the resulting NPVs (NOK/m^2) are shown in Table 17.

Table 17: Net present values with variations in the construction costs

	LOW (NOK/m^2)	**BASE CASE** (NOK/m^2)	**HIGH** (NOK/m^2)
Sports building	286	226	166
School building	247	210	173
Kindergarten	468	418	368
Office building	384	318	252

Compared to the original analysis, changes in the increased construction costs would not have altered the sign of the NPVs of the various building types. However, the NPVs would have differed somewhat. The "low" values would have resulted in an increase in the NPV of all building types due to lower costs. The "high" values, on the other hand, would have resulted in lower NPVs for all building types. These values could, in fact, have resulted in negative NPVs if the increased costs were higher than the increased benefits. However, the NPVs of all building types remained positive with these changes. This indicates that the benefits are large enough to cover an increase in the construction costsof 10%. Hence, the tightening of the energy requirements would have been an improvement to society even though the increased costs were 10% higher than in the base case.

5.4.2. Level of supplied energy

With respect to the difference in the level of supplied energy to a TEK10 building and a PHS building, many factors play a part. This is due to the relationship between the level of delivered energy (net energy need) and the level of supplied energy. This relationship depends on the relative amount of energy needed for the two main areas, the choice of energy conversion systems and these energy conversion systems' COPs (see Section 5.3.2.). The relative amounts of energy needed and the COPs are relatively safe estimates, as they are based on studies of buildings' actual net energy need and the efficiencies of energy conversion systems. These factors were therefore not varied. Neither were the assumptions with respect to the buildings' energy conversion system. The numerous possibilities with respect to the choice of energy conversion systems make it difficult to consider all possibilities. Instead, the variations in the level of supplied energy were based on changes in the buildings' reduced net energy need. As the energy requirements in TEK10 and the Passive House Standard require buildings' net energy need to stay below what was used as the base case values, the actual net energy need in buildings can only be lower than these limits. The difference in the energy need of a TEK10 building and a PHS building can therefore only arise if the actual energy consumption of either the TEK10 building or the PHS building is lower than the requirement. The variations in this sensitivity analysis were therefore based on scenarios where either the net energy need of the TEK10 building or the PHS building was 10% lower than the base case while the other building's net energy need remained unchanged. The difference in the level of supplied energy were then found based on the base case assumptions with respect to the relative amount of energy needed for the two main areas, the choice of energy conversion systems and the COPs.

If the net energy need of the TEK10 building was lower than in the base case, while the net energy need of the PHS building remained unchanged, the difference in the net energy need and the level of supplied energy would have been lower than in the base case. On the other hand, if the net energy need of the PHS building was lower than in the base case, while the net energy need of the TEK10 building remained unchanged, the reduced net energy need and the difference in the level of supplied energy would have been higher than in the base case.

The “low” and “high” values of the difference in the level of supplied energy for the four buildings are listed in Table 23 (see Section 5.4.7.), and the resulting NPVs for the various buildings (NOK/m^2) are shown in Table 18.

Table 18: Net present values with variations in the level of supplied energy

	LOW (NOK/m^2)	BASE CASE (NOK/m^2)	HIGH (NOK/m^2)
Sports building	19	226	344
School building	48	210	299
Kindergarten	241	418	492
Office building	126	318	421

Compared to the original analysis, changes in the level of supplied energy would not have altered the sign of the NPVs. However, as the reduced level of supplied energy is a major factor in this analysis, these changes would have had large impacts on the NPVs. The “high” values would have resulted in an increase in the NPVs of all building types, as a larger difference in the level of supplied energy would have increased the energy- and environmental benefits. The “low” values, on the other hand, would have resulted in a substantial decreased in the NPVs for all building types. This is due to the fact that, if the difference in the level of supplied energy was reduced, the energy- and environmental benefits would have been affected. Hence, if the actual net energy need of a TEK10 building was lower than the set limits, the NPV would have decreased substantially as the tightening of the energy requirements would have resulted in lower benefits. Despite this decrease, all NPVs would have remained positive.

5.4.3. Future electricity prices

The estimated future electricity prices are associated with the a lot of uncertainty. This is due to the many factors that can affect this price. In order to evaluate how changes in the electricity price would affect the NPV for the various building types, the NPVs were recalculated with both higher and lower electricity prices. The Nordic electricity price in the years 2015 through 2024 was kept constant for both the “low” and “high” values, while the prices in the years 2025 through 2074 were changed. In addition, the variable transmission tariff was varied for all years. The higher Nordic electricity prices were based on a 2% yearly increase from 2025 until 2074. This increase is based on the average increase in the Nordic electricity price in the 10 years forecasted by NASDAQ OMX. In addition, the variable transmission tariff was increased by 1.64% each year from 2015 until 2074. This increase is based on the average increase in the transmission tariff during the past 10 years. The lower electricity prices were based on the same numbers. Hence, the Nordic electricity prices and the transmission tariff were decreased by 2% and 1.64% respectively. However, in order to avoid future electricity prices of 0 NOK/kWh, the Nordic electricity prices were only decreased by 2% until it reached a value of about 0.10 NOK/kWh. This is the lowest historical price of Nordic electricity in the past 16 years. Also, the variable transmission tariff was only decreased by 1.64% until it reached a value of about 0.22 NOK/kWh. This is the lowest historical price for the variable transmission tariff in the past 10 years. After having reached these lower limits, the Nordic electricity price and the variable transmission tariff were set to 0.10 NOK/kWh and 0.22 NOK/kWh respectively. As the future demand is likely to be higher due to the use of more electricity, it is quite unlikely that the future electricity prices will be lower than today's prices. Also, NASDAQ OMX expects an increase in the price for the next 10 years. In spite of this, a scenario where the electricity price is lower than today's price was considered in order to see how that would affect the NPVs. The resulting "low" and "high" values of the future electricity prices are shown in Table 24 (see Section 5.4.7.), and the resulting NPVs (NOK/m^2) for all building types are shown in Table 19.

Table 19: Net present values with variations in the future electricity prices

	LOW (NOK/m^2)	BASE CASE (NOK/m^2)	HIGH (NOK/m^2)
Sports building	23	226	497
School building	69	210	399
Kindergarten	193	418	718
Office building	78	318	637

A change in the future electricity prices would have had a sizable impact on the NPVs of all building types because it would have affected the energy benefit. Lower electricity prices would have resulted in lower NPVs, and higher future electricity prices would have resulted in higher NPVs. However, these changes in the future electricity prices would not have altered the sign of the NPVs. Hence, even though the electricity prices are not likely to be reduced, it would not have changed the results of the original analysis. The electricity prices are more likely to increase, and that would have resulted in higher NPVs for all building types. Hence, it would only have strengthened the results found in the original analysis.

5.4.4. Future emission factors of electricity

The future emission factors of electricity are also associated with a high degree of uncertainty. This is both due to the many possible ways to evaluate emission factors and the insecurities with respect to the development in the technologies used in the future electricity production. In order to assess some of this uncertainty, the NPVs of the four building types were calculated with both higher and lower emission factors. First, the future production of electricity in Europe is expected to be more environmental friendly, but the two-degree target might not be met. The higher emission factors were therefore based on a less optimistic scenario than the base case. For this purpose, the EU-reference from Statsbygg (2012) was used. This approach entails a linear reduction in the emission factors of electricity from 391 g CO_2e/kWh in 2012 to 0 g CO_2e/kWh in 2100 (see Table 24 in Section 5.4.7.). Hence, the EU-reference is based on a slower reduction in the emission factors than the approach based on the two-degree target. Based on the assumptions in this analysis, a scenario with lower emission factors than the two-degree target is very unlikely. It could, however, be assumed that the Norwegian electricity system is "closed off" from all other countries' electricity systems. With this assumption, the emission factor of electricity consumed in Norway could be set close to zero due to the large quantity of hydropower. An emission factor of 0 was therefore applied in order to see how a reduction in the emission factors would have affected the NPVs. The resulting NPVs (NOK/m^2) are shown in Table 20.

Table 20: Net present values with variations in the future emission factors

	LOW (NOK/m^2)	BASE CASE (NOK/m^2)	HIGH (NOK/m^2)
Sports building	110	226	430
School building	129	210	352
Kindergarten	289	418	644
Office building	181	318	558

Compared to the original analysis, changes in the future emission factors would not have altered the sign of the NPVs of the various building types. However, higher emission factors would have resulted in a sizable increase in all NPVs due to an increase in the environmental benefit. The "low" values, on the other hand would have reduced all NPVs. As these values represent a scenario where there are no emissions associated with the production and consumption of electricity, the positive NPVs indicate that the total benefits of stricter energy requirements would have exceeded the costs even though there was no environmental benefit.

5.4.5. Future emission prices

In order to assess the uncertainty related to the future emission prices, the "low" and "high" values of the estimates from Climate Cure 2020 (2010) were applied for 2015 and 2020. For 2030 and 2050, the variations were based on the mean and standard deviation of the estimated price paths in Table 9.2. in NOU 2012: 16 (2012). The "low" emission prices were estimated by subtracting the standard deviation from the mean (base case), while the "high" emission prices were found by adding the standard deviation to the mean. As in the original analysis, these values were converted to NOK and corrected for inflation. The resulting values of the future emission prices are shown in Table 24 (see Section 5.4.7.), and the resulting NPVs (NOK/m^2) for the various building types are shown in Table 21.

Table 21: Net present values with variations in the future emission prices

	LOW (NOK/m^2)	BASE CASE (NOK/m^2)	HIGH (NOK/m^2)
Sports building	157	226	297
School building	162	210	259
Kindergarten	341	418	496
Office building	236	318	401

Compared to the original analysis, changes in the future emission prices would not have altered the sign of the NPVs of the various building types. However, higher emission prices would have increased the NPVs because it would have resulted in increased environmental benefit. Lower emission prices, on the other hand, would have resulted in lower NPVs.

5.4.6. The social discount rate

The SDR is often seen as a source of uncertainty as there is no consensus as to what the correct SDR is. There are many opinions concerning the optimal SDR, and it may have a large effect on the NPV as it decides how future costs and benefits will be valued. A SDR could therefore be chosen in order to get the results one wish. In order to provide objectivity and show the robustness of this analysis, the NPVs of the various building types were recalculated with a SDR that is both 1% higher and 1% lower than the SDR in the base case. These SDRs were, however, still assumed to be declining. Hence, the "low" scenario represents a SDR of 3% for the first 40 years and a SDR of 2% for the last 20 years, while the "high" scenario represents a SDR of 5% for the first 40 years and a SDR of 4% for the last 20 years of the analysis. The resulting emission factors are listed in Table 24 (see Section 5.4.7.), and the resulting NPVs (NOK/m^2) for the various building types are listed in table 22.

