ZEB The Research Centre on Zero Emission Buildings

# MEMO

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| **Proposal for CO2-factor for electricity and outline of a full ZEB-definition** | | | | |
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## BACKGROUND

There has been extensive work for one and a half year to make a preliminary ZEB[1] definition. Three seminars with ZEB partners have been held in 2010 and 2011. The most difficult thing to define have been the CO2-factor for electricity. The CO2-factor for electricity is also extensively discussed in other projects like Future Built, Fremtidens Byer and Klimagassregnskap.no.

This memo proposes an approach for defining the GHG[2]-emission for electricity use during the lifetime of the building. An approach for the total GHG emission over the buildings lifetime is also discussed.

## ASSUMPTIONS

The approach to define CO2-emissions from electricity use is based on the following main assumptions:

- The two degree goal for global warming defined by IPCC \1\, also redefined by IEA as the 450 ppm scenario \2\, is basis for the European Union goal for GHG-emissions\3\. The European target is to reduce the GHG-emissions from electricity production by 85-95 % before 2050.
- This large reduction presuppose political and economical measures which underpins and supports such a long term transition. Both new- and modified policy measures area necessary to reach this ambitious target.
- Increased transmission capacity between regions and countries has to be developed towards a so-called supergrid \4\, enabling large quantities of electricity to be transported between regions- and countries. By enlarged transmission capacity it is possible to export renewable energy, and released energy from energy efficiency in Norway to offset fossil based electricity production in countries like Denmark, Netherland and Germany. A smart supergrid is also necessary for maximum utilization of variable power generation from wind and solar electricity production. Development of an European supergrid will take a long time, but is probably realistic in a 2050 perspective.
- In a situation where the total European GHG-emission from electricity production shall be reduced by 90 %, an average consideration of the specific emission (g/kWh) in Europe will be the most correct, assuming a

[1] ZEB: Zero Emission Buildings.
[2] GHG: Green House Gas

common European electricity market. Temporary and national effects during the lifetime in such a setting is of less importance.

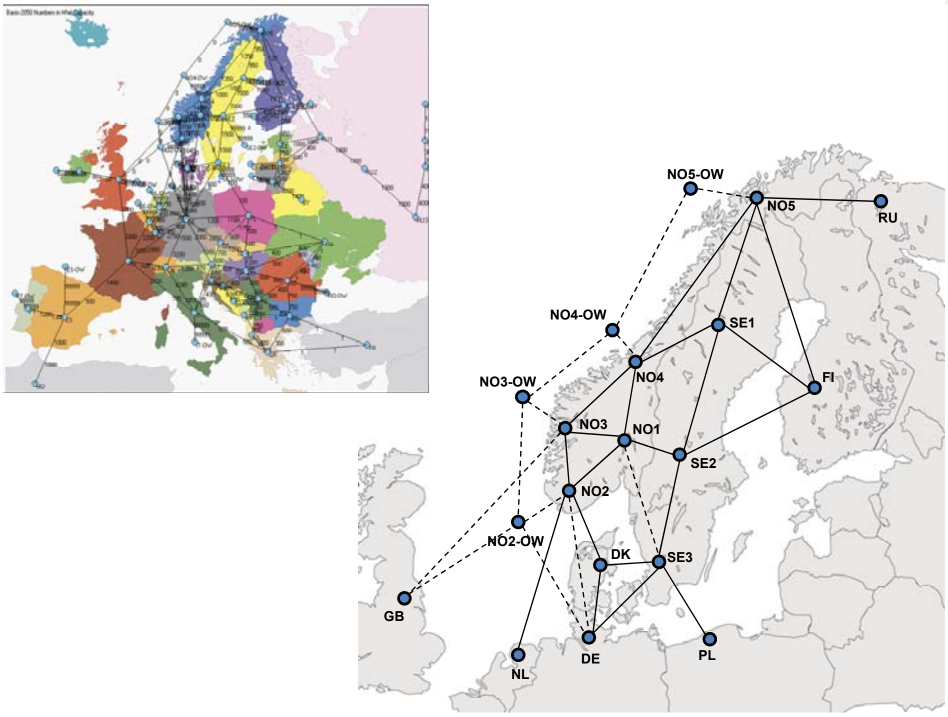


Figure 1: A possible development of a supergrid in Europa and Norway used in the simulations \5\ given below.

