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# Greenhouse gas balances in Zero Emission Buildings – Electricity conversion factors revisited



SINTEF Academic Press

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Inger Andresen<sup>1)</sup>, Kristian M. Lien<sup>1)</sup>, Thomas Berker<sup>1)</sup>, Igor Sartori<sup>2)</sup> and Birgit Risholt<sup>2)</sup>

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## Abstract

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Reduction of energy use and GHG emissions in the building sector is a high priority. The EU 2050 roadmap that was established in 2010, states that to achieve a global warming of less than 2°C in this century, Europe should reduce its GHG emissions by 80 % by 2050, using 1990 emissions as the reference. The roadmap shows that it is the power sector and the building sector that face the most severe reductions, with emission reductions of around 90%.

The Norwegian research centre for Zero Emission Buildings (ZEB) was established in 2008, with the objective to "develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero GHG emissions of greenhouse gases related to their production, operation and demolition" ([www.zeb.no](http://www.zeb.no)). According to the ZEB Centre, a building may be defined as a Zero Emission Building when all the GHG emissions from the entire life cycle of the building are compensated by GHG emission credits from the generation of renewable energy. However, the calculation of the life time compensation of greenhouse gas emissions in ZEBs involves a number of difficult issues, and has been subject to extensive discussions among the ZEB researchers and among different professions. A central issue is the methodology for calculating the carbon emission credits for electricity use and generation, and how the generation of renewable energy in the operation phase should be valued with respect to offsetting the embodied carbon emissions from the production of the building. Since buildings have a life time of several decades, this involves the stipulation of the future carbon intensity of grid electricity. Another issue is how to balance the historic emissions from the production of materials against the future GHG emission offset of the renewable energy surplus from the operation phase of the building.

These issues are elaborated on in the report. It includes a review of previous work and methods that have been applied in the ZEB Centre, with focus on the calculation of embodied emissions and the conversion factor for electricity in the operation phase. It also gives an overview of different methods and approaches for establishing emission credits from electricity use and generation, as well as related policy measures for GHG abatement. It discusses how to balance historic GHG emissions vs future emission credits, and challenges of the exchange of electricity between ZEBs and the grid.

A key challenge of the center has been to produce innovations within the inherent space of uncertainty given by the related frontiers of the research. Thus, a research strategy for the ZEB centre has been to maximize the incentives for the development of different solutions that reduce the overall GHG emissions connected to a building. If the GHG emission credits favour only one solution to reach a zero emission balance, then the result may be easier to reach in the present. However, given the fundamental uncertainty of future developments, preparing only for one route to reach the goal is a risky navigational strategy. On the other hand, if the conversion factor is chosen in a way so that a zero emission balance is impossible to reach in the present no matter which solution is chosen, then interesting research may be the result, but the industry will be very unlikely to participate in the construction of an "impossible" building. Thus, one must find a balance between assumptions about the future that discourage innovation completely and assumptions that lead to only one innovation.

The experiences from the pilot building projects within the ZEB center show that reaching the highest levels of ambition for ZEB is very challenging, given the boundary conditions and the applied CO<sub>2</sub>-factor for grid electricity. The analyses and discussion indicate that the CO<sub>2</sub>-factor that have been used in the ZEB pilot projects probably does not "favor" energy measures on ZEBs compared to other measures for CO<sub>2</sub>-mitigation. Nevertheless, such a challenging CO<sub>2</sub>-factor have promoted innovation in that it has spurred the teams to reach further than they otherwise would have done, resulting in new solutions being implemented and tested out. As such, the chosen CO<sub>2</sub>-factor may be said to have served its purpose.

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# 1. Background

Buildings account for 40% of energy use in the EU<sup>1</sup> and for about one third of both energy use and greenhouse gases (GHG) emissions in OECD countries<sup>2,3</sup>. Reduction of energy use and greenhouse gas (GHG) emissions in the building sector is therefore a high priority. The EU 2050 roadmap<sup>4</sup>, established in 2010, states that to achieve a global warming of less than 2°C in this century<sup>5</sup>, Europe should reduce its GHG emissions by 80 % by 2050, using 1990 emissions as the reference. The roadmap shows that it is the power sector and the building sector that face the most severe reductions with emission reductions of around 90%.

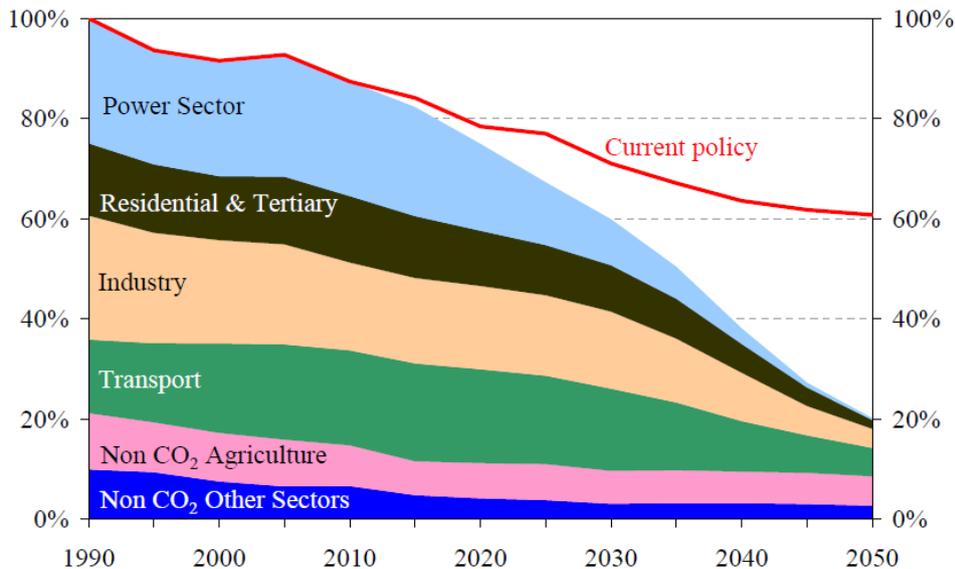


Figure 1 Pathway towards an 80% reduction in greenhouse gas emissions by 2050, as described in the EU 2050 Roadmap<sup>1</sup>.

If the power sector fails to deliver the substantial reductions required by the 2050 roadmap, this will put additional pressure on the other sectors, and Zero Emission Buildings may become a future necessity to reach the 2050 targets. Buildings will typically have a lifetime of 60 years or more, and present renovation and renewal rates are less than two percent per year. EU authorities have recognized the nature of the gradual replacement of our present inefficient buildings, and have therefore decided that already from 2021, all new buildings should be “nearly Zero Energy Buildings” (nZEB)<sup>6</sup>.

<sup>1</sup> EPBD (2010) Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (recast), Brussels.

<sup>2</sup> IEA (2012) Energy balance flows: OECD total, final consumption 2012, see <http://www.iea.org/Sankey/#?c=OECD Total&s=Final consumption>

<sup>3</sup> IEA (2015) CO<sub>2</sub> emissions statistics: Factsheets, available at: <http://www.iea.org/publications/freepublications/publication/co2-emissions-from-fuel-combustion-for-oecd-countries---2015-preliminary-edition--factsheet.html>, accessed on 12 April 2016.

<sup>4</sup> EU (2011): Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. *A Roadmap for moving to a competitive low carbon economy in 2050*. COM (2011) 112 final. Brussels, 8.3.2011.

<sup>5</sup> This two degrees target has later been reemphasized in the Paris Climate Summit in Dec. 2015, where also a new and more ambitious target of 1.5 degrees has been put forth.

<sup>6</sup> Directive 2010/31/EU of the European parliament and of the council of 19 May 2010 on the energy performance of buildings (recast).

## 2. Introduction

The Norwegian research centre for Zero Emission Buildings (ZEB) was established in 2008, with the objective to:

"develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition" ([www.zeb.no](http://www.zeb.no)).

According to the ZEB Centre, a building may be defined as a Zero Emission Building when all the GHG emissions from the entire life cycle of the building are compensated (balanced) by GHG emission credits from the generation of renewable energy, see Figure 2. A detailed description of the ZEB center definition and associated calculation methods may be found in (Fufa et al 2016).