Table 22: Net present values with variations in the social discount rate

	LOW (NOK/m^2)	BASE CASE (NOK/m^2)	HIGH (NOK/m^2)
Sports building	412	226	90
School building	339	210	115
Kindergarten	623	418	267
Office building	537	318	157

Compared to the original analysis, changes of 1% in the SDR would not have altered the sign of the NPVs for the various building types. Hence, changes in the SDR would not have changed the conclusion concerning the social benefit of a tightening of the energy requirements. However, these variations would have resulted in sizable impacts on the NPVs. With a lower SDR, the NPVs would have increased. On the other hand, with a higher SDR, the NPVs would have decreased due to the fact that the future benefits would have been discounted more than the immediate costs. With an even higher SDR, like a declining rate of 6% and 5%, the NPV for the sports building would have turned negative (-12). The NPVs for the other building types would, however, have remained positive even with such high SDRs. Hence, the results in the original analysis can be said to be quite robust.

5.4.7. The input values used in the partial sensitivity analysis

Table 23 summarizes the variations in the input values that are specific for each of the four buildings, while Table 24 summarizes the variations in the general input values.

Table 23: Variations in the spesific input values

	INCREASED CONSTRUCTION COSTS (NOK/m^2)		REDUCTION IN SUPPLIED ENERGY (kWh/m^2/year)	
	LOW	HIGH	LOW	HIGH
Sports building	541	661	42	64
School building	329	403	28	45
Kindergarten	448	548	50	67
Office building	591	723	53	73

Table 24: Variations in the general input values

YEAR	ELECTRICITY PRICE (NOK/kWh)		EMISSION FACTOR (t CO2e/kWh)		EMISSION PRICE (NOK/t CO2e)		SOCIAL DISCOUNT RATE		DISCOUNT FACTOR	
	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
2014	-	-	-	-	-	-	3 %	5 %	1,00	1,00
2015	0,52	0,53	0	0,000378	150	336	3 %	5 %	0,97	0,95
2016	0,51	0,52	0	0,000373	156	375	3 %	5 %	0,94	0,91
2017	0,49	0,52	0	0,000369	161	414	3 %	5 %	0,92	0,86
2018	0,49	0,52	0	0,000364	166	453	3 %	5 %	0,89	0,82
2019	0,49	0,54	0	0,000360	172	492	3 %	5 %	0,86	0,78
2020	0,50	0,55	0	0,000356	177	530	3 %	5 %	0,84	0,75
2021	0,51	0,58	0	0,000351	180	571	3 %	5 %	0,81	0,71
2022	0,52	0,59	0	0,000347	184	612	3 %	5 %	0,79	0,68
2023	0,52	0,60	0	0,000342	187	653	3 %	5 %	0,77	0,64
2024	0,53	0,62	0	0,000338	191	694	3 %	5 %	0,74	0,61
2025	0,46	0,63	0	0,000333	194	735	3 %	5 %	0,72	0,58
2026	0,42	0,64	0	0,000329	198	775	3 %	5 %	0,70	0,56
2027	0,38	0,65	0	0,000324	201	816	3 %	5 %	0,68	0,53
2028	0,35	0,66	0	0,000320	205	857	3 %	5 %	0,66	0,51
2029	0,32	0,67	0	0,000316	208	898	3 %	5 %	0,64	0,48
2030	0,32	0,69	0	0,000311	211	939	3 %	5 %	0,62	0,46
2031	0,32	0,70	0	0,000307	229	1063	3 %	5 %	0,61	0,44
2032	0,32	0,71	0	0,000302	246	1187	3 %	5 %	0,59	0,42
2033	0,32	0,72	0	0,000298	263	1310	3 %	5 %	0,57	0,40
2034	0,32	0,74	0	0,000293	281	1434	3 %	5 %	0,55	0,38
2035	0,32	0,75	0	0,000289	298	1558	3 %	5 %	0,54	0,36
2036	0,32	0,76	0	0,000284	315	1682	3 %	5 %	0,52	0,34
2037	0,32	0,78	0	0,000280	333	1806	3 %	5 %	0,51	0,33
2038	0,32	0,79	0	0,000276	350	1930	3 %	5 %	0,49	0,31
2039	0,32	0,81	0	0,000271	367	2054	3 %	5 %	0,48	0,30
2040	0,32	0,82	0	0,000267	385	2178	3 %	5 %	0,46	0,28
2041	0,32	0,84	0	0,000262	402	2302	3 %	5 %	0,45	0,27
2042	0,32	0,85	0	0,000258	419	2426	3 %	5 %	0,44	0,26
2043	0,32	0,87	0	0,000253	437	2549	3 %	5 %	0,42	0,24
2044	0,32	0,88	0	0,000249	454	2673	3 %	5 %	0,41	0,23
2045	0,32	0,90	0	0,000244	471	2797	3 %	5 %	0,40	0,22
2046	0,32	0,92	0	0,000240	489	2921	3 %	5 %	0,39	0,21
2047	0,32	0,93	0	0,000236	506	3045	3 %	5 %	0,38	0,20
2048	0,32	0,95	0	0,000231	524	3169	3 %	5 %	0,37	0,19
2049	0,32	0,97	0	0,000227	541	3293	3 %	5 %	0,36	0,18
2050	0,32	0,98	0	0,000222	558	3417	3 %	5 %	0,35	0,17
2051	0,32	1,00	0	0,000218	576	3541	3 %	5 %	0,33	0,16
2052	0,32	1,02	0	0,000213	593	3665	3 %	5 %	0,33	0,16
2053	0,32	1,04	0	0,000209	610	3788	3 %	5 %	0,32	0,15
2054	0,32	1,06	0	0,000204	628	3912	3 %	5 %	0,31	0,14
2055	0,32	1,08	0	0,000200	645	4036	2 %	4 %	0,30	0,14
2056	0,32	1,10	0	0,000196	662	4160	2 %	4 %	0,29	0,13
2057	0,32	1,12	0	0,000191	680	4284	2 %	4 %	0,29	0,13
2058	0,32	1,14	0	0,000187	697	4408	2 %	4 %	0,28	0,12
2059	0,32	1,16	0	0,000182	714	4532	2 %	4 %	0,28	0,12
2060	0,32	1,18	0	0,000178	732	4656	2 %	4 %	0,27	0,11
2061	0,32	1,20	0	0,000173	749	4780	2 %	4 %	0,27	0,11
2062	0,32	1,22	0	0,000169	766	4904	2 %	4 %	0,26	0,10
2063	0,32	1,25	0	0,000164	784	5027	2 %	4 %	0,26	0,10
2064	0,32	1,27	0	0,000160	801	5151	2 %	4 %	0,25	0,10
2065	0,32	1,29	0	0,000156	818	5275	2 %	4 %	0,25	0,09
2066	0,32	1,31	0	0,000151	836	5399	2 %	4 %	0,24	0,09
2067	0,32	1,34	0	0,000147	853	5523	2 %	4 %	0,24	0,09
2068	0,32	1,36	0	0,000142	870	5647	2 %	4 %	0,23	0,08
2069	0,32	1,39	0	0,000138	888	5771	2 %	4 %	0,23	0,08
2070	0,32	1,41	0	0,000133	905	5895	2 %	4 %	0,22	0,08
2071	0,32	1,44	0	0,000129	922	6019	2 %	4 %	0,22	0,07
2072	0,32	1,47	0	0,000124	940	6143	2 %	4 %	0,21	0,07
2073	0,32	1,49	0	0,000120	957	6266	2 %	4 %	0,21	0,07
2074	0,32	1,52	0	0,000116	974	6390	2 %	4 %	0,21	0,06

5.4.8. Time horizon

In the analysis of this thesis, a longer time horizon would have resulted in higher NPVs. This is due to the fact that the costs only arise once, while the benefits arise in each year of the analysis. A shorter time horizon, on the other hand, could have resulted in negative NPVs. This would have been the case if the benefits in the chosen time horizon were too small to exceed the construction costs. In order to assess this uncertainty, the years in which the total NPVs turn positive were found. This is the year when the present value of the benefits surpasses the increased construction costs. For the sports building this happens in 2041 (NPV=1). Hence, the NPV would have been positive with a time horizon of 27 years or longer. For the school building, kindergarten and office building, this happens in years 2036 (NPV=1), 2032 (NPV=7), and 2038 (NPV=2) respectively. Hence, the NPVs of these building types would have been positive for time horizons of 22, 18, and 25 years or longer. In other words, the payback periods for the sports building, the school building, the kindergarten and the office building are 27, 22, 18, and 25 years respectively. Hence, the NPV of all building types would be positive for a time horizon of 30 years.

5.4.9. The input values' impact on the net present value

In order to assess how a 10% increase in the input values would affect the NPVs, the NPVs of the various building types were recalculated after having decreased and increased the estimated values in Tables 10 and 11 by 10%. These changes are listed in Appendix H. For most of the input values, a decrease resulted in the same change in the NPV as an increase, only with opposite signs. This was the case for changes in the estimated difference in the construction costs, the difference in the level of supplied energy, the future electricity prices, the future emission factors of electricity, and the future emission prices. For changes in the SDR, however, decreasing and increasing the rate resulted in different changes in the NPVs. The changes in the NPVs due to a 10% change in the input values are listed in Table 25.

Table 25: Changes in the net present values (NOK/m^2)

	SPORTS BUILDING	SCHOOL BUILDING	KINDERGARTEN	OFFICE BUILDING
Construction costs	60	37	50	66
Level of supplied energy	83	58	92	97
Electricity prices	71	49	79	84
Emission factors	12	8	13	14
Emission prices	12	8	13	14
Social discount rate (-10%)	66	100	73	78
Social discount rate (+10%)	-59	5	-65	-69

The percentage changes in the NPVs, relative to the original analysis, were then found. These changes, resulting from a 10% change in the various input variables, are listed in Table 26.

