THE GROUND-REACH MODEL TO DETERMINE THE CHANGE OF ENVIRONMENTAL IMPACT DUE TO REPLACEMENTS OF HEATING SYSTEMS ON THE EUROPEAN MARKET

Deliverable 3 Ground-Reach

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The Ground-Reach model

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Introduction

This report explains the development of the methodology to estimate the potential for a reduction of greenhouse gases when heat pumps are replacing conventional heating systems that is used in the Ground-Reach project. The main objective of this report is thus to reveal how the calculations are performed and not to present the overall results that may be achieved by a wide introduction of ground source heat pumps. Some example calculations have however been included in order to increase the readability of this report. The detailed deduction of some of the equations have been put in the Appendix as with the data sets that will be used as input for the calculations.

Given the overall aim of the Ground-Reach project, the environmental benefits will be estimated and expressed in terms of the reduction of CO$_2$-equivalents. At local and regional level additional aspects, such as eutrophication, acidification and health hazards have to be considered. These aspects are however, beyond the scope of this study. In addition to the calculations related to the environmental impact, the model is extended to include calculations of primary energy savings, end use energy savings as well as consumer cost savings and renewable energy provided by ground source heat pumps.

The second part of the report explains how the methodology will be applied on available national energy statistics. This will be done by use of three different scenarios. The scenarios are estimating how the heating sector in each country will be affected by a rapid market growth of ground source heat pumps by 2020 and 2050. The first scenario, “Reach Out”, assumes that emissions from generation of electricity and all other sources of heating remain constant. The second scenario, “Jackpot”, assumes that generation of electricity will develop according to the “Role of Electricity”, a scenario described by Eurelectric. The last scenario, “Full Impact” serves as a reference scenario and will reveal the theoretical potential that may be achieved if 100% of all existing fossil and electric based heating will be replaced by ground source heat pumps and that generation of electricity will develop according to the “Role of Electricity”. All other conditions alike present state, except for the assumption that the efficiency of the heat pump systems will increase in the order of 25% between 2020 and 2050, which is assumed in all three scenarios.
1. The Ground-Reach model

The main objective of this study is to develop a model to determine green house gas emissions related to different sources of heating. The model includes the methodology that will be used to estimate the potential for mitigation of green house gas emissions that may be reached, by a wide introduction of ground source heat pumps in the European Union. In addition to the main objective, the model is extended to include calculations of primary energy savings, end use energy savings as well as consumer cost savings and renewable energy provided by heat pumps. The use of the model will be revealed by use of examples given in this study and its Appendixes.

1.1 Green house gas emissions in the heating sector

In order to reduce the environmental impact from the building sector, the existing buildings and the technical installations need to be refurbished or replaced to become more energy efficient. This study will only consider the benefits that may be achieved by improvements of the technical installations. Even though substantial improvements may well be achieved by use of many different technologies, this study will focus on heat pumps and especially ground source heat pumps. Given the overall aim of the Ground-Reach project, the environmental benefits will be estimated and expressed in terms of the reduction of CO₂-equivalents. At local and regional level additional aspects, such as eutrophication, acidification and health hazards have to be considered. These aspects are however, beyond the scope of this study.

The CO₂-equivalents are expressed as emission factors, \( ef \, (\text{kg} \, \text{CO}_2/\text{kWh}) \). Based on the extraction, refinement, transportation, energy content and chemical composition, emission factors for different fuels may be established for the whole energy chain upstream the final energy conversion at the building site. Emission factors for different fuels and different mixes of electricity generation in this report are based on the values retrieved from GEMIS 4.2 (Oeko-Institut) and stated Appendix I