## SIMULATION OF THE EUROPEAN ELECTRICITY SYSTEM 2010-2050

Advanced and comprehensive simulations of the Eurpopean electricity system towards 2050, has been undertaken by SINTEF Energy \5\. Five storylines have been simulated: blue, yellow, red, green and ultra-green scenario. In the ultra-green scenario is based on comprehensive measures on energy efficiency, renewable enrgy (wind, solar,..), and also to some extent new nuclear power. Energy efficiency is assumed to reduce the electricty demand by 13,6 % compared to the 2010 level. The renewable production is increased from 669 TWh/y in 2010 to 2194 TWh/y in 2050, a treefold increase[3]. An increase of the nuclear capacity from todays 138 GW to 170 GW in 2050 (23 % increase) is also assumed. The simulations shows that this measures together with large increase in transmission capacity between countries and regions will reduce the European average specific emission to 31 g/KWh. This is a reduction by more than 90 % compared to the 2010 level. If we assume a linear development, we get a CO2-factor trend as shown in figure 2. An extrapolation of this trend beyond 2050, leads to a zero emission level in 2054[4].

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[3] This is still lower renewable volume than the three more "moderate" scenarios blue, yellow and green. However, the renewable share is high, due to the energy efficiency effort in the ultra green scenario, showing how important energy efficiency is for approaching a carbon free energy system.
[4] The simulations are only done from 2010 to 2050, and a zero carbon electricity system is an extrapolation of this linear curve towards 2055.

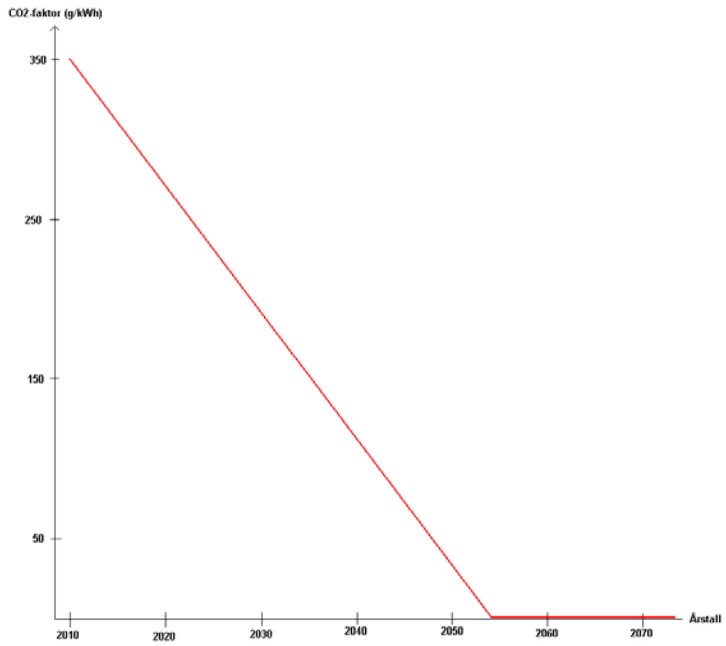


Figure 2: Simulated and extrapolated specific CO2-emission from the European electricty system from 2010 to 2070 (typical life time of a new building constructed in 2010).

## CO2-EMISSIONS FROM ELECTRICITY USE IN THE LIFETIME OF THE BUILDING

Based on the simulation towards 2050, and extrapolation to 2070 as shown i figure 2, an average specific CO2-factor during the lifetime of the building can be estimated. A building constructed in 2010, with a lifetime of 60 years, with a constant energy use[5], can use the following specific CO2-emission for electricity:

$$\overline{K}_{el} = \frac{361}{2} \cdot \frac{2054-2010}{60} = 132 \text{ g/kWh}$$

More general we have to take into account when the building is constructed and if the annual energy use is expected to change during the lifetime of the building. A more general formulation of this is given i appendix A.