Table 26: Changes in the net present values (%)

	SPORTS BUILDING	SCHOOL BUILDING	KINDERGARTEN	OFFICE BUILDING
Construction costs	27 %	18 %	12 %	21 %
Level of supplied energy	37 %	28 %	22 %	31 %
Electricity prices	31 %	23 %	19 %	26 %
Emission factors	5 %	4 %	3 %	4 %
Emission prices	5 %	4 %	3 %	4 %
Social discount rate (-10%)	29 %	48 %	17 %	25 %
Social discount rate (+10%)	-26 %	2 %	-16 %	-22 %

From Table 26 one can see that, by changing the estimated difference in the costs by 10%, the NPV for the sports building would have changed by 27%. The percentage change in the NPV for the sports building resulting from a 10% change in the difference in the level supplied energy would have been even higher, at 37%. The change in the NPV caused by a change in the electricity prices would also have been quite high, at 31%. Changes in the emission factors and the emission prices would, on the other hand, have had a rather small effect of 5%. More specifically, the NPV would have increased if the difference in the construction costs were reduced by 10% and decrease if they were increased by 10%. For the difference in the level of supplied energy, the electricity prices, the emission factors and the emission prices, however, a decrease in the estimated values would have resulted in a decrease in the NPV, while an increase would have resulted in an increase in the NPV. The changes in the NPVs for the other building types would have followed the same pattern. Changes in the supplied energy would have resulted in the largest percentage change in the NPVs for all building types. Changes in the electricity price and the construction costs would have followed close behind for most of the building types. Changes in the NPVs caused by changes in the emission factor and the emission prices would, however, have been pretty small.

As mentioned, a decrease and an increase in the SDR will not result in the same changes in the NPVs. For the sports building, a decrease in the SDR would have resulted in an increase in the NPV of 29%, while an increase in the SDR would have resulted in a decrease of 26%. For the kindergarten and the office building changes in the SDR would have followed the same pattern. For the school building, however, a decrease in the SDR would have resulted in a large increase in the NPV (48%), while an increase in the SDR would have resulted in a slightly positive increase (2%).

Based on the percentage changes in the NPV, one can see that the analysis is very sensitive to changes in the estimated value for the difference in the level of supplied energy. This was expected as both benefits depend on this value. Furthermore, the analysis is quite sensitive to changes in the electricity prices and the construction costs. As expected, the analysis is also sensitive to changes in the SDR. As changes in these values are likely to affect the results of the analysis, one should pay close attention to these values in potential future studies.

5.5. RECOMMENDATION AND LIMITATIONS

As was explained in Section 4.3.1., a government intervention can be defined as socially efficient if the expected benefits exceed the expected costs. This is related to the potential Pareto efficiency rule stating that, if the benefits exceed the costs, it would be possible for those who reap the benefits of the intervention to compensate those who bear the costs. As a result, at least one person will be better off without making anyone else worse off. An intervention can therefore be justified if the NSB are positive. This is referred to as the NSB criterion. However, as costs and benefits often arise in multiple time periods, the NSB will have to be discounted (see Section 4.3.3.). The NSB criterion can therefore be rewritten to a NPV criterion stating that an intervention can be justified if the NPV is positive.

As was seen in Section 5.3.8., the NPV for all building types turned out to be positive. Hence, it is expected that the energy- and environmental benefits from stricter energy requirements will exceed the increased construction costs related to the fulfilment of these energy requirements. It would therefore be possible for the ones reaping the energy- and environmental benefits to compensate those who bear the increased construction costs. In fact, the reduced energy costs (the energy benefit) over 60 years, alone, are expected to compensate the increased construction costs (see Table 16). The energy benefit represents 89% of the total benefit, and is thereby the largest of the two benefits (see Table 27). Based on the positive NPVs for all four building types, the tightening of the energy requirements in the Technical Building Regulation is expected to be positive for the society as a whole. A tightening of the energy requirement for commercial buildings in Norway can therefore be justified and recommended. This recommendation can be said to be robust as the NPVs for all building types remained positive after having conducted a sensitivity analysis.

Table 27: The benefits of the analysis

	ENERGY BENEFIT		ENVIRONMENTAL BENEFIT		TOTAL BENEFITS
	(NOK/m^2)	(%)	(NOK/m^2)	(%)	(NOK/m^2)
Sports building	1889	89 %	232	11 %	2121
School building	1315	89 %	161	11 %	1476
Kindergarten	2091	89 %	256	11 %	2347
Office building	2226	89 %	273	11 %	2499

It is important to note that this analysis was based on many assumptions and estimated values. First, the additional construction costs were based on standard values and estimates. The actual construction costs may be both higher and lower. The expected levels of supplied energy were also based on expected levels of net energy need, instead of measurements of buildings' actual net energy need. This is due to the fact that such measurements would have been quite difficult as this analysis evaluated the various building types in general. In order to use historical numbers for the net energy need for various building types, one would need to have access to data from many historical projects. Also, as the number of buildings constructed with the Passive House Standard is still relatively low, it is difficult to obtain data that can be generalized. It was also assumed that all building used a combination of electrical boilers and heat pumps. The results could have varied if other energy conversion systems were assumed, but it is not expected to affect the results significantly. In addition, this analysis focused on three of the major impacts associated with stricter energy requirements. As was mentioned, there are other costs and benefits associated with stricter energy requirement. However, this analysis focused on three of these impacts due to the limited time frame of this thesis and the difficulty related to the measurement of other impacts.

In future studies, the analysis could be altered in order to evaluate the tightening of the energy requirements with different assumptions and estimated values. For example, actual construction costs and the net energy need of a selection of TEK10 buildings and PHS building could have been used. Also, other costs and benefits could have been included in the analysis. For example, the energy consumption and emissions in the whole life cycle of a building could have been included. This would have resulted in an inclusion of the energy and emissions related to the production of the materials for the various buildings.

6. CONCLUSION

The focus of this thesis was the energy requirements in the Norwegian Technical Building Regulation, which are expected to be tightened in 2015. In order to evaluate whether this planned tightening of the energy requirements for Norwegian buildings are likely to be positive for the society as a whole, a cost-benefit analysis was conducted. In this analysis, three of the major social costs and benefits associated with stricter energy requirements were identified and estimated; the increased construction costs, the benefit of reduced energy consumption (energy benefit), and the benefit of reduced emissions of GHGs (environmental benefit). The objective of this analysis was to find out whether the expected benefits associated with these requirements were likely to exceed the increased costs related to stricter energy requirements.

In the analysis of this thesis, the increased costs and benefits associated with stricter energy requirements for four building types were estimated. The requirements in TEK10 represented the current requirements, and the energy requirements in the Passive House Standard represented the stricter energy requirements. Hence, the costs and benefits of one TEK10 building and one PHS building of each building type were estimated. The difference between the costs and benefits of the TEK10 building and the PHS building were then found in order to find the increased costs and benefits associated with stricter energy requirements.

Based on the estimated increased costs and benefits, the net social benefits for each building type were found. These net social benefits were then discounted in order to find the net present values. A sensitivity analysis was then performed in order to see how changes in the assumptions and the estimated values would have affected the net present values of the four building types. This was important, as there is a lot of uncertainty associated with the values needed in order to measure the costs and benefits. This is especially the case for the future electricity prices, the future emission factors of electricity, and the future emission prices.

The NPVs in both the original analysis and the sensitivity analysis were positive for all building types. Hence, it is expected that the increased benefits associated with stricter energy requirements for Norwegian commercial buildings will exceed the increased costs, and thereby be positive for the society as a whole. A tightening of the energy requirements in the Technical Building Regulation can therefore be recommended.

REFERENCES

Baujard, A. (2013, November). *Welfare economics.* Retrieved February 28, 2014 from http://halshs.archives-ouvertes.fr/docs/00/90/69/07/PDF/1333.pdf

Boardman, A. E., Greenberg, D. H., Vining, A. R., & Weimer, D. L. (2011). *Cost-benefit Analysis* (4. ed.). New Jersey: Pearson Education International.

Cicero. (n.d.). *Hva kan vi gjøre med klimaendringene?* Retrieved March 28, 2014 from http://www.cicero.uio.no/webnews/index.aspx?id=11152

Climate Cure 2020 (2010). *Measures and Instruments for Achieving Norwegian Climate Goals by 2020.* Retrieved March 2, 2014 from http://miljodirektoratet.no/old/klif/publikasjoner/2590/ta2590.pdf

Clinch, J. P., & Healy, J. D. (2000, January). *Energy policy.* Retrieved January 9, 2014 from http://www.sciencedirect.com/science/article/pii/S0301421500001105

Confederation of Norwegian Enterprise (2009, December). *Energieffektivisering.* Retrieved January 12, 2014 from http://legacyweb.nho.no/getfile.php/global/konvertert/NHO/RootNY/filer_og_vedlegg1/Temahefte%20Energieffektivisering.pdf

DeNyse, G. (2000). *How can we get there?* Retrieved March 10, 2014 from http://web.mit.edu/10.391J/www/proceedings/Sustainability&Markets_DeNyse2000.pdf

Dokka, T. H. (2011, March 5.). *Proposal for CO2-factor for electricity and outline of a full ZEB-definition.* Retrieved April 4, 2014 from http://zeb.no/index.php/reports/item/116-proposal-for-co2-factor-for-electricity-and-outline-of-a-full-zeb-definition

Enova. (n.d.-a). *Our history and our mission*. Retrieved February 1, 2014 from http://www.enova.no/about-enova/about-enova/259/0/

Enova. (n.d.-b). *Passivhus*. Retrieved February 2, 2014 from http://www.enova.no/radgivning/privat/rad-om-produkter-og-losninger/tiltak-i-bygningskroppen/passivhus-hjelp-til-deg-som-skal-kjope-eller-bygge-/passivhus-hjelp-til-deg-som-skal-kjope-eller-bygge-/103/242/

Environmental Energy Technologies Division. (2014). *What is energy efficiency?* Retrieved January 12, 2014 from http://eetd.lbl.gov/ee/

Eurelectric (2011). *Hydro in Europe: Powering renewables.* Retrieved April 14, 2014 from http://www.eurelectric.org/media/26690/hydro_report_final-2011-160-0011-01-e.pdf

Hagen, K. P. (2012, September 20). *Appropriate discount rates for long term public projects.* Retrieved March 4, 2014 from http://www.concept.ntnu.no/symposium/cs2012/presentations/3_1_Hagen.pdf

International Energy Agency (2013a). *Nordic Energy Technology Perspectives.* Retrieved January 27, 2014 from http://www.iea.org/media/etp/nordic/NETP.pdf

International Energy Agency (2013b). *Tracking Clean Energy Progress 2013.* Retrieved January 20, 2014 from http://www.iea.org/publications/TCEP_web.pdf

Karlstrøm, H., Ryghaug, M., & Sørensen, K. H. (n.d.). *Towards new national policy instruments for promoting energy efficiency* . Retrieved January 7, 2014 from http://henrikkarlstrom.files.wordpress.com/2012/11/paper_-towards-new-national-policy-instruments-for-promoting-energy-efficiency_final.pdf

Klimagassregnskap (2012, March 29.). *Utslippsfaktorer for bygg.* Retrieved April 4, 2014 from http://www.klimagassregnskap.no/portal/index.php/2-generelt/29-enighet-om-utslippsfaktorer

Klimaløftet (2012, December). *Kalkulator for beregning av klimagassutslipp fra husholdninger* . Retrieved March 2, 2014 from http://www.klimakalkulatoren.no/media/2382/klimakalkulatoren_bakgrunnstall_dokumentasjon_030413.pdf

Kolstad, C. D. (2011). *Environmental Economics* (2. ed.). Oxford: Oxford university press.