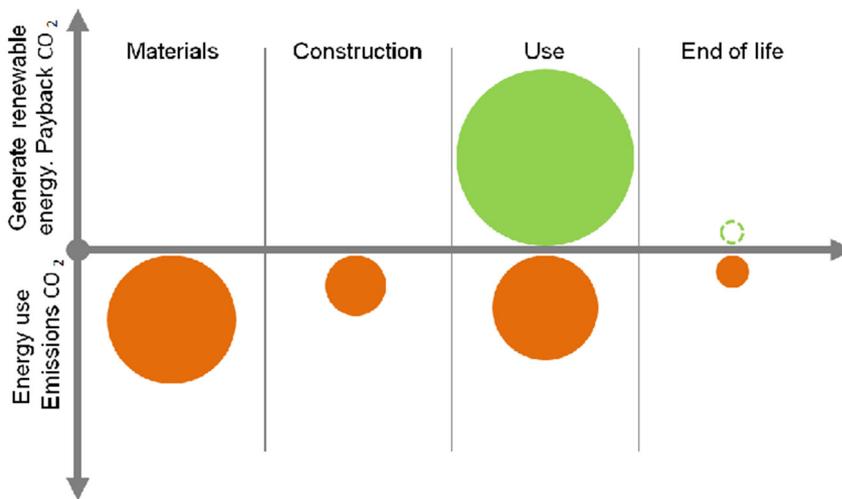


Figure 2 The illustration shows how the generation of renewable energy (green circle) may compensate for all greenhouse gas emissions from all life cycle stages of the building (red circles).

Equation (1) shows a simplified equation for calculating the net emission balance of a building.  $E_{GHG}$  are the net emissions in  $\text{kgCO}_2\text{-eq}$  over the life time of the building.  $E_{exp,ij}$  ( $\text{kgCO}_2\text{-eq/year}$ ) is the avoided emissions due to exported renewable energy generation during year  $i$  for each energy carrier  $j$ ,  $E_{del,ij}$  are the emissions from delivered energy to the building during year  $i$  for each energy carrier  $j$  ( $\text{kg CO}_2\text{-eq/year}$ ), and  $f_{ij}$  are the yearly average conversion factors ( $\text{CO}_2\text{-factors}$ ) for year  $i$  and energy carrier  $j$  ( $\text{kg CO}_2\text{-eq}/(\text{kWh}\cdot\text{year})$ ).  $E_{emb}$  is the total *embodied emissions* over the life time, i.e. the GHG emissions resulting from extraction of raw materials, the production and transport of the building materials, the construction of the building, the maintenance and replacement of components, and finally the end-of-life demolition/recycling of the building (see chapter 3). A net zero emission balance is reached if  $E_{GHG}$  is zero, and if it is larger, a net GHG reduction is achieved.

$$E_{GHG} = \sum_{i,j} E_{exp,ij} f_{exp,ij} - \sum_{i,j} E_{del,ij} f_{del,ij} - E_{emb} \quad (1)$$

The equation shows a simplified representation of the calculation procedure, however, a detailed calculation of the life time compensation of greenhouse gas emissions in ZEBs involves a number of more difficult issues. A central issue is the methodology for calculating the carbon emission credits for electricity use and generation, and how the generation of renewable energy in the operation phase should be valued with respect to offsetting the embodied carbon emissions from the production of the building. Since the building has a life time of several decades, this may involve the stipulation of the future carbon intensity of grid electricity. Another issue is how to balance the historic emissions from the production of materials against the future GHG emission offset of the renewable energy surplus from the operation phase of the building.

These issues will be elaborated on in the following chapters. Chapter 3 gives a review of previous work and methods that have been applied in the ZEB Centre, with focus on the calculation of embodied emissions and the conversion factor for electricity in the operation phase.

Chapter 4 gives an overview of different methods and approaches for establishing emission credits from electricity use and generation.

Chapter 5 provides a short overview of related policy measures for GHG abatement.

Chapter 6 presents a discussion of how to balance historic GHG emissions vs future emission credits.

In Chapter 7, challenges of the exchange of electricity between ZEBs and the grid, are discussed.

Chapter 8 includes a summary and discussion of the challenges, Chapter 9 discusses the issue of navigating under uncertainty, and finally in Chapter 10 some conclusions are given.

## 3. Previous work and methodological choices of the ZEB centre

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### 3.1 Methods for calculating the embodied emissions

One important aspect of Zero Emission Buildings is the energy or emissions that are embodied in the materials that compose the building. The term “embodied” can be confusing when used in relation to embodied emissions in buildings. The term does not refer to the carbon that is stored in the building material itself, but rather to the emissions of greenhouse gases released into the atmosphere during the production of the materials.

Looking at the embodied emissions, the emissions are both due to emissions of CO<sub>2</sub> equivalents from the use of energy as well as emissions from non-energy related processes. For example, the embodied emissions for cement are not only related to the emissions from the energy combusted during the production, but also due to the calcination of limestone.

Ideally, the calculation of embodied emissions for ZEBs should be based on an extensive operational database for all construction materials and technical system components used in Norway: a database based on consistent and robust methodological approaches for all the different inputs (Kristjansdottir et al 2014). However, such a database does not exist, and consequently the embodied emissions calculations are currently based on a selection of best available environmental data. These data include specific information from producers, Environmental Product Declarations (EPDs), generic databases (e.g. Ecolnvent<sup>7</sup>), and scientific articles.

Thus, the materials inventory analysis is challenging, and may be prone to a significant degree of uncertainty. Materials used in buildings are produced in many different ways at many different geographic locations. Finding reliable and comparable data for embodied emissions may therefore be a challenge. This issue is further discussed in (Kristjansdottir et al. 2014).

One significant factor determining the embodied emissions of a product is the choice of electricity mix used for the production phase. According to Holthe et al. (2011), some of the Norwegian EPDs use the electricity mix for Norway based on an average for the last three years, while others use the average Nordic electricity mix. Currently there is no consensus on which electricity mix should be used in the EPDs, however, for Norwegian EPDs, it is required that the emission factor is specified (EPD-Norge.no, 2013).

### 3.2 Conversion factor for electricity in the operation phase

The ZEB Research Centre has so far assumed a future carbon intensity based on a European power grid scenario that assume a 90% reduction in GHG emissions in 2050 compared to 2010, according to the EU roadmap for moving to a low carbon economy (EU 2011), (Dokka 2011). This scenario, called “the Ultra Green scenario”, was based on a study performed by SINTEF Energy Research in 2011 (Graabak et al 2011). The report of Graabak et al. (2011) provided input for the definition of zero emission buildings (ZEB) by quantifying emissions of CO<sub>2</sub> from the power system in Europe in a time perspective up to 2050. The EMPS<sup>8</sup> model was utilized to analyze the future-year operation of the European power system, and corresponding CO<sub>2</sub> emissions. In the analysis, 5 different scenarios (storylines) were specified based on differences in possible technological developments and public attitudes. A basic assumption for the storylines was a strong political drive in Europe to promote renewable energy sources (RES) and security of supply. It was assumed that the EU “20-20-20” targets

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<sup>7</sup> The Swiss-based European database Ecolnvent is widely used for life cycle inventory analysis in Europe, [www.ecoinvent.ch](http://www.ecoinvent.ch)

<sup>8</sup> The EMPS model (no: Samkjøringsmodellen) is a tool for calculating impacts on electricity markets for any given change in the system, which is utilized by producers, regulators and system operators in the Nordic area.

are met, and that the development of RES in Europe will continue towards 2050, although with different momentum in the different storylines. In simplified terms, the 5 storylines were (for further details see (Graabak and Feilberg 2011)):

- Red:** Characterized by slow technology development and low environmental focus in the population.
- Blue:** Characterized by fast technology development but low environmental focus in the population.
- Yellow:** Characterized by slow technology development and high environmental focus in the population.
- Green:** Characterized by fast technology development and high environmental focus in the population.
- Ultra-Green:** Like Green, but the scenario is modeled with and even higher deployment of energy-efficiency technologies, a large increase in trans-national transmission capacities, and larger increase in nuclear capacity.