[5] During the life time of the building, here estimated to be 60 years, it is probable that major changes will be done both to the building envelope, the buildings services and also the energy supply to the building, which will alter the energy use of the building. In such cases using a fixed CO2-factor will give a wrong picture of the total CO2-emissions.

## OUTLINE FOR A TOTAL ZEB-DEFINITION

In a buildings lifetime emission of GHG can arise from different phases:

1. Emission for production of materials, so-called "embodied emissions"
2. Emissions in connection with construction of the building, arising from use of machinery, operation and heating of barracks and heating and drying of the building during the construction process.
3. Emission during the operation of the building
4. Emissions due to maintenance and service, and also replacement, rebuilding and renovation during the lifetime of the building
5. Emission related to demolition and or recycling of the building

In phase 1. and partly 4. or 5. emissions will be a function of the mass flows of different materials used in the building and the respective CO2-factors. In 2010 a review of CO2-factors for different materials based on national and international databases have beeen undertaken \6\. This work will continue in 2011, and the plan is to make a ZEB-database of CO2-factors for the most common building materials. Since emission from a given material fully or partly can be a function of the energy use in the production process, the production year be of importance. E.g. an aluminium window replaced after 25 year can have substantially lower CO2-emissions in production than the original window (with the same construction), based on the assumptions in this memo that the European electricity production gets cleaner. CO2-factors used in phase 1 can therefore not be used in phase 4 (renovation/rebuilding) for the same material.

I phase 2., 3.and partly 4. and 5. emissions will be a function of the use of different energy sources (electricity, diesel, bioenergy, district heating...) and their respective CO2-factors. CO2-factors for other energy sources (energy wares) than electricity is given i table 1 (based on \7\), and have been used in evaluation of potential ZEB pilot buildings during 2010. In 2011 a review of CO2-factors for other energy sources than electricity will be undertaken, with special attetion on district heating and bioenergy (in different forms). A revision of values in table 1 will be the result. Like electricity, emission factors for other energy sources will also change over time, and instead of constant CO2-factors they will maybe have to be given as function of time like electricity (fig.1).

Table 1: CO2-factors for other energy sources, taken from \7\.

| Energisource (energyware) | $CO_2$-factor (g/kWh) |
|---|---|
| Biofuel (solids) | 14 |
| District heating | 231 |
| Gas (fossile) | 211 |
| Oil (fossile) | 284 |

During 2011 further work on defining the system boundaries for the ZEB-definition will also be done, discussing if there will be seperate definition for stand-alone buildings, small group of buildings or rather large development areas, and how the buildings will interact with the local energy grid (both electricity and heat). Rules for how the interaction between the buildings and the grid, with export and import and how this is accounted during day and nigth and during the year will be analyzed. Minimum requirements for components or energy efficiency, similar to NS3700 \8\, will also be discussed and analyzed.

## REFERENCES


\1\ http://www.ipcc.ch/pdf/assessment-report/ar4/syr/ar4_syr.pdf

\2\ http://www.iea.org/techno/etp/ETP_2008_Exec_Sum_English.pdf

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\3\ http://ec.europa.eu/clima/documentation/brief/eu/docs/2010_05_26_communication_en.pdf

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\4\ Energy: Supergrid. Nature, December 2010. http://www.nature.com/news/2010/101201/full/468624a.html

\5\ I. Graabak, N. Feilberg, "CO2 emissions in different scenarios of electricity generation in Europe." TR A7058, SINTEF Energy Research, January 2011. *Preliminary report.*

\6\ Wiberg A.H., "Rapport om klimagassregnskap", NTNU, Postdoc Aoife Wiberg.

\7\ Dokka TH, Klinski M, Haase M, Mysen M., "Kriterier for passivhus- og lavenergibygg – Yrkesbygg". SINTEF Byggforsk Prosjektrapport 42, 2009. www.sintef.no/Byggforsk/Publikasjoner/Prosjektrapporter

\8\ NS 3700 Criteria for low energy- and passive houses – Residentials. Standard Norge 2010.