Lexow, T. (2012, September 11). *Passivhusstandarden*. Retrieved February 1, 2014 from http://www.standard.no/Global/PDF/Arrangementer/Passivhus%20yrkesbygg/7%20Om%20NS%203701%20Tor%20Lexow.pdf

Lie, Ø. (2013, October 4). *Enova dropper støtten til passivhus*. Retrieved February 2, 2014 from http://www.tu.no/bygg/2013/10/04/enova-dropper-stotten-til-passivhus

Low-Energy Programme (n.d.). *Fordeler og utfordringer med pasivhus*. Retrieved March 14, 2014 from http://www.lavenergiprogrammet.no/fordeler-og-utfordringer-med-passivhus/fordeler-og-utfordringer-med-passivhus-article1550-236.html

Multiconsult & Sintef (2012). *Kostnadsoptimalitet.* Retrieved January 28, 2014 from http://www.dibk.no/Global/Energi/Rapport%20kostnadsoptimalitet.pdf

NASDAQ OMX (2014, April 29.). *Market prices*. Retrieved April 29, 2014 from http://www.nasdaqomx.com/commodities/market-prices

Nilsen, M. A. (2011). *Energitiltak og -merking av bygg.* Retrieved January 27, 2014 from http://brage.bibsys.no/xmlui/bitstream/handle/11250/138396/Marius%20Arion%20Nilsen.pdf?sequence=1

Norconsult Informasjonssystemer (n.d.). *Brukerdokumentasjon ISY Calcus.* Retrieved April 29, 2014 from http://download.nois.no/old/Calcus_6.0.pdf

Nord Pool (n.d.). *Market members*. Retrieved February 2, 2014 from http://www.nordpoolspot.com/How-does-it-work/The-market-members/Producers/

Nord Pool (2014, April). *Power system overview*. Retrieved April 4, 2014 from http://www.nordpoolspot.com/Market-data1/Maps/Power-System-Overview/Power-System-Map/

Norges Bank (2014, April 29.). *Exchange rates*. Retrieved April 29, 2014 from http://www.norges-bank.no/en/price-stability/exchange-rates/eur/

Norwegian Building Authority (2013). *Energi*. Retrieved January 28, 2014 from http://www.dibk.no/no/Tema/Energi/

Norwegian Building Authority (2010). *Regulations on technical requirementsfor building works*. Retrieved January 28, 2014 from http://www.dibk.no/Documents/Byggeregler/Regulations_on_technical_requirements_for_building_works.pdf

Norwegian Building Authority (n.d.). *Veiledning om tekniske krav til byggverk*. Retrieved January 16, 2014 from http://dibk.no/no/BYGGEREGLER/Gjeldende-byggeregler/Veiledning-om-tekniske-krav-til-byggverk/?dxp=/dxp/content/tekniskekrav/14/

Norwegian Environment Agency (2013, May 24). *Energiproduksjon stadig like karbonintensiv*. Retrieved January 12, 2014 from http://www.miljostatus.no/Tema/Klima/Nytt-fra-forskning/Energiproduksjon-stadig-like-karbonintensiv/

Norwegian Government Agency for Financial Management (2010, October). *Håndbok for samfunnsøkonomiske analyser.* Retrieved March 28, 2014 from http://www.sfso.no/upload/forvaltning_og_analyse/Publikasjoner%20og%20rapporter/Veileder_samfunnsokonomiske_analyser.pdf

Norwegian Ministry of Climate and Environment (2012, April 25). *Norsk klimapolitikk.* Retrieved January 14, 2014 from http://www.regjeringen.no/pages/37858627/PDFS/STM201120120021000DDDPDFS.pdf

Norwegian Ministry of Local Government and Regional Development (2010, August 23). *KRDs arbeidsgruppe for energieffektivisering av bygg.* Retrieved January 20, 2014 from http://www.regjeringen.no/upload/KRD/Vedlegg/BOBY/rapporter/energieffektivisering_av_bygg_rapport_2010.pdf

Norwegian Ministry of Petroleum and Energy (2013, May 16). *Kraftmarkedet og strømprisen*. Retrieved February 1, 2014 from http://www.regjeringen.no/nb/dep/oed/tema/energi_og_vannsressurser/kraftmarkedet.html?id=443423

Norwegian Ministry of Petroleum and Energy (2007, September 3). *The power market*. Retrieved February 1, 2014 from http://www.regjeringen.no/en/dep/oed/Subject/energy-in-norway/The-power-market.html?id=443423

Norwegian Water Resources and Energy Directorate (2011). *Energibruk.* Retrieved January 28, 2014 from http://www.nve.no/Global/Publikasjoner/Publikasjoner%202011/Rapport%202011/rapport9-11.pdf

Norwegian Water Resources and Energy Directorate (2014). *Nettleiestatistikk næringskunder - 2005 og nyere*. Retrieved April 4, 2014 from http://www.nve.no/no/Kraftmarked/Nettleie1/Nettleiestatistikk/Nettleiestatistikk-naringskunder---2005-og-senere/

Norwegian Water Resources and Energy Directorate (2003). *Samfunnsøkonomisk analyse av energiprosjekter.* Retrieved February 12, 2014 from http://www.nve.no/Global/Publikasjoner/Publikasjoner%202003/H%C3%A5ndbok%202003/Trykkefil%20h%C3%A5ndbok%201-03.pdf

Norwegian Water Resources and Energy Directorate (2013, June 3). *Varedeklarasjonen 2012*. Retrieved March 4, 2014 from http://www.nve.no/no/Nyhetsarkiv-/Nyheter/Varedeklarasjonen-2012/

NOU 2012: 16 (2012, October 3). *Cost-Benefit Analysis.* Retrieved January 4, 2014 from http://www.regjeringen.no/pages/38220627/PDFS/NOU201220120016000EN_PDFS.pdf

NOU 2012: 9 (2012). *Energiutredningen - verdiskaping, forsyningssikkerhet og miljø.* Retrieved February 4, 2014 from http://www.regjeringen.no/pages/37306204/PDFS/NOU201220120009000DDDPDFS.pdf

Pettersen, I. S.S. (2014, February 12.). Nordic electricity at NASDAQ OMX (Personal communication via e-mail).

Pindyck, R. S., & Rubinfeld, D. L. (2009). *Microeconomics* (7. ed.). New Jersey: Pearson Education International.

Rambøll (2013, July). *Energiregler 2015.* Retrieved January 14, 2014 from http://www.dibk.no/Documents/Energi/Hovedrapport_Ramboll_072013.pdf

Sandmo, A. (2003). *Striking the balance: Economics and the environment.* Retrieved February 28, 2014 from http://www.nhh.no/Files/Filer/institutter/sam/Discussion%20papers/2003/17.pdf

Santamouris, M. (2005). *Energy performance of residential buildings.* London: James&James/Earthscan.

Standard Norge (2012). *NS 3701: Criteria for passive houses and low energy buildings.* Retrieved February 1, 2014 from http://www.standard.no/en/PDF/FileDownload/?redir=true&filetype=Pdf&preview=true&item=587802&category=5

Statistics Norway (2014, April 10.). *Consumer price index*. Retrieved March 2, 2014 from https://www.ssb.no/en/priser-og-prisindekser/statistikker/kpi/maaned/2014-04-10?fane=tabell#content

Statistics Norway (2013, November 8). *Energiregnskap og energibalanse*. Retrieved February 24, 2014 from http://ssb.no/energi-og-industri/statistikker/energiregn/aar/2013-11-08?fane=tabell&sort=nummer&tabell=147452

Statnett (2013, April 10). *News Archive 2013*. Retrieved February 3, 2014 from http://www.statnett.no/en/News/News-archives/News-archive-2013/Joint-statement-Interconnector-project-NORDLINK-first-developed/

Statsbygg (2012, October 10.). *Klimagassregnskap.no/versjon 4.* Retrieved March 18, 2014 from http://www.klimagassregnskap.no/dok/kgr4-dokumentasjonsrapport.pdf

Statsbygg (2011, March 3.). *Utslippsfaktorer for elektrisitetsbruk.* Retrieved April 4, 2014 from http://www.klimagassregnskap.no/portal/images/El-utslippsfaktor%20-%20oppsummering%20og%20forklaring%20til%20versjon%203%20-%2003.03.2011.pdf

UngEnergi (2013, April 2). *Energieffektivisering*. Retrieved January 10, 2014 from http://ungenergi.no/miljovennlig-teknologi/energieffektivisering/

University of California (2014). *What is a greenhouse gas?* Retrieved January 14, 2014 from http://beacon.berkeley.edu/GHGs.aspx

Wangensteen, I. (2005). Retrieved February 4, 2014 from https://www.fer.hr/_download/repository/KompendiumTET4185-nov05%20justert-4.pdf

Ward, F. A. (2006). *Environmental and natural resource economics.* New Jersey: Pearson Education International.

World Green Building Council (2013). *The business case for green building.* Retrieved February 4, 2014 from http://www.worldgbc.org/files/1513/6608/0674/Business_Case_For_Green_Building_Report_WEB_2013-04-11.pdf

Zhang, W. (2006, June). *Cost and benefit of energy efficient buildings.* Retrieved March 4, 2014 from http://dspace.mit.edu/bitstream/handle/1721.1/36819/82370718.pdf?sequence=1.pdf

APPENDICES

Appendix A: Chapter 14 of the Technical Building Regulation TEK10

Chapter 14 Energy

I Introductory provisions concerning energy

Section 14-1. *General requirements relating to energy*

(1) Structures shall be designed and constructed to promote low energy needs and environmentally friendly heating solutions. Energy requirements apply to a building's heated usable floor space.