For each scenario and year (2010, 2020, 2030, 2040, 2050), marginal and average GHG emissions were calculated. Results are shown in Figures 3 and 4. The marginal emissions in the different scenarios are the marginal changes in emissions in Europe as a consequence of changes in the demand of 1 TWh in Norway. The following methodology was used to calculate the marginal emissions (Graabak et al 2014): First the energy demand in Norway was increased with 1 TWh/year distributed proportionately over all load periods in a year. Then the EMPS was run with and without this increase in demand. Finally, the resulting differences in energy generation showed how the increased demand was covered in each time period, and the corresponding changes in emissions were calculated. Since Norway is connected to other countries through transmission lines, increases in demand in Norway will in most cases increase production in other European countries.

The Ultra-Green scenario has higher marginal emissions than Yellow, Blue and Green since the marginal production is covered by a larger share of coal than gas. The emissions in the Blue scenario are among the lowest. The reason for this is that the Blue scenario has a very high wind and solar production that covers the marginal increase in consumption. Furthermore, a considerable part of the marginal increase is covered by gas and biomass that have considerable less carbon content than coal and lignite.

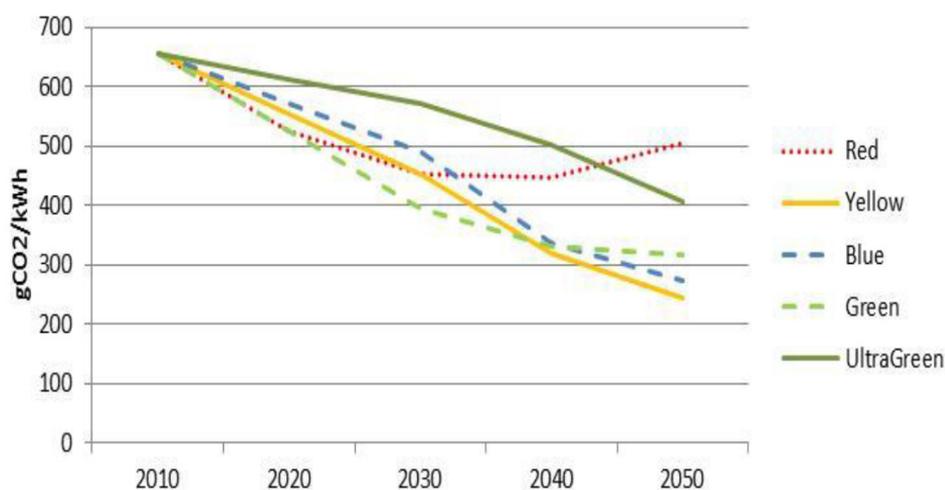


Figure 3 Development of marginal GHG emissions from 2010 to 2050 (Graabak et al 2014).

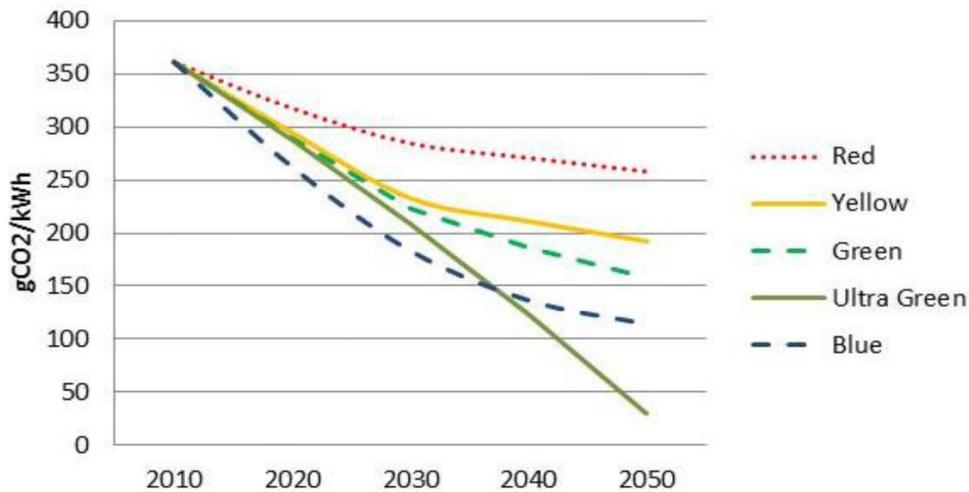


Figure 4 Development of average specific emissions from 2010 to 2050 (Graabak et al 2014).

As described in Dokka (2011), the ZEB centre has chosen to use the results of the Ultra Green scenario and the average emissions as a basis for the ZEB work. In this scenario, average emissions<sup>9</sup> decline from 361 gCO<sub>2-ekv</sub>/kWh in 2010 to 31 gCO<sub>2-ekv</sub>/kWh in 2050, see Figure 5. Still, acknowledging the large uncertainties of the GHG emission scenario, the ZEB centre has stated that “it is often relevant to include different scenarios for the emission factor” (Kristjansdottir et al. 2014).

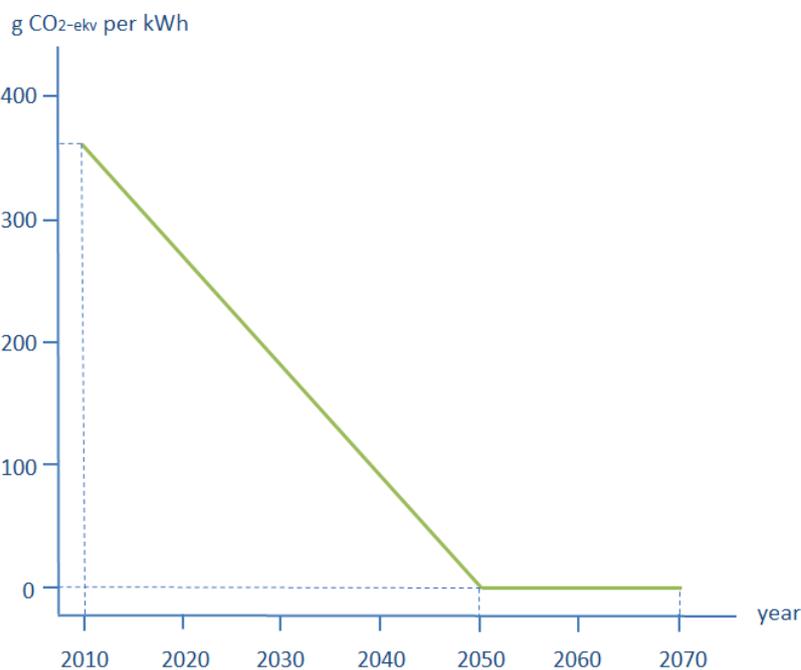


Figure 5 The CO<sub>2</sub>-factor scenario for grid electricity employed by the ZEB centre, (Dokka 2011), (Dokka et al 2013).

<sup>9</sup> Average annual emissions from the power system, calculated as the total annual CO<sub>2</sub> emissions from power generation in the simulated system, divided by gross electricity demand.

### 3.3 Consequences of different choices of CO<sub>2</sub> factors

Georges et al. (2015) analyzed the life cycle GHG emissions from a residential building and an office building in Norway using different scenarios for the electricity weighting factor. The analyzed buildings were virtual case studies for which extensive and detailed information was available about the inventory of materials used, and the operating energy performance was estimated by use of dynamic simulations. The buildings were all-electric, meaning they used heat pump technology for heating and hot water purposes, and used PV on all the available roof area as the sole generation option.

The paper showed that the relative contribution of embodied emissions to the total GHG emissions strongly depends on the CO<sub>2</sub>-factor chosen for electricity. Embodied emissions dominate operational emissions with low CO<sub>2</sub>-factors, while high factors lead to the opposite case. Thus, if we assume a fully decarbonized grid in future with a low CO<sub>2</sub>-factor (e.g. the Ultra-Green scenario) it means that we put a lower weight on measures that reduce operational energy (in the future) and higher weight on efforts to reduce the initial embodied emissions. On the other hand, a high CO<sub>2</sub>-factor for grid electricity would favor efforts to reduce the future operational energy relatively to efforts on reducing initial embodied emissions.

Furthermore, the choice of the CO<sub>2</sub> factors will affect the relative value of energy carriers, hence favouring the choice of certain carriers over others and influencing the required (electricity) generation capacity to achieve the ZEB balance.

Noris *et. al.* (2014) carried out a parametric analysis on six buildings of different typologies and climates (all in Europe) in order to assess how different weighting factors would impact the choice of technical systems to be installed. For each combination the amount of PV capacity necessary to achieve a net zero balance has been calculated, and has been used as the main indicator for comparison; where less PV area means more favourable condition.