## APPENDIX A: GENERAL FORMULATION OF GHG-EMISSIONS DUE TO ELECTRICITY USE OVER THE LIFE TIME OF THE BUILDING

With assumptions taken in this memo the specific emission factor will decrease over time, which will imply that buildings constructed later will have lower GHG-emissions than those constructed earlier. Further, annual energy use of a building can change during the lifetime of the building, which is mot cases is probablr in a 60 year period. The CO2-emission during the lifetime of the building due to electricity use can be calculated by the following equation:

$$m_{el} = \int_{t_{yr,st}}^{t_{yr,end}} K_{el}(t_{yr}) E_{el}(t_{yr})\, dt_{yr} \qquad \text{(g)} \qquad \text{(A.1)}$$

Based on fig.2, the CO2-factor for electricity as a function of year is given by:

$$K_{el}(t) = \begin{cases} 361 - 8,3 \cdot \lfloor t_{yr} - 2010 \rfloor,\ t_{yr}\ mellom\ 2010\ \ og\ 2055 \\ 0\ ,\ t_{yr}\ etter\ 2055 \end{cases} \qquad \text{(g/kWh)} \qquad \text{(A.2)}$$

| | |
|---|---|
| $E_{el}$ | The buildings electricity use, which can change during the lifetime of the building (KWh) |
| $m_{el}$ | CO2-emissions due to electricity use during the life time of the building (g) |
| $K_{el}$ | CO2-factor for electricity use (g/kWh) |
| $dt_{yr}$ | Small time differential |
| $t_{yr}$ | Year |
| $t_{yr,st}$ | The year the building is put to use |
| $t_{yr,end}$ | The year the building is taken out of use, usually estimated to be 60 years after $t_{yr,st}$ |

## APPENDIX B: SUMMARY OF SINTEF Energy report TR A7058

The objective of the work described in this report has been to quantify emissions of CO2 from power demand and production in Europe in a time perspective up to 2050. The quantification of CO2 emissions will contribute to establishing a definition of a zero emission building (ZEB). The definition of ZEB must be connected to the energy system, which the buildings are part of. Since the energy system in Europe is expected to change significantly in the coming decades it is neccessary to tie the definition of ZEB to possible scenarios of development of the energy system.

Five scenarios are elaborated to describe possible future developments in a time perspective up to 2050. The scenarios are created on variations in demand and in production portfolios of electricity. The scenarios are Red (high demand, limited growth in RES-E production), Yellow (limited demand, some growth in RES-E production), Green (limited demand, high growth in local and regional RES-E production), Blue (high demand, high growth in large-scale RES-E production), Ultra Green (decreased demand, some increase in nuclear production, increased RES-E production, mainly small scale). All scenarios except Red are assumed to have more than 50% RES-E in 2050.

Emissions of CO2 are analysed by the European Multi-area Power Market Simulator (EMPS). The EMPS model is a stochastic optimization model for hydro-thermal electricity markets. Most of the methodology and parts of the data input are from the EU FP7 project SUSPLAN (www.susplan.eu). Important sources for input data have been “World Energy Outlook” from IEA and reports from Eurelectric.

The total CO2 emissions for Yellow, Green and Blue will be reduced from 1088 Mtonne/y in 2010 to 600 - 800 Mtonne/y in 2050. The total emissions for Red will increase. The specific emissions for Yellow, Green and Blue will be reduced from 361 gCO2/kWh in 2010 to 100-200 gCO2/KWh in 2050.

The Ultra Green scenario represents a nearly emission free electricity system in 2050. The situation in 2050 is modelled with a reduction in demand of 13.6 % compared 2010 and increase of nuclear capacity from 138 GW in 2010 to 170 GW in 2050. In addition there is assumed a large increase in transmission capacities. The results from EMPS show that the RES production is increased from 669 TWh in 2010 to 2194 TWh in 2050.

The total emissions from Ultra Green are only 102 MTonne/y in 2050, i.e. less than 10% of the emissions in 2010. The specific emissions are only 31 gCO2/kWh in 2050. The emissions could have been even lower if higher CO2 prices had been assumed