(2) Calculations of buildings' energy needs and heat loss figures shall be carried out in accordance with *Norwegian Standard NS 3031 Energy and Power Demand for Heating of Buildings - Calculation Rules.* U-values shall be calculated as mean values for the various parts of the building.

(3) In this chapter, small houses include detached houses, semi-detached houses, rows of terraced houses and linked houses.

(4) In the case of projects where compliance with the requirements in this chapter is incompatible with the preservation of cultural monuments and buildings of antiquarian value, the requirements apply insofar as they are appropriate.

II Energy efficiency

Section 14-2. *Energy efficiency*

(1) Buildings shall satisfy the level stipulated in section 14-3 or have a total net energy lower then the energy budget stipulated in section 14-4. The minimum requirements in section 14-5 shall be complied with regardless of whether or not section 14-3 or section 14-4 is used. Only section 14-5, second paragraph, and section 14-6 apply to residential buildings and leisure homes with log outer walls.

(2) Sections 14-3 to 14-8, with the exception of section 14-5, first and second paragraphs, do not apply to buildings with less than 30 m^2 of heated usable floor space.

(3) This chapter does not apply to buildings which, based on their intended use, shall maintain a low interior temperature if they are designed to ensure that their energy needs are kept at a reasonable level.

Section 14-3. *Energy measures*

(1) Buildings shall have the following energy characteristics:

a) Transmission heat loss:

1st Proportion of window and door areas ≤ 20% of heated usable floor space

2ndU-value outer wall ≤ 0.18 W/(m^2K)

3rd U-value roof ≤ 0.13 W/(m^2K)

4th U-value floor ≤ 0.15 W/(m^{2}K)

5th U-value glass/windows/doors including frames ≤ 1.2 W/(m^{2}K).

6th Normalised thermal bridge value, where m^2 is stated in heated usable floor space:

- small houses ≤ 0.03 W/(m^{2}K)
- other buildings ≤ 0.06 W/(m^{2}K)

b) Infiltration and ventilation heat loss:

1st Leakage figures at 50 Pa pressure differential:

- small houses ≤ 2.5 air changes per hour
- other buildings ≤ 1.5 air changes per hour

2nd Annual mean temperature efficiency for heat recuperator in ventilation systems:

- residential buildings, as well as floor spaces in which heat recovery poses a risk of spreading pollution/contagions ≥ 70%
- other buildings and floor spaces ≥ 80%

c) Other measures:

1st Specific fan power (SFP) in ventilation systems:

- residential buildings ≤ 2.5 kW/(m^3/s)
- other buildings ≤ 2.0 W/(m^3/s)

2nd Ability to lower indoor temperatures at night and weekends

3rd Measures that eliminate the building's need for local cooling.

(2) The energy measures in points (a) and (b) can be departed from in residential buildings providing the building's heat loss figure does not increase.

(3) The energy measures in point (a) can be departed from in other buildings providing the building's heat loss figure does not increase.

Section 14-4. *Energy budgets*

(1) The total net energy needs of buildings shall not exceed the budgets stipulated in the following table:

Table: Energy budgets

Building category	Total net energy needs (kWh/m2 of heated usable floor space per year)
Small houses and leisure homes with more than 150 m2 of heated usable floor space.	120 + 1600/ m2 of heated usable floor space
Block of flats	115
Nursery school	140
Office building	150
School building	120

University/university college	160
Hospital	300 (335)
Nursing home	215 (250)
Hotel	220
Sports building	170
Business building	210
Cultural building	165
Light industry/workshops	175 (190)

(2) The requirements stated in parentheses apply to floor spaces in which heat recovery and ventilation air pose a risk of spreading pollutants/contagions.

(3) Multifunctional buildings shall be divided up into zones based on the building's category and the respective energy budgets complied with within in each zone.

Section 14-5. *Minimum requirements*

(1) The following minimum requirements shall be complied with:

Table: Minimum requirements

U-value outer wall [W/(m²K)]	**U-value roof [W/(m²K)]**	**U-value floors on ground and facing open air [W/(m²K)]**	**U-value windows and doors including frames [W/(m²K)]**	**Leakage figures at 50 Pa pressure differential (air change per hour):**
≤ 0.22	≤ 0.18	≤ 0.18	≤ 1.6	≤ 3.0

(2) Pipes, equipment and ducting connected to a building's heating and distribution system shall be insulated to prevent unnecessary heat loss.

(3) The following minimum requirements also apply, except to small houses:

a) The U-value for glass/windows/doors including frames multiplied by the proportion of window and door areas of a building's heated usable floor shall be less than 0.24.

b) The total sun factor for glass/windows (g_t) shall be less than 0.15 on façades that catch the sun, unless it can be documented that the building does not need cooling.

Section 14-6. *Buildings with log outer walls*

The following apply to residential buildings or leisure homes with log outer walls:

Table: Buildings with log outer walls

Building category	Dimensions of outer wall:	U-valure roof [W/(m²K)]	U-value floors on ground and facing open air [W/(m²K)]	U-value windows and doors including frames [W/(m²K)]
Residential buildings and leisure homes with one dwelling unit and heated usable floor space of greater than 150 m²	≥ 8″ logs	≤ 0.13	≤ 0.15	≤ 1.4
Leisure homes with one dwelling unit and heated usable floor space of less than 150 m²	≥ 6″ logs	≤ 0.18	≤ 0.18	≤ 1.6

III Energy supply

Section 14-7. *Energy supply*

(1) Installation of a boiler for fossil oil to accommodate the basic energy load for space- and water heating is not permitted.

(2) A building exceeding usable area of 500m² shall be designed and constructed so that a minimum of 60 % of the net energy need for space- and water heating may be obtained by energy supply other than direct acting electricity or fossil fuels at the point of end user.

(3) A building less than 500m² shall be designed and constructed so that a minimum of 40 % of the net energy need for space- and water heating may be obtained by energy supply other than direct acting electricity or fossil fuels at the point of end user.

(4) The requirements to energy supply according to clause 2 and 3 shall not apply where local conditions do not make it practically possible to comply with the requirements. For housing the requirements do not apply if the net energy demand for space- and water heating is calculated to be less than 15000 kWh/year or if the requirements results in increased cost over the life cycle of the building

(5) Dwellings that according to clause 4 are exempt from the requirements to energy supply according to clause 2 and 3 shall have a chimney and an enclosed heating unit suitable for bio fuels. This requirement shall not apply to dwellings less than 50m² usable area or dwellings that are designed and constructed as passive houses.

Section 14-8. *District heating*

Wherever provisions in plans stipulate an obligation to connect to a district heating system pursuant to section 27-5 of the Planning and Building Act, buildings shall be equipped with a heating system allowing for the use of district heating for heating rooms, ventilation heating and hot water.

Source: Norwegian Building Authority (2010)

Appendix B: Costs included in the construction cost categories

CATEGORY	COSTS:
1. Overhead costs	Costs related to the rigging and operation of the construction site.
2. Building structure	Costs of foundations, supporting structures, walls, floors, and roofs.
3. Heating, ventilation and sanitary	Costs of sanitary installations, heating installations, fire protection, and air treatment.
4. Electrical power system	Costs of the installation of the electrical support system, high- and low voltage electrical distribution, lighting and electrical heating.
5. Telecommunication and automation	Costs are related to communication and support systems, integrated communication systems, telephony and paging, alarms and audiovisuals.
6. Other installations	Costs related to the installation of conveying systems, waste handling, vacuum cleanings, and fixed equipment and furnishing.
7. Outdoor structure and facilities	Costs related to terrain treatment, roads and open areas, parks and gardens, and outdoor constructions, sanitary work, electrical power and telecommunications.
8. General costs	Costs related to the planning of the project, management and administration and insurances and fees.
9. Special costs	Financial expenses and the value added tax.
10. Contingency	An amount included as a safety buffer in case of unforeseen costs.

Source: Information from Norconsult Informasjonssystemer (n.d.)

Appendix C: The specific construction costs for each building type

Table C1: Construction costs for a sports building

	TEK10 BUILDING (Total)	PHS BUILDING (Total)	DIFFERENCE (Total)	DIFFERENCE (NOK/m^2)
Overhead costs	3 431 811	3 741 582	309 771	160
Building structure	17 537 995	18 603 200	1 065 205	550
Heating, ventilation and sanitary	3 695 387	3 344 360	-351 027	-181
Electrical power system	2 226 991	2 226 991	0	0
Telecommunication and automation	1 040 644	1 040 644	0	0
Other installations	0	0	0	0
General costs	4 726 944	4 726 944	0	0
Contingency	4 490 719	4 631 512	140 793	73
Total construction costs	**37 150 491**	**38 315 233**	**1 164 742**	**601**

Table C2: Construction costs for a school building

	TEK10 BUILDING (Total)	PHS BUILDING (Total)	DIFFERENCE (Total)	DIFFERENCE (NOK/m^2)
Overhead costs	15 520 920	16 522 860	1 001 940	157
Building structure	63 659 621	66 126 721	2 467 100	386
Heating, ventilation and sanitary	18 093 386	16 222 048	-1 871 338	-293
Electrical power system	11 994 240	11 994 240	0	0
Telecommunication and automation	6 114 061	6 114 061	0	0
Other installations	1 930 783	1 930 783	0	0
General costs	21 661 341	22 076 047	414 706	65
Contingency	22 583 332	22 910 349	327 017	51
Total construction costs	**161 557 684**	**163 897 109**	**2 339 425**	**366**

Table C3: Construction costs for a kindergarten

	TEK10 BUILDING (Total)	PHS BUILDING (Total)	DIFFERENCE (Total)	DIFFERENCE (NOK/m^2)
Overhead costs	1 605 266	1 761 735	156 469	215
Building structure	7 187 627	7 818 482	630 855	867
Heating, ventilation and sanitary	2 474 741	2 169 733	-305 008	-419
Electrical power system	1 059 922	1 059 922	0	0
Telecommunication and automation	388 522	388 522	0	0
Other installations	203 210	0	-203 210	-279
General costs	2 586 189	2 618 715	32 526	45
Contingency	2 519 640	2 570 280	50 640	70
Total construction costs	**18 025 117**	**18 387 389**	**362 272**	**498**

(Continues on next page)

Table C4: Construction costs for an office building

	TEK10 BUILDING (Total)	PHS BUILDING (Total)	DIFFERENCE (Total)	DIFFERENCE (NOK/m^2)
Overhead costs	14 128 385	14 781 843	653 458	139
Building structure	50 684 448	51 710 813	1 026 365	218
Heating, ventilation and sanitary	14 399 364	15 149 530	750 166	160
Electrical power system	10 603 977	10 603 977	0	0
Telecommunication and automation	4 916 179	4 916 179	0	0
Other installations	3 803 357	3 803 357	0	0
General costs	14 717 945	14 972 054	254 109	54
Contingency	16 988 048	17 390 663	402 615	86
Total construction costs	**130 241 703**	**133 328 416**	**3 086 713**	**657**

Source: Numbers from simulations with ISY Calcus

Appendix D: Historical variable transmission tariff

	VARIABLE TRANSMISSION TARFIFF	
	(NOK/kWh)	(Yearly change)
2005	0,232	0 %
2006	0,220	-5,2 %
2007	0,225	2,3 %
2008	0,233	3,6 %
2009	0,243	4,3 %
2010	0,264	8,6 %
2011	0,267	1,1 %
2012	0,263	-1,5 %
2013	0,266	1,1 %
2014	0,267	0,4 %
Average	0,248	**1,64 %**

Source: Norwegian Water Resources and Energy Directorate (2014)

Appendix E: Scenarios for the development in emission prices

	EMISSION PRICES ($EUR/t\ CO_2e$)		
Year	LOW	MEDIUM	HIGH
2012	16	18	25
2015	17	26	38
2020	20	40	60

Source: Adapted from Table 8.1 in Climate Cure 2020 (2010, p. 70).