With current national weighting factors, biomass boiler is largely the preferred solution, frequently achieving the balance with PV installable on the roof; while gas boiler is the most penalized. The situation changes with adoption of strategic factors. Lower weighting factors for electricity and district heating, e.g. reflecting national targets of increased penetration of renewables in such grids, would promote the use of heat pump and district heating, respectively. In the extreme – though desirable – case of very low weighting factors for electricity, e.g. reflecting a scenario of high decarbonisation of the power system, only few technical solutions would be able to reach the balance within the available roof space for PV, because of the low value credited to exported electricity. In this situation, the preferred solution would be heat pumps combined with solar thermal.

The choice of weighting factors and the resulting favoured technologies will also influence the temporal matching of load and generation. While all-electric solutions will tend to use the grid as seasonal storage, other solutions will have a net yearly export of electricity to the grid to compensate for the supply of other (thermal) energy carriers. Therefore, implications for the electricity grid resulting from the choice of weighting factors should also be considered.

## 4. Methods for establishing emission credits from electricity use and generation

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### 4.1 Average and marginal emission credits for current and future electricity mix

There are in principle two different methods for evaluating the GHG emissions from the generation and use of energy; i.e. using *average* emission credits or *marginal* emission credits.

The *average* emission approach is a "book-keeping" methodology that takes into account the actual (historic) GHG emissions from systems within a well-defined boundary. It may, for example, be the average of the GHG emissions from the electricity system in the Nordic countries during the previous three years. This is the method that is currently applied in the production of Environmental Product Declarations (EPDs). The method does not attempt to model any effects or consequences that the production and use of energy may have outside the system boundary (i.e. substitution). It is often called "static", "context independent", and "attributorial".

The *marginal* emission approach aims to show the consequences of a certain change in some parts of the system. For example, this method may be used to show the change in the annual GHG emissions (e.g. in Mt CO<sub>2-eq</sub>) of the European power system if the electricity demand in Norway is changed e.g. by 1 TWh. The approach is often called "dynamic", "prospective" or "consequential".

For wind- and solar-power there are considerable investment costs. However, when the investments have been carried out, operating costs are very low because wind and solar radiation has no costs. Available wind- and solar-power generation will therefore be utilized as much as possible in optimization tools for the power market, and in efficient markets, and in this way the expenditures for coal and gas consumption can be reduced. The implication of this is that additional demand never can be supplied by extra wind- or solar power in a given system. All wind- and solar-power will be applied anyway, so extra supply must therefore come from other technologies. Average considerations for each technology's share in total production can therefore be misleading when considering how the operation of a given system will respond to any given change.

Both methods are sensitive to subjective methodological choices such as system boundaries, economic models, etc. Since the marginal emission approach is used for forecasting future emission scenarios, it is naturally more uncertain, especially for longer time spans.

Graabak et al. (2014) recommend that average conversion factors are used for planning and designing future deployment of ZEBs, i.e. for politicians and decision-makers to gain knowledge on how ZEBs may contribute to reducing GHG emissions during their life time. On the other hand, they recommend the use of the marginal conversion factors to optimize the design of a single building according to local conditions and context. Graabak et al (2014) also recommends using a marginal conversion factor when optimizing the operation of a building. They state that to achieve zero emissions from the operation of the building, it is crucial to export energy in periods when the marginal emissions from the power production are high and to import energy in periods when the marginal emissions are low. Furthermore, they claim that a marginal conversion factor is necessary for accounting and crediting each building for the reduction of emissions. In real time operation, a marginal reduction of electricity consumption from a building will result in a marginal reduction of the production and a corresponding reduction of the emissions. Thus, they argue that the ZEB should be credited according to the marginal production and emissions.

## 4.2 GHG emission scenarios by Eurelectric (2010)

In September 2010, the Union of the European Electricity Industry – Eurelectric, published a study where they examined possible pathways to carbon neutral electricity generation in 2050 (Eurelectric 2010). The study used the PRIMES<sup>10</sup> energy market model to develop two alternative scenarios for the EU-27<sup>11</sup> countries during 1990-2050:

- 1) *Baseline Scenario*, assuming all existing policies are pursued; and
- 2) *Power Choices Scenario*, which sets a 75% reduction target for greenhouse gases across the entire EU economy.

The *Power Choices* scenario aims for an optimal portfolio of power generation based on an integrated energy market. The PRIMES model calculates the market optimum, taking into account the technology assumptions developed by the industry. The result is shown in Figure 6.

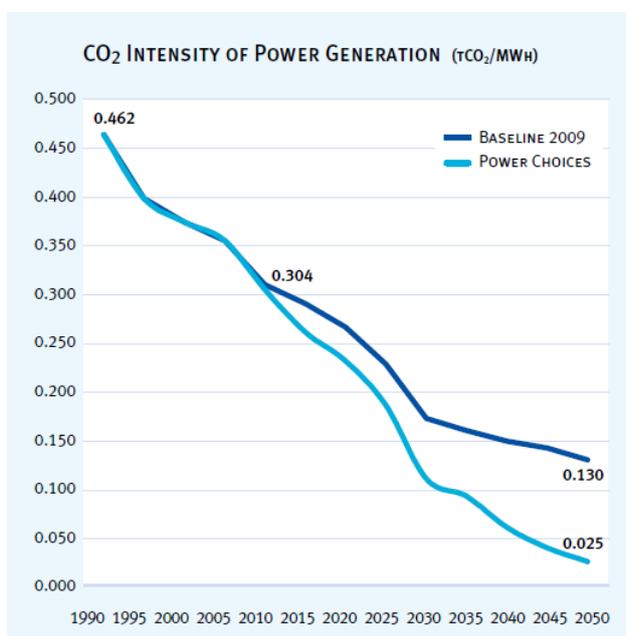


Figure 6 The carbon intensity of power generation in the two scenarios of the Eurelectric study (Eurelectric 2010).

Under the *Baseline* scenario, the power sector would emit 134 kg/MWh in 2050, thus delivering a reduction of less than 65% on the 2005 level. Under the *Power Choices* scenario, the carbon intensity of power generation falls by almost 95%, from roughly 360 kg/MWh in 2005 to 26 kg/MWh in 2050. Until 2025, the main drivers for carbon reductions are energy efficiency improvements and a fuel switch from oil and coal to gas, while the increasing deployment of renewable energy sources also plays an important role. As from 2025, CO<sub>2</sub> emissions decline quite rapidly, primarily due to the deployment of CCS technologies, first applied to coal-fired plants and then also to gas- and oil fired plants. The two other main drivers for reducing CO<sub>2</sub> emissions in the *Power Choices* scenario are the higher penetration

<sup>10</sup> The PRIMES energy model is developed and run by Athens Technical University and simulates the European energy system and markets on a country-by-country basis and across Europe for the entire energy system, [www.e3mlab.ntua.gr/e3mlab/index.php?option=com\\_content&view=category&id=35%3Aprimes&Itemid=80&layout=default&lang=en](http://www.e3mlab.ntua.gr/e3mlab/index.php?option=com_content&view=category&id=35%3Aprimes&Itemid=80&layout=default&lang=en)

<sup>11</sup> Non-EU countries (Switzerland and Norway, as well as all Balkan countries and Turkey) are fully considered in the PRIMES model regarding exchanges of electricity and the operation of the interconnected system. However, in the study, these countries were only assessed in terms of EU import-export projections.

rate of RES plus new installed nuclear power capacity, which is in line with the assumptions for the Ultra Green scenario in (Graabak and Feilberg, 2011).

It should be noted that several important events have happened since the publication of the report, which have had significant impact on energy policies in Europe, e.g. the Fukushima accident in 2011 and the Paris agreement in 2015.

### 4.3 Nordic Energy Technology Perspectives

The Nordic Energy Technology Perspectives released in 2013 (IEA, 2013) describes how the Nordic countries can meet their national climate targets and achieve a carbon-neutral energy system by 2050. This regional scenario is even more ambitious than the global 2°C scenario adopted by the IEA in its global scenarios. The report highlights that to realise the Carbon-Neutral Scenario, Nordic electricity generation needs to be fully decarbonised by 2050. Considering some development of CCS, the Nordic generation by 2050 is even slightly negative in terms of CO<sub>2</sub> emissions.

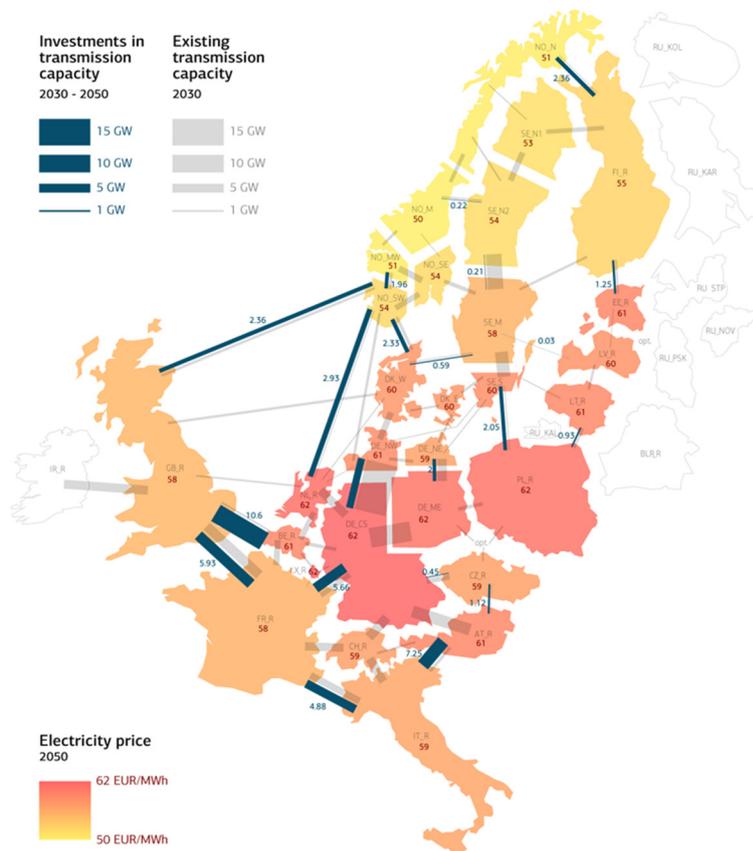


Figure 7 Investments in transmission capacity between 2030 and 2050 and electricity prices in 2050 in a carbon neutral scenario. Source: IEA 2016.

In the 2016 release of the Nordic Energy Technology Perspectives (IEA, 2016) the scenario's targets are confirmed and the report analyses more in detail the impacts and the requirements of such a decarbonised Nordic system, especially in terms of exchange capacity with the surrounding area, see Figure 7. A Nordic decarbonised power system is intrinsically based on interconnection and largely expanded transmission capacity with the rest of Europe, expanding the market for the Nordic renewable energy resources, CCS and storage resources.

## 5. Related policy measures for GHG abatement

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### 5.1 Guarantees of Origin

The Guarantee of Origin (GO) is an instrument defined in European legislation that labels electricity from renewable sources to provide information to electricity customers on the source of their energy. A GO in the meaning of Directive 2009/28/EC is an instrument evidencing the origin of electricity generated from renewable energy sources. In short, a GO is a 'tracker' guaranteeing that one MWh of electricity has been produced from renewable energy sources; and if the customer buys the GO, they can be certain that they have purchased green electricity, as the GO is then taken out of circulation and discarded ('cancelled').

According to the Norwegian Water Resources and Energy Directorate (NVE), in 2011, GOs corresponding to 98.1 TWh were sold from Norwegian electricity producers to overseas customers, while GOs corresponding to 8.3 TWh were purchased from abroad (nve.no). In comparison, a total of 128.1 TWh of electricity was generated in Norway in 2011.

NVE also publishes the greenhouse gas emissions from the Norwegian "residual mix" (rest mix). A country's residual mix represents the shares of electricity generation attributes available for disclosure after the use of GOs has been accounted for. If a consumer uses grid electricity without a GO certificate they are obligated to use the residual mix when calculating/reviewing their consumed electricity attributes (footprint). The residual mix takes into account the countries' exports and imports of GOs, as well as the composition of electricity generation in the countries.

The calculated carbon emissions linked to the Norwegian residual mix was 307 g/kWh in 2011, in 2012 it was 420 g/kWh, in 2013 it was 500 g/kWh, and in 2014 it was 493 g/kWh (nve.no).

### 5.2 Emissions trading

The system of emission trading, also called the "cap and trade" or the "CO<sub>2</sub>-quota system" applies a maximum (cap, ceiling) that is set on the total amount of greenhouse gases that can be emitted by all participating installations. CO<sub>2</sub>-quotas or allowances for emissions are then auctioned off or allocated for free, and can subsequently be traded. Installations must monitor and report their CO<sub>2</sub> emissions, ensuring they hand in enough allowances to the authorities to cover their emissions. If emission exceeds what is permitted by its allowances, an installation must purchase allowances from others. Conversely, if an installation has performed well at reducing its emissions, it can sell its surplus credits. This allows the system to find the most cost-effective ways of reducing emissions without significant government intervention.

The European Union Emissions Trading System (EU ETS) was launched in 2005 to fight Global warming and is a major pillar of EU climate policy. As of 2013, the EU ETS covers more than 11,000 factories, power stations, and other installations with a net heat excess of 20 MW in 31 countries—all 28 EU member states plus Iceland, Norway, and Liechtenstein.

The design of future environmental agreements is under intense negotiation, and there exist no specified emission ceiling for all future years. If an emission permit system exists towards 2050, the future ceiling value will be affected by many different factors. It is for instance likely that it will be easier for governments to agree upon a relatively low ceiling if affordable low-emitting technologies exist. Reduced electricity consumption will also contribute to a reduced need for polluting power generation, and may thus affect the future emission ceiling.

### **5.3 Carbon taxes**

In Europe, a number of countries have imposed energy taxes or energy taxes based partly on carbon content. These include Denmark, Finland, Germany, Ireland, Italy, the Netherlands, Norway, Slovenia, Sweden, Switzerland, and the UK. For a review of Europe's experience with carbon taxation, see Andersen (2010). Norway introduced a CO<sub>2</sub> tax on hydrocarbon fuels in 1991. The tax started at a rate of US\$51 per metric ton of CO<sub>2</sub> on gasoline, with an average tax of US\$21 per metric ton. The tax was also applied to diesel, mineral oil, oil and gas used in North Sea extraction activities. Some industry sectors have been granted exemptions from the tax to preserve their competitive position.

## 6. Balancing historic GHG emissions with future emission credits

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Traditionally, LCA and carbon footprint methods make no explicit differentiation between emissions at different points in time (Hellweg et al., 2003); whether an emission contributes to increasing the concentration of GHGs today or in 60 to 100 years, it is treated equally. Hellweg et al. (2003) concluded that discounting is only applicable when temporally differentiated data are available. Given the timeframe in which carbon reductions need to be made, one may argue that carbon savings made at the start of a building's life could be more valuable than predicted savings in the future. In Stern (2006) and Aaheim (2010), it is argued that the cost of measures to mitigate climate change increase for every year the measures are delayed.

Kristjansdottir et al (2014) suggests that a possible option for addressing this issue could be to adopt the economic science approach where future costs and benefits are discounted to a present value. In such an approach, the Net Present Value principle (NPV) of an investment is calculated as a function of benefits, costs and the discount rate. The magnitude of the discount rate determines the value of future costs and benefits compared to the current investment. Thus, for GHG emission accounting, the magnitude of the discount rate would represent the difference in importance of early emission reductions compared to future reductions. A high discount rate would signify that a high importance is put on early emissions reductions.