Appendix F: Emission price paths based on the two-degree target

Table F1: The mean and standard deviation of several emission price paths

	EMISSION PRICES (EUR/t CO_2e)	
Year	**MEAN**	**STANDARD DEVIATION**
2030	68	43
2050	235	169

Source: Adapted from Table 9.2. in NOU 2012: 16 (2012, p. 137).

Table F2: Three scenarios for the development in the future emission price

	EMISSION PRICES (EUR/t CO_2e)		
Year	**LOW**	**MEDIUM**	**HIGH**
2030	25	68	111
2050	66	235	404

The "low" values were found by subtracting the standard deviation from the mean, and the "high" values were found by adding the standard deviation to the mean.

Source: Adapted from Table 9.2. in NOU 2012: 16 (2012).

Appendix G: The model used for the calculations

Table G1: Model for a sports building

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
6 7 8			YEAR	REDUCTION IN SUPPLIED ENERGY (kWh/m²)	ELECTRICITY PRICE (NOK/kWh)	EMISSION FACTOR (tCO2e/kWh)	EMISSION PRICE (NOK/tCO2e)	INCREASED COSTS (NOK/m²)	ENERGY BENEFIT (NOK/m²)	ENVIRONMENTAL BENEFIT (NOK/m²)	NET SOCIAL BENEFITS (NOK/m²)	SOCIAL DISCOUNT RATE (%)	DISCOUNT FACTOR (Factor)	NET PRESENT VALUE (NOK/m²)
9		0	2014	0	0,0000	0,0000000	0,0000	601	0	0	-601	4 %	1,00	-601
10		1	2015	56	0,5208	0,0003195	229,8607	0	29	4	33	4 %	0,96	32
11		2	2016	56	0,5150	0,0003112	254,6149	0	29	4	33	4 %	0,92	31
12		3	2017	56	0,5038	0,0003029	279,3691	0	28	5	33	4 %	0,89	29
13		4	2018	56	0,5067	0,0002946	304,1234	0	28	5	33	4 %	0,85	29
14		5	2019	56	0,5144	0,0002863	328,8776	0	29	5	34	4 %	0,82	28
15		6	2020	56	0,5225	0,0002780	353,6318	0	29	6	35	4 %	0,79	27
16		7	2021	56	0,5440	0,0002697	375,7789	0	30	6	36	4 %	0,76	27
17		8	2022	56	0,5519	0,0002614	397,9259	0	31	6	37	4 %	0,73	27
18		9	2023	56	0,5601	0,0002531	420,0729	0	31	6	37	4 %	0,70	26
19		10	2024	56	0,5684	0,0002448	442,2200	0	32	6	38	4 %	0,68	26
20		11	2025	56	0,5684	0,0002365	464,3670	0	32	6	38	4 %	0,65	25
21		12	2026	56	0,5684	0,0002282	486,5140	0	32	6	38	4 %	0,62	24
22		13	2027	56	0,5684	0,0002199	508,6611	0	32	6	38	4 %	0,60	23
23		14	2028	56	0,5684	0,0002116	530,8081	0	32	6	38	4 %	0,58	22
24		15	2029	56	0,5684	0,0002033	552,9552	0	32	6	38	4 %	0,56	21
25		16	2030	56	0,5684	0,0001950	575,1022	0	32	6	38	4 %	0,53	20
26		17	2031	56	0,5684	0,0001867	645,7214	0	32	7	39	4 %	0,51	20
27		18	2032	56	0,5684	0,0001784	716,3405	0	32	7	39	4 %	0,49	19
28		19	2033	56	0,5684	0,0001701	786,9597	0	32	7	39	4 %	0,47	19
29		20	2034	56	0,5684	0,0001618	857,5789	0	32	8	40	4 %	0,46	18
30		21	2035	56	0,5684	0,0001535	928,1980	0	32	8	40	4 %	0,44	17
31		22	2036	56	0,5684	0,0001452	998,8172	0	32	8	40	4 %	0,42	17
32		23	2037	56	0,5684	0,0001369	1069,4364	0	32	8	40	4 %	0,41	16
33		24	2038	56	0,5684	0,0001286	1140,0555	0	32	8	40	4 %	0,39	16
34		25	2039	56	0,5684	0,0001203	1210,6747	0	32	8	40	4 %	0,38	15
35		26	2040	56	0,5684	0,0001120	1281,2939	0	32	8	40	4 %	0,36	14
36		27	2041	56	0,5684	0,0001037	1351,9130	0	32	8	40	4 %	0,35	14

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37		28	2042	56	0,5684	0,0000954	1422,5322	0	32	8	39	4 %	0,33	13
38		29	2043	56	0,5684	0,0000871	1493,1514	0	32	7	39	4 %	0,32	13
39		30	2044	56	0,5684	0,0000788	1563,7705	0	32	7	39	4 %	0,31	12
40		31	2045	56	0,5684	0,0000705	1634,3897	0	32	6	38	4 %	0,30	11
41		32	2046	56	0,5684	0,0000622	1705,0089	0	32	6	38	4 %	0,29	11
42		33	2047	56	0,5684	0,0000539	1775,6280	0	32	5	37	4 %	0,27	10
43		34	2048	56	0,5684	0,0000456	1846,2472	0	32	5	37	4 %	0,26	10
44		35	2049	56	0,5684	0,0000373	1916,8664	0	32	4	36	4 %	0,25	9
45		36	2050	56	0,5684	0,0000290	1987,4855	0	32	3	35	4 %	0,24	9
46		37	2051	56	0,5684	0,0000207	2058,1047	0	32	2	34	4 %	0,23	8
47		38	2052	56	0,5684	0,0000124	2128,7239	0	32	1	33	4 %	0,23	8
48		39	2053	56	0,5684	0,0000041	2199,3430	0	32	1	32	4 %	0,22	7
49		40	2054	56	0,5684	0	2269,9622	0	32	0	32	4 %	0,21	7
50	1	41	2055	56	0,5684	0	2340,5814	0	32	0	32	3 %	0,20	6
51	2	42	2056	56	0,5684	0	2411,2005	0	32	0	32	3 %	0,20	6
52	3	43	2057	56	0,5684	0	2481,8197	0	32	0	32	3 %	0,19	6
53	4	44	2058	56	0,5684	0	2552,4389	0	32	0	32	3 %	0,19	6
54	5	45	2059	56	0,5684	0	2623,0581	0	32	0	32	3 %	0,18	6
55	6	46	2060	56	0,5684	0	2693,6772	0	32	0	32	3 %	0,17	6
56	7	47	2061	56	0,5684	0	2764,2964	0	32	0	32	3 %	0,17	5
57	8	48	2062	56	0,5684	0	2834,9156	0	32	0	32	3 %	0,16	5
58	9	49	2063	56	0,5684	0	2905,5347	0	32	0	32	3 %	0,16	5
59	10	50	2064	56	0,5684	0	2976,1539	0	32	0	32	3 %	0,15	5
60	11	51	2065	56	0,5684	0	3046,7731	0	32	0	32	3 %	0,15	5
61	12	52	2066	56	0,5684	0	3117,3922	0	32	0	32	3 %	0,15	5
62	13	53	2067	56	0,5684	0	3188,0114	0	32	0	32	3 %	0,14	5
63	14	54	2068	56	0,5684	0	3258,6306	0	32	0	32	3 %	0,14	4
64	15	55	2069	56	0,5684	0	3329,2497	0	32	0	32	3 %	0,13	4
65	16	56	2070	56	0,5684	0	3399,8689	0	32	0	32	3 %	0,13	4
66	17	57	2071	56	0,5684	0	3470,4881	0	32	0	32	3 %	0,13	4
67	18	58	2072	56	0,5684	0	3541,1072	0	32	0	32	3 %	0,12	4
68	19	59	2073	56	0,5684	0	3611,7264	0	32	0	32	3 %	0,12	4
69	20	60	2074	56	0,5684	0	3682,3456	0	32	0	32	3 %	0,12	4
70			**TOTAL**	-	-	-	-	**601**	**1889**	**232**	**1520**	-	-	**226**