While this is a compelling financial analogy, it may not necessarily correctly reflect the problem. In economic investment analysis, money is intrinsically less worth in the future than at present. Therefore a maximization of present value makes sense. For global warming one may argue that it is the future we are worried about, and the investments made today will show their final merit at the end of the life time of the building. When attempting to minimize future impacts of present emissions, it may therefore make more sense to analyze the overall effect of the building at the end of the life time. Thus, from this perspective one might argue that it is the initial emissions and the offsets of initial years that should be most substantially discounted (aka "net future value", NFV). Such an approach may also be more consistent with the physical time behavior of greenhouse gas emissions in the atmosphere, because greenhouse gases emitted to the atmosphere will decay over time. If all the CO<sub>2</sub> emitted in the process of making all constituent materials and constructing the building is viewed as a CO<sub>2</sub> pulse emission to the atmosphere in year zero<sup>12</sup>, then only about half of this CO<sub>2</sub> will remain in the atmosphere after 30 years, the rest has been absorbed by oceans and the biosphere<sup>13</sup>. It may seem counterintuitive that nature will remove emitted CO<sub>2</sub> over time from the atmosphere in our present situation where the CO<sub>2</sub> concentration in the atmosphere increases every year. However, our present emission levels exceed the rate by which nature is able to transfer emissions to the oceans and to the biosphere. We may compare this to the task of pouring water into a leaky bag: At low pouring rates, the level in the bag will be reduced, but at high pouring levels, the level will increase.

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<sup>12</sup> a reasonable assumption if the production and construction period is short compared to the building life time

<sup>13</sup> based on the Bern2.5 Carbon Cycle model, a widely used and recognized aggregate carbon cycle model (Joos 2001).

## 7. Import – export mismatch

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Exploiting local renewable energy sources available at the building site and exporting surplus energy to utility grids is part of the strategy to increase the share of renewable energy within the grids, thereby reducing resource consumption and associated carbon emissions. On the other hand, especially for the power grid, wide diffusion of distributed generation may give rise to some problems such as power stability and quality in today's grid structures, mainly at local distribution grid level. It is clear that the mere satisfaction of an annual balance is not in itself a guarantee that the building is designed in a way that minimizes its (energy use related) environmental impact. Therefore, ZEBs should be designed – to the extent that is in the control of the designers – to work in synergy with the grids and not to put additional stress on it.

Until recently, the exchange of electricity between ZEB and the grid has not been taken thoroughly into consideration. From a ZEB viewpoint, the grid is basically seen as an infinite capacity battery; surplus electricity is exported to the grid and re-imported in periods of net demand. Onsite energy generation and loads have a temporal mismatch both at seasonal level, i.e. PV generation is concentrated in summer, and at hourly level; especially in residential buildings since the peak demand is usually in the evening while PV generation peaks in the central hours of the day. Furthermore, at a local scale all PV installations in several buildings would peak their generation at the same time due to the geographical proximity; which in residential neighbourhoods coincides with the time of minimum building load. The result is an aggregated peak of electricity exported to the distribution grid, which might challenge its limits or cause curtailment of the PV generation (Sartori *et. al.*, 2014; Baetens *et. al.*, 2012). Such mismatch issues could be abated by introducing local energy storage and load management. These issues are addressed in the work of the projects within IEA Annex 52<sup>14</sup>, see for example Salom *et. al.* (2014), and IEA Annex 67 "Energy Flexible Buildings"<sup>15</sup>.

Also, the relationship between increased local production of renewable electricity in Norway and reduced demand for fossil fuel based electricity in Europe is not a straight forward issue. It may be presumed that this relation is one-to-one, but the presumption needs justification. The key to such a justification lies in the difference between marginal production in the EU and in Norway. The large hydropower reservoirs in Norway are in principle huge storage devices, we have a large capacity for "storage of electric power": Production for export as well as for domestic consumption when prices are high, and import instead of domestic production when prices are low. In the EU, marginal power production is based on natural gas, with high marginal cost. When EU electricity demand is high enough (or the EU production from intermittent renewable capacity is low enough) to require the use of this marginal capacity, the high marginal cost causes the momentary market spot price to increase in the EU, as well as in Norway. At these high prices, it is profitable for Norway to produce hydropower for export. Contrary, when the intermittent renewable EU capacity is high, momentary spot prices will be low, and it will be profitable for Norway to turn down domestic hydropower production to a minimum and save our hydropower capacity for later, and under these circumstances the domestic consumption will have a large portion of imported power.

We may therefore argue that our hydropower reservoir capacity makes it possible to "buy cheap, and sell expensive", which corresponds to "import renewable, and export renewable for fossil substitution". While it is clear that our ability to "buy cheap, and sell expensive" will increase with our hydro power capacity, it should also be recognized that a similar effect may be said to take place with reduced building-related electricity consumption, ref (Lien 2014).

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<sup>14</sup> <http://www.iea-ebc.org/projects/completed-projects/ebc-annex-52/>

<sup>15</sup> <http://www.iea-ebc.org/projects/ongoing-projects/ebc-annex-67/>

Due to the complexity of the energy infrastructure, the conversion factors for electricity are often estimated only as average values for a period of time. However, ideally, the conversion factors should vary over time to reflect the dynamics of the larger grid with export/import issues as described above. It is for example possible to evaluate conversion factors on an hourly basis, leading to a dynamic accounting procedure. As an intermediate option, a quasi-static accounting could be applied that have seasonal/monthly average values and/or daily bands for base/peak load. For energy prices it is already quite common to have seasonal or hourly fluctuating prices, while for other metrics such as primary energy and carbon emissions this is not the standard practice today, but it may become more common in future. Dynamic and quasi-static accounting would help, at least in theory, the design of buildings that optimize their interaction with the grids. However, including dynamic accounting in the ZEB balance would considerably increase the complexity of calculations and the assumptions on future time dependent patterns. As a compromise it should be feasible to calculate the ZEB balance with static or quasi-static values and then use additional dynamic values to address the temporal energy mismatch characteristics (Sartori *et al.*, 2012).

## 8. The value of GHG reduction in buildings vs in other sectors

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### 8.1 Relative merits – economics of GHG abatement

In order to assess whether large scale implementation of Zero Emission Buildings will be cost effective from a greenhouse gas emission abatement perspective, the cost should be compared to the anticipated costs of its alternatives.

In the major national greenhouse gas analysis project “Klimakur 2020”. Norwegian authorities<sup>16</sup> analyzed the costs and accumulated emission reductions of alternative abatement measures that could contribute to an overall reduction target of 15–17 million annual tons of CO<sub>2</sub> by 2020. The building sector was predicted to make a modest contributions to GHG emissions in the Klimakur analyses, which is no surprise since no export/import substitution effects were included in, only direct greenhouse gas emissions on Norwegian territory were accounted for. A number of the included building related measures did however demonstrate attractive economic merits. Also, an interesting aspect of the Klimakur study is the cost level that may be anticipated beyond the 15–17 mill. reduction target related to 2020: A marginal abatement cost of ~1500 NOK/tonCO<sub>2</sub>, increasing rapidly with increasing ambitions.

### 8.2 Studies of GHG abatement in other sectors in Norway

It is also interesting to have a look at CO<sub>2</sub>-factors used in other studies of GHG abatement measures in Norway. In (Völler et al. 2014) the authors have used the EMPS model (European Multi-area Power Market Simulator) to study how introduction of electric vehicles in Norway will affect the energy system in Norway and Europe, and the related GHG emissions<sup>17</sup>. The authors describe that the increased energy use from the larger use of electric vehicles will imply that the net export of hydro electricity from Norway will decrease. They further conclude that this will lead to an increased fossil-fuel based energy generation in Northern Europe, which corresponds to a CO<sub>2</sub>-coefficient of 486 g/kWh by 2020<sup>18</sup>. Considering the reduced use of gasoline and diesel in the fleet of Norwegian cars, a total reduction in CO<sub>2</sub>-emissions of 0,95 Mt/yr was calculated.

In another study by Wolfgang and Mo (2007), the authors used the EMPS model (European Multi-area Power Market Simulator) to study how much the CO<sub>2</sub>-emissions in the European power system would be reduced by an increase in renewable energy generation in Norway. The authors conclude that the emissions in Europe would be reduced by 526 g/kWh per extra renewable energy generation in Norway (year 2005).

A third study performed by Korpås et al. (2010) focused on how different alternatives for electrification of petroleum installations and wind-power onshore and offshore would affect European CO<sub>2</sub>-emissions. The EMPS model was utilized to carry out power market simulations. The simulated system was the existing system in 2010, adjusted for expected changes towards 2020. Marginal emission coefficients for the power system were not explicitly calculated, but can be extracted on basis of reported results; ranging between 675 and 711 gCO<sub>2</sub>/kWh.