Table G2: Model with formulas

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1														
2				REDUCTION IN	ELECTRICITY	EMISSION		INCREASED	ENERGY	ENVIRONMENTAL	NET SOCIAL	SOCIAL		NET PRESENT
3				SUPPLIED ENERGY	PRICE	FACTOR	EMISSION PRICE	COSTS	BENEFIT	BENEFIT	BENEFIT	DISCOUNT RATE	DISCOUNT FACTOR	VALUE
4			YEAR	(kWh/m^2)	(NOK/kWh)	(tCO2e/kWh)	(NOK/tCO2e)	(NOK/m^2)	(NOK/m^2)	(NOK/m^2)	(NOK/m^2)	(%)	(Factor)	(NOK/m^2)
5		0	2014	0	0	0	0	601	0	0	=I5+J5-H5	0,04	=1/1,04^B5	=M5*K5
6		1	2015	56	0,52081265	0,0003195	229,8606856	0	=D6*E6	=D6*F6*G6	=SUM(H6:J6)	0,04	=1/1,04^B6	=M6*K6
7		2	2016	56	0,51501595	0,0003112	254,61491328	0	=D7*E7	=D7*F7*G7	=SUM(H7:J7)	0,04	=1/1,04^B7	=M7*K7
8		3	2017	56	0,5038366	0,0003029	279,36914096	0	=D8*E8	=D8*F8*G8	=SUM(H8:J8)	0,04	=1/1,04^B8	=M8*K8
9		4	2018	56	0,50673495	0,0002946	304,12336864	0	=D9*E9	=D9*F9*G9	=SUM(H9:J9)	0,04	=1/1,04^B9	=M9*K9
10		5	2019	56	0,51443628	0,0002863	328,87759632	0	=D10*E10	=D10*F10*G10	=SUM(H10:J10)	0,04	=1/1,04^B10	=M10*K10
11		6	2020	56	0,52246885	0,000278	353,631824	0	=D11*E11	=D11*F11*G11	=SUM(H11:J11)	0,04	=1/1,04^B11	=M11*K11
12		7	2021	56	0,54399945	0,0002697	375,77886164	0	=D12*E12	=D12*F12*G12	=SUM(H12:J12)	0,04	=1/1,04^B12	=M12*K12
13		8	2022	56	0,5518664	0,0002614	397,92589928	0	=D13*E13	=D13*F13*G13	=SUM(H13:J13)	0,04	=1/1,04^B13	=M13*K13
14		9	2023	56	0,5601474	0,0002531	420,07293692	0	=D14*E14	=D14*F14*G14	=SUM(H14:J14)	0,04	=1/1,04^B14	=M14*K14
15		10	2024	56	0,5684284	0,0002448	442,21997456	0	=D15*E15	=D15*F15*G15	=SUM(H15:J15)	0,04	=1/1,04^B15	=M15*K15
16		11	2025	56	0,5684284	0,0002365	464,3670122	0	=D16*E16	=D16*F16*G16	=SUM(H16:J16)	0,04	=1/1,04^B16	=M16*K16
17		12	2026	56	0,5684284	0,0002282	486,51404984	0	=D17*E17	=D17*F17*G17	=SUM(H17:J17)	0,04	=1/1,04^B17	=M17*K17
18		13	2027	56	0,5684284	0,0002199	508,66108748	0	=D18*E18	=D18*F18*G18	=SUM(H18:J18)	0,04	=1/1,04^B18	=M18*K18
19		14	2028	56	0,5684284	0,0002116	530,80812512	0	=D19*E19	=D19*F19*G19	=SUM(H19:J19)	0,04	=1/1,04^B19	=M19*K19
20		15	2029	56	0,5684284	0,0002033	552,95516276	0	=D20*E20	=D20*F20*G20	=SUM(H20:J20)	0,04	=1/1,04^B20	=M20*K20
21		16	2030	56	0,5684284	0,000195	575,1022004	0	=D21*E21	=D21*F21*G21	=SUM(H21:J21)	0,04	=1/1,04^B21	=M21*K21
22		17	2031	56	0,5684284	0,0001867	645,721367655	0	=D22*E22	=D22*F22*G22	=SUM(H22:J22)	0,04	=1/1,04^B22	=M22*K22
23		18	2032	56	0,5684284	0,0001784	716,34053491	0	=D23*E23	=D23*F23*G23	=SUM(H23:J23)	0,04	=1/1,04^B23	=M23*K23
24		19	2033	56	0,5684284	0,0001701	786,959702165	0	=D24*E24	=D24*F24*G24	=SUM(H24:J24)	0,04	=1/1,04^B24	=M24*K24
25		20	2034	56	0,5684284	0,0001618	857,57886942	0	=D25*E25	=D25*F25*G25	=SUM(H25:J25)	0,04	=1/1,04^B25	=M25*K25
26		21	2035	56	0,5684284	0,0001535	928,198036675	0	=D26*E26	=D26*F26*G26	=SUM(H26:J26)	0,04	=1/1,04^B26	=M26*K26
27		22	2036	56	0,5684284	0,0001452	998,81720393	0	=D27*E27	=D27*F27*G27	=SUM(H27:J27)	0,04	=1/1,04^B27	=M27*K27
28		23	2037	56	0,5684284	0,0001369	1069,436371185	0	=D28*E28	=D28*F28*G28	=SUM(H28:J28)	0,04	=1/1,04^B28	=M28*K28
29		24	2038	56	0,5684284	0,0001286	1140,05553844	0	=D29*E29	=D29*F29*G29	=SUM(H29:J29)	0,04	=1/1,04^B29	=M29*K29
30		25	2039	56	0,5684284	0,0001203	1210,674705695	0	=D30*E30	=D30*F30*G30	=SUM(H30:J30)	0,04	=1/1,04^B30	=M30*K30
31		26	2040	56	0,5684284	0,000112	1281,29387295	0	=D31*E31	=D31*F31*G31	=SUM(H31:J31)	0,04	=1/1,04^B31	=M31*K31
32		27	2041	56	0,5684284	0,0001037	1351,913040205	0	=D32*E32	=D32*F32*G32	=SUM(H32:J32)	0,04	=1/1,04^B32	=M32*K32
33		28	2042	56	0,5684284	0,0000954	1422,53220746	0	=D33*E33	=D33*F33*G33	=SUM(H33:J33)	0,04	=1/1,04^B33	=M33*K33
34		29	2043	56	0,5684284	0,0000871	1493,151374715	0	=D34*E34	=D34*F34*G34	=SUM(H34:J34)	0,04	=1/1,04^B34	=M34*K34
35		30	2044	56	0,5684284	0,0000788	1563,77054197	0	=D35*E35	=D35*F35*G35	=SUM(H35:J35)	0,04	=1/1,04^B35	=M35*K35

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36		31	2045	56	0,5684284	0,0000705	1634,389709225	0	=D36*E36	=D36*F36*G36	=SUM(H36:J36)	0,04	=1/1,04^B36	=M36*K36
37		32	2046	56	0,5684284	0,0000622	1705,00887648	0	=D37*E37	=D37*F37*G37	=SUM(H37:J37)	0,04	=1/1,04^B37	=M37*K37
38		33	2047	56	0,5684284	0,0000539	1775,628043735	0	=D38*E38	=D38*F38*G38	=SUM(H38:J38)	0,04	=1/1,04^B38	=M38*K38
39		34	2048	56	0,5684284	0,0000456	1846,24721099	0	=D39*E39	=D39*F39*G39	=SUM(H39:J39)	0,04	=1/1,04^B39	=M39*K39
40		35	2049	56	0,5684284	0,0000373	1916,866378245	0	=D40*E40	=D40*F40*G40	=SUM(H40:J40)	0,04	=1/1,04^B40	=M40*K40
41		36	2050	56	0,5684284	0,000029	1987,4855455	0	=D41*E41	=D41*F41*G41	=SUM(H41:J41)	0,04	=1/1,04^B41	=M41*K41
42		37	2051	56	0,5684284	0,0000207	2058,104712755	0	=D42*E42	=D42*F42*G42	=SUM(H42:J42)	0,04	=1/1,04^B42	=M42*K42
43		38	2052	56	0,5684284	0,0000124	2128,72388001	0	=D43*E43	=D43*F43*G43	=SUM(H43:J43)	0,04	=1/1,04^B43	=M43*K43
44		39	2053	56	0,5684284	0,000004	2199,343047265	0	=D44*E44	=D44*F44*G44	=SUM(H44:J44)	0,04	=1/1,04^B44	=M44*K44
45		40	2054	56	0,5684284	0	2269,96221452	0	=D45*E45	=D45*F45*G45	=SUM(H45:J45)	0,04	=1/1,04^B45	=M45*K45
46	1	41	2055	56	0,5684284	0	2340,581381775	0	=D46*E46	=D46*F46*G46	=SUM(H46:J46)	0,03	=1/((1,04^40)*(1,03^A46))	=M46*K46
47	2	42	2056	56	0,5684284	0	2411,20054903	0	=D47*E47	=D47*F47*G47	=SUM(H47:J47)	0,03	=1/((1,04^40)*(1,03^A47))	=M47*K47
48	3	43	2057	56	0,5684284	0	2481,819716285	0	=D48*E48	=D48*F48*G48	=SUM(H48:J48)	0,03	=1/((1,04^40)*(1,03^A48))	=M48*K48
49	4	44	2058	56	0,5684284	0	2552,43888354	0	=D49*E49	=D49*F49*G49	=SUM(H49:J49)	0,03	=1/((1,04^40)*(1,03^A49))	=M49*K49
50	5	45	2059	56	0,5684284	0	2623,058050795	0	=D50*E50	=D50*F50*G50	=SUM(H50:J50)	0,03	=1/((1,04^40)*(1,03^A50))	=M50*K50
51	6	46	2060	56	0,5684284	0	2693,67721805	0	=D51*E51	=D51*F51*G51	=SUM(H51:J51)	0,03	=1/((1,04^40)*(1,03^A51))	=M51*K51
52	7	47	2061	56	0,5684284	0	2764,296385305	0	=D52*E52	=D52*F52*G52	=SUM(H52:J52)	0,03	=1/((1,04^40)*(1,03^A52))	=M52*K52
53	8	48	2062	56	0,5684284	0	2834,91555256	0	=D53*E53	=D53*F53*G53	=SUM(H53:J53)	0,03	=1/((1,04^40)*(1,03^A53))	=M53*K53
54	9	49	2063	56	0,5684284	0	2905,534719815	0	=D54*E54	=D54*F54*G54	=SUM(H54:J54)	0,03	=1/((1,04^40)*(1,03^A54))	=M54*K54
55	10	50	2064	56	0,5684284	0	2976,15388707	0	=D55*E55	=D55*F55*G55	=SUM(H55:J55)	0,03	=1/((1,04^40)*(1,03^A55))	=M55*K55
56	11	51	2065	56	0,5684284	0	3046,773054325	0	=D56*E56	=D56*F56*G56	=SUM(H56:J56)	0,03	=1/((1,04^40)*(1,03^A56))	=M56*K56
57	12	52	2066	56	0,5684284	0	3117,39222158	0	=D57*E57	=D57*F57*G57	=SUM(H57:J57)	0,03	=1/((1,04^40)*(1,03^A57))	=M57*K57
58	13	53	2067	56	0,5684284	0	3188,011388835	0	=D58*E58	=D58*F58*G58	=SUM(H58:J58)	0,03	=1/((1,04^40)*(1,03^A58))	=M58*K58
59	14	54	2068	56	0,5684284	0	3258,63055609	0	=D59*E59	=D59*F59*G59	=SUM(H59:J59)	0,03	=1/((1,04^40)*(1,03^A59))	=M59*K59
60	15	55	2069	56	0,5684284	0	3329,249723345	0	=D60*E60	=D60*F60*G60	=SUM(H60:J60)	0,03	=1/((1,04^40)*(1,03^A60))	=M60*K60
61	16	56	2070	56	0,5684284	0	3399,8688906	0	=D61*E61	=D61*F61*G61	=SUM(H61:J61)	0,03	=1/((1,04^40)*(1,03^A61))	=M61*K61
62	17	57	2071	56	0,5684284	0	3470,488057855	0	=D62*E62	=D62*F62*G62	=SUM(H62:J62)	0,03	=1/((1,04^40)*(1,03^A62))	=M62*K62
63	18	58	2072	56	0,5684284	0	3541,10722511	0	=D63*E63	=D63*F63*G63	=SUM(H63:J63)	0,03	=1/((1,04^40)*(1,03^A63))	=M63*K63
64	19	59	2073	56	0,5684284	0	3611,726392365	0	=D64*E64	=D64*F64*G64	=SUM(H64:J64)	0,03	=1/((1,04^40)*(1,03^A64))	=M64*K64
65	20	60	2074	56	0,5684284	0	3682,34555962	0	=D65*E65	=D65*F65*G65	=SUM(H65:J65)	0,03	=1/((1,04^40)*(1,03^A65))	=M65*K65
66			**TOTAL**	-	-	-	-	**=SUM(H5:H65)**	**=SUM(I6:I65)**	**=SUM(J6:J65)**	**=SUM(K5:K65)**	-	-	**=SUM(N5:N65)**