In figure 8, the CO<sub>2</sub>-factors used in the three studies described above are plotted together with the scenario study described in chapter 3 and compared to the current CO<sub>2</sub>-factor scenario used in the ZEB centre. The figure illustrates that by using a much lower CO<sub>2</sub>-factor for ZEB, the abatement measures in

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<sup>16</sup> Klimakur2020 (2010): *KLIMAKUR 2020. Tiltak og virkemidler for å nå norske klimamål mot 2020*, KLIF, NVE, OD, SSB, Statens vegvesen, 2010.

<sup>17</sup> by replacing half of the private cars in Norway by electric cars.

<sup>18</sup> Increased GHG emissions per kWh as a consequence of the increased use of electricity for cars.

the building industry may be perceived to give a substantially smaller contribution to reduction of global warming than competitors such as electric vehicles, offshore electrification, offshore wind power, etc., per kWh power produced/saved. This is a challenging situation to be in, since it implies that in order to be a cost effective global warming abatement measure, the kWh that are produced or saved by ZEBs have to be substantially less expensive than its competitors'. If such cost differences cannot be demonstrated, there is a significant risk that the ZEB concept will be perceived to be inferior as a cost effective measure.

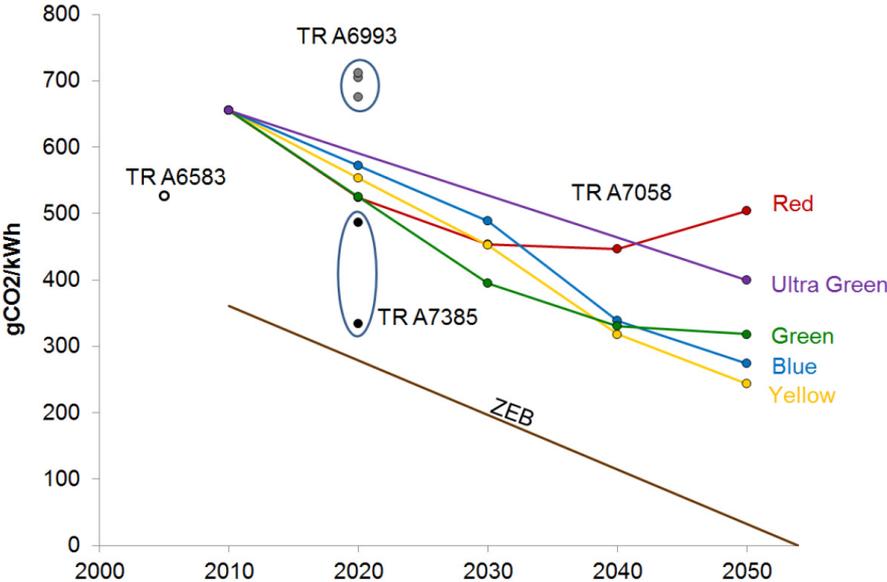


Figure 8 A comparison of the resulting marginal CO<sub>2</sub>-factors from different studies of GHG abatement measures in Norway, compared to the ZEB centre CO<sub>2</sub>-factor (Dokka et al 2011), (figure from Wolfgang and Feilberg, 2014). TR A6583 refers to (Wolfgang and Mo 2007), TR A6993 refers to (Korpås et al. 2010), TR A7385 refers to (Völler et al. 2014) and TR A7058 refers to (Graabak and Feilberg 2011).

## 9. The effect of ZEB solutions on the larger energy system

### 9.1 Actual substitution – short term effects

ZEB solutions will manifest themselves both through reduced demands (i.e. energy efficiency) and through increased renewables production (e.g. solar power). As illustrated in (Graabak and Feilberg, 2011) see Figure 9, the *short term effects* will here be to:

- 1) shift the supply side curve slightly to the right (renewables production)
- 2) shift the demand side curve slightly to the left

The net effect of these two combined would be to shift the market crossing point<sup>19</sup> towards the left and downwards. On the short term, this market crossing point will represent a *mixture of coal based and gas based power production capacity*, which will get fewer active operating hours as the result of introducing “ZEB capacity”. It would therefore be reasonable to assume that the corresponding substituted emissions would be such a mixture of coal based and gas based emissions.

In the model described by Graabak and Feilberg (2011), the introduction of a CO<sub>2</sub> tax will change the cost levels of technologies, and it will also influence the total CO<sub>2</sub> emissions if the tax is large enough to change the order of technologies in the marginal cost curve. In Figure 10, the effect of increasing the CO<sub>2</sub> tax (or quota price) is illustrated. If the CO<sub>2</sub> prices are increased, the price of lignite will increase the most, because the emissions from lignite are the highest. The “lignite step” will then move upwards in the curve (see Figure 10). As a consequence, the emissions from production of the marginal kWh will be reduced, because the most polluting technologies are pushed out of the production portfolio.

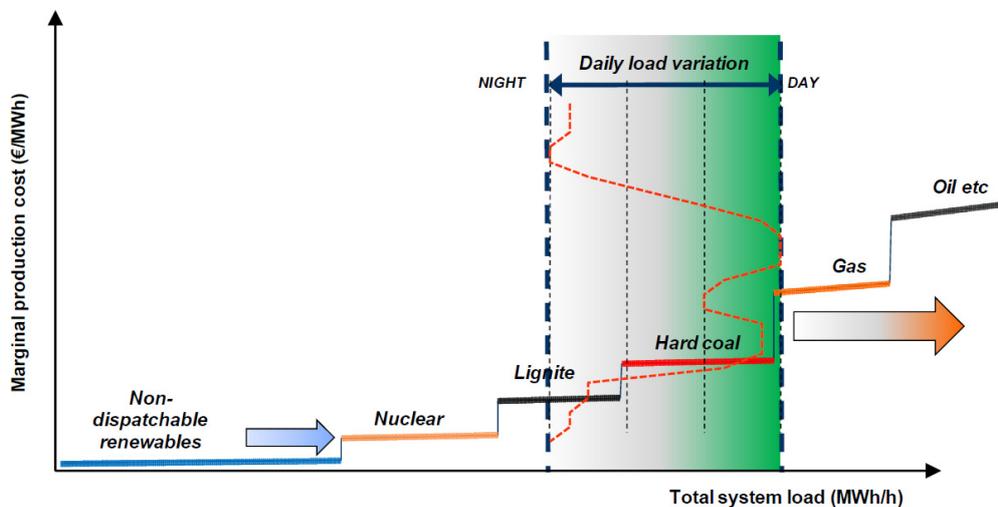


Figure 9 Illustration of the effect of increased share of renewables, from (Graabak and Feilberg 2011).

<sup>19</sup> The point where the supply curve crosses the demand curve.

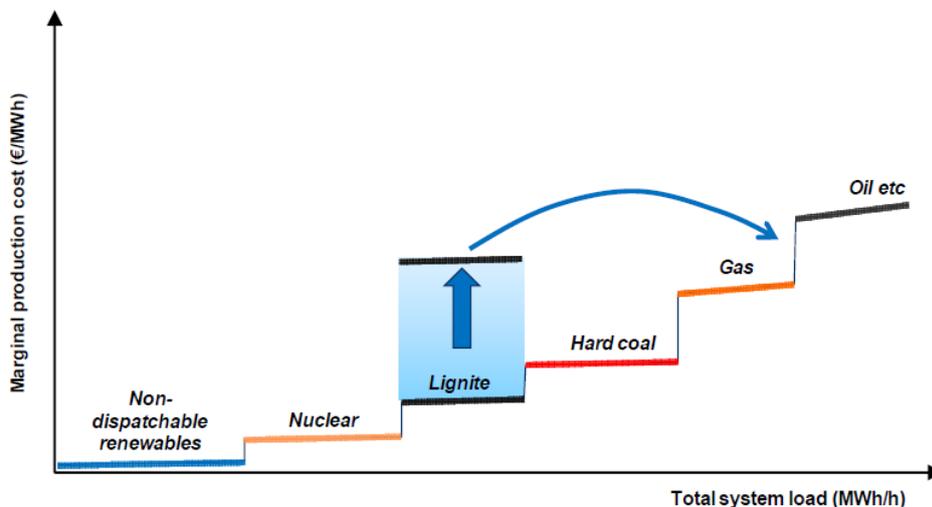


Figure 10 Illustration of the effect of increased CO<sub>2</sub> tax / quota price, from (Graabak and Feilberg 2011).

## 9.2 Actual substitution – long term effects

Long term effects of the introduction of ZEB capacity has to account for *investment considerations in addition to the marginal considerations* that will be sufficient for short term considerations.

These are more difficult to analyze than the short term marginal emissions, for two reasons:

- 1) Long term replacements in the power market have to ensure the long term power system stability and security of supply, not only marginal economics.
- 2) Political choices (e.g. with respect to subsidies or moratoria for new generation capacity) will impact on the power system modernization. (e.g. whether future nuclear capacity is judged to be a viable option.)

Some trends are however quite easy to predict:

- 1) Fossil fuels (i.e. coal and lignite) cannot continue to have a significant role as base load capacity if the stated target of 80 – 90 % reduction of greenhouse gas emissions from the power sector is to be achieved by 2050. A substantial part of *the long term substitution will therefore have to be the substitution of present coal based power<sup>20</sup>* in order to reach the stated long term goals.
- 2) If gas based power is not going to remain to be the marginal power source in the future power market, new technologies serving the purpose of maintaining power system stability and security of supply have to be introduced on a large scale. Presently available renewable technologies (i.e. wind power and solar power) are not able to fulfil this role, since they are intermittent, and will continue to need backup alternatives when they are not available.

It is therefore reasonable to assume that the long term effects of substitution will be a mixture of coal and gas based power.

<sup>20</sup> Possibly augmenting it with Carbon Capture. Present technology status and worldwide plans do however indicate that if this shift will come, it will not to any significant extent be as parts of *existing* plants.

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## 10. Discussion

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### 10.1 Average vs marginal emissions

ZEB has an expressed ambition to be a contributor to the de-carbonization of the European electric power system. Such contributions can be made if ZEB solutions substitute present electric power production which have carbon intensities that are *higher* than the present average.

ZEB does however presently assume, at any given point in time, that ZEB solutions will in principle merely substitute the average mix. It could be argued that solutions that substitute the average mix can never drive the value of the average mix downwards: Substitution of the average mix represents status quo; no net change with time.

Before one can conclude regarding what is a reasonable emission coefficient for ZEB, we should consider why there is such a big difference between the average coefficient (31 gCO<sub>2</sub>/kWh) and marginal coefficient (400 gCO<sub>2</sub>/kWh) for 2050 in the Ultra Green scenario.

For average emissions, the low value is basically a result of emission-free power generation. The supply is dominated by renewable power supply and nuclear power. Thermal power generation is only a small fraction of the total supply. However, to supply electricity for additional demand, coal power is utilized together with nuclear power. The reason for this is that renewable power generation already is fully deployed, so additional supply must come from other technologies. The report by Graabak and Feilberg (2011) comments (page 52):

"If we had assumed that all coal capacity was phased out in a future like 'Ultra Green', other technologies would be used for marginal production, most likely gas".

If such a relatively small adjustment (small considering the small fraction of coal-power in total supply) in assumptions had been applied, the calculated marginal emission coefficient would be reduced by roughly 50 %. Furthermore, the marginal coefficient for 2050 could be even lower and close to zero if e.g. CCS technologies or energy storage for renewable electricity are deployed sufficiently. This discussion shows that results for marginal emissions in the future, especially towards 2050 and beyond, are very sensitive for moderate changes in assumptions.

### 10.2 Navigating under uncertainty

As the previous chapters have shown, the definition of GHG emission credits for producing and operating buildings is associated with a considerable amount of uncertainty. This is due to a) the spatial dimension of how building materials and energy are sourced and b) the temporal dimension of a building's life time for 60+ years. In this section we will first describe these two dimensions more in depth and then propose a means for "navigation in unknown terrain" (Jørgensen et al. 2012).

#### 10.2.1 Reach and complexity of supply chains

The various materials used to produce a building and its installations are sourced from a broad variety of locations. Construction today is characterized by complex supply chains. Despite recent efforts to increase the use of local resources in construction projects, the more likely scenario is that these supply chains continue to grow in spatial reach and complexity in the future. The same applies to the energy used to produce materials and installations and to operate a building: Here, constantly growing international distribution networks for electricity add complexity and reach to an already globalized market for energy.

### **10.2.2 Temporal dimension: The unknown future**

The industrial revolution of the 19<sup>th</sup> and 20<sup>th</sup> century was based on a steep increase of energy consumption. The consequences of this energy revolution were highly visible, but it was not before the 1970s that changes in energy systems were framed as something more than just a matter of unidirectional progress where more energy consumption equals more progress equals a better life for everyone (Nye 1999). The oil shock of the 1970s was caused by international conflicts (that are far from resolved today). Since then, international efforts to change energy infrastructures have gained rapidly in importance (see Dresner 2002 for a short history of this development). On this background, it is reasonable to assume that energy systems will continue to change based on political and environmental grounds also in the near and medium term future. However, we have no way of knowing for certain at which speed these changes actually will happen and which direction they will take. Since speed and direction will profoundly influence GHG emissions related to the production, distribution and consumption of the energy needed to build, operate and maintain buildings in the future, the uncertainty about future energy systems is directly passed on to the calculations and models involving GHG emission credits.

The spatial and the temporal dimensions are connected. We can expect even more complex and geographically extended supply chains for energy and construction materials in the future, but we do not know the speed and direction of the changes within this broader trend. And even this prediction of an overarching trend may turn out wrong, revealing that the current, still limited efforts of local sourcing of energy and building materials are the beginning of a much broader transformation of industrial societies. We just do not know because the energy market is so dependent on politics.

## 11. Conclusions

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The main goal of the ZEB research centre is to develop new products and solutions for buildings that will lead to market penetration of buildings with zero greenhouse gas emissions related to their production, operation, and demolition. Thus a key challenge of the center is to produce innovations within the inherent space of uncertainty that is given by the related frontiers of the research.

As a useful metaphor for how to support innovation under the condition of high uncertainty, “navigation in unknown terrain” has been proposed (Jørgensen et al. 2012; see also Berker 2010 for alternative metaphors). At any time, successful navigators have a good grasp of where they are, which presupposes that they are constantly updating the knowledge about their current position. At the same time, they have a firm idea about where they want to go and the various possible ways of how to relate current and future positions to each other. This is also the strategy chosen in the ZEB centre: Information about relevant current GHG emissions is collected and updated regularly to give a sense of the current position. At the same time, policy goals on the national and European levels are used as end-points and goals for the navigation. The researchers follow closely the progress of the implementation of these goals. In this way, like a successful navigator, the researchers are constantly updating the connection between current position and future goal.

Part of this navigational strategy is to retain a certain degree of openness towards unforeseen events that are quite likely to be encountered while traveling through unknown terrain. Translated into a research strategy for the ZEB centre, this openness corresponds to maximizing the incentives for the development of different solutions that reduce the overall GHG emissions connected to a building. If the GHG emission credits chosen favour one and only one solution to reach a zero emission balance, then the result may be easier to reach in the present. However, given the fundamental uncertainty of future developments, preparing only for one route to reach the goal is a risky navigational strategy. On the other hand, if the conversion factor is chosen in a way so that a zero emission balance is impossible to reach in the present no matter which solution is chosen, then interesting research may be the result, but the industry will be very unlikely to participate in the construction of an “impossible” building. Thus, a balance between assumptions about the future that discourage innovation completely and assumptions that lead to only one innovation, has to be struck.

The experiences from the pilot building projects within the ZEB center show that reaching the highest levels of ambition for ZEB (including both materials and operation) is very challenging, given the boundary conditions and the applied CO<sub>2</sub>-factor for grid electricity. The above analyses and discussion indicate that the CO<sub>2</sub>-factor that has been used in the ZEB pilot projects probably does not “favor” energy measures on ZEBs compared to other measures for CO<sub>2</sub>-mitigation. Nevertheless, such a challenging CO<sub>2</sub>-factor has promoted innovation in that it has spurred the teams to reach further than they otherwise would have done, resulting in new solutions being implemented and tested out. As such, the chosen CO<sub>2</sub>-factor may be said to have served its purpose.

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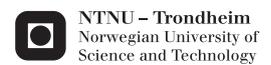
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## The Research Centre on Zero emission Buildings (ZEB)

The main objective of ZEB is to develop competitive products and solutions for existing and new buildings that will lead to market penetration of buildings that have zero emissions of greenhouse gases related to their production, operation and demolition. The Centre will encompass both residential and commercial buildings, as well as public buildings.



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