Appendix H: A 10% decrease and increase in the input values

Table H1: A 10% decrease and increase in the specific input values

	INCREASED CONSTRUCTION COSTS (NOK/m²)		REDUCTION IN SUPPLIED ENERGY (kWh/m²/year)	
	-10%	+10%	-10%	+10%
Sports building	541	661	50	62
School building	329	403	35	43
Kindergarten	448	548	56	68
Office building	591	723	59	73

Table H2: A 10% decrease and increase in the general input values

	ELECTRICITY PRICE (NOK/kWh)		EMISSION FACTOR (t CO2e/kWh)		EMISSION PRICE (NOK/t CO2e)		SOCIAL DISCOUNT RATE		DISCOUNT FACTOR	
YEAR	-10%	+10%	-10%	+10%	-10%	+10%	-10%	+10%	-10%	+10%
2014	0,0000	0,0000	0,0000000	0,0000000	0,0000	0,0000	3,6 %	4,4 %	1,00	1,00
2015	0,4687	0,5729	0,0002876	0,0003515	206,8746	252,8468	3,6 %	4,4 %	0,97	0,96
2016	0,4635	0,5665	0,0002801	0,0003423	229,1534	280,0764	3,6 %	4,4 %	0,93	0,92
2017	0,4535	0,5542	0,0002726	0,0003332	251,4322	307,3061	3,6 %	4,4 %	0,90	0,88
2018	0,4561	0,5574	0,0002651	0,0003241	273,7110	334,5357	3,6 %	4,4 %	0,87	0,84
2019	0,4630	0,5659	0,0002577	0,0003149	295,9898	361,7654	3,6 %	4,4 %	0,84	0,81
2020	0,4702	0,5747	0,0002502	0,0003058	318,2686	388,9950	3,6 %	4,4 %	0,81	0,77
2021	0,4896	0,5984	0,0002427	0,0002967	338,2010	413,3567	3,6 %	4,4 %	0,78	0,74
2022	0,4967	0,6071	0,0002353	0,0002875	358,1333	437,7185	3,6 %	4,4 %	0,75	0,71
2023	0,5041	0,6162	0,0002278	0,0002784	378,0656	462,0802	3,6 %	4,4 %	0,73	0,68
2024	0,5116	0,6253	0,0002203	0,0002693	397,9980	486,4420	3,6 %	4,4 %	0,70	0,65
2025	0,5116	0,6253	0,0002129	0,0002602	417,9303	510,8037	3,6 %	4,4 %	0,68	0,62
2026	0,5116	0,6253	0,0002054	0,0002510	437,8626	535,1655	3,6 %	4,4 %	0,65	0,60
2027	0,5116	0,6253	0,0001979	0,0002419	457,7950	559,5272	3,6 %	4,4 %	0,63	0,57
2028	0,5116	0,6253	0,0001904	0,0002328	477,7273	583,8889	3,6 %	4,4 %	0,61	0,55
2029	0,5116	0,6253	0,0001830	0,0002236	497,6596	608,2507	3,6 %	4,4 %	0,59	0,52
2030	0,5116	0,6253	0,0001755	0,0002145	517,5920	632,6124	3,6 %	4,4 %	0,57	0,50
2031	0,5116	0,6253	0,0001680	0,0002054	581,1492	710,2935	3,6 %	4,4 %	0,55	0,48
2032	0,5116	0,6253	0,0001606	0,0001962	644,7065	787,9746	3,6 %	4,4 %	0,53	0,46
2033	0,5116	0,6253	0,0001531	0,0001871	708,2637	865,6557	3,6 %	4,4 %	0,51	0,44
2034	0,5116	0,6253	0,0001456	0,0001780	771,8210	943,3368	3,6 %	4,4 %	0,49	0,42
2035	0,5116	0,6253	0,0001382	0,0001689	835,3782	1021,0178	3,6 %	4,4 %	0,48	0,40
2036	0,5116	0,6253	0,0001307	0,0001597	898,9355	1098,6989	3,6 %	4,4 %	0,46	0,39
2037	0,5116	0,6253	0,0001232	0,0001506	962,4927	1176,3800	3,6 %	4,4 %	0,44	0,37
2038	0,5116	0,6253	0,0001157	0,0001415	1026,0500	1254,0611	3,6 %	4,4 %	0,43	0,36
2039	0,5116	0,6253	0,0001083	0,0001323	1089,6072	1331,7422	3,6 %	4,4 %	0,41	0,34
2040	0,5116	0,6253	0,0001008	0,0001232	1153,1645	1409,4233	3,6 %	4,4 %	0,40	0,33
2041	0,5116	0,6253	0,0000933	0,0001141	1216,7217	1487,1043	3,6 %	4,4 %	0,38	0,31
2042	0,5116	0,6253	0,0000859	0,0001049	1280,2790	1564,7854	3,6 %	4,4 %	0,37	0,30
2043	0,5116	0,6253	0,0000784	0,0000958	1343,8362	1642,4665	3,6 %	4,4 %	0,36	0,29
2044	0,5116	0,6253	0,0000709	0,0000867	1407,3935	1720,1476	3,6 %	4,4 %	0,35	0,27
2045	0,5116	0,6253	0,0000635	0,0000776	1470,9507	1797,8287	3,6 %	4,4 %	0,33	0,26
2046	0,5116	0,6253	0,0000560	0,0000684	1534,5080	1875,5098	3,6 %	4,4 %	0,32	0,25
2047	0,5116	0,6253	0,0000485	0,0000593	1598,0652	1953,1908	3,6 %	4,4 %	0,31	0,24
2048	0,5116	0,6253	0,0000410	0,0000502	1661,6225	2030,8719	3,6 %	4,4 %	0,30	0,23
2049	0,5116	0,6253	0,0000336	0,0000410	1725,1797	2108,5530	3,6 %	4,4 %	0,29	0,22
2050	0,5116	0,6253	0,0000261	0,0000319	1788,7370	2186,2341	3,6 %	4,4 %	0,28	0,21

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2051	0,5116	0,6253	0,0000186	0,0000228	1852,2942	2263,9152	3,6 %	4,4 %	0,27	0,20
2052	0,5116	0,6253	0,0000112	0,0000136	1915,8515	2341,5963	3,6 %	4,4 %	0,26	0,19
2053	0,5116	0,6253	0,0000037	0,0000045	1979,4087	2419,2774	3,6 %	4,4 %	0,25	0,19
2054	0,5116	0,6253	0	0	2042,9660	2496,9584	3,6 %	4,4 %	0,24	0,18
2055	0,5116	0,6253	0	0	2106,5232	2574,6395	2,7 %	3,3 %	0,24	0,17
2056	0,5116	0,6253	0	0	2170,0805	2652,3206	2,7 %	3,3 %	0,23	0,17
2057	0,5116	0,6253	0	0	2233,6377	2730,0017	2,7 %	3,3 %	0,22	0,16
2058	0,5116	0,6253	0	0	2297,1950	2807,6828	2,7 %	3,3 %	0,22	0,16
2059	0,5116	0,6253	0	0	2360,7522	2885,3639	2,7 %	3,3 %	0,21	0,15
2060	0,5116	0,6253	0	0	2424,3095	2963,0449	2,7 %	3,3 %	0,21	0,15
2061	0,5116	0,6253	0	0	2487,8667	3040,7260	2,7 %	3,3 %	0,20	0,14
2062	0,5116	0,6253	0	0	2551,4240	3118,4071	2,7 %	3,3 %	0,20	0,14
2063	0,5116	0,6253	0	0	2614,9812	3196,0882	2,7 %	3,3 %	0,19	0,13
2064	0,5116	0,6253	0	0	2678,5385	3273,7693	2,7 %	3,3 %	0,19	0,13
2065	0,5116	0,6253	0	0	2742,0957	3351,4504	2,7 %	3,3 %	0,18	0,12
2066	0,5116	0,6253	0	0	2805,6530	3429,1314	2,7 %	3,3 %	0,18	0,12
2067	0,5116	0,6253	0	0	2869,2102	3506,8125	2,7 %	3,3 %	0,17	0,12
2068	0,5116	0,6253	0	0	2932,7675	3584,4936	2,7 %	3,3 %	0,17	0,11
2069	0,5116	0,6253	0	0	2996,3248	3662,1747	2,7 %	3,3 %	0,16	0,11
2070	0,5116	0,6253	0	0	3059,8820	3739,8558	2,7 %	3,3 %	0,16	0,11
2071	0,5116	0,6253	0	0	3123,4393	3817,5369	2,7 %	3,3 %	0,15	0,10
2072	0,5116	0,6253	0	0	3186,9965	3895,2179	2,7 %	3,3 %	0,15	0,10
2073	0,5116	0,6253	0	0	3250,5538	3972,8990	2,7 %	3,3 %	0,15	0,10
2074	0,5116	0,6253	0	0	3314,1110	4050,5801	2,7 %	3,3 %	0,14	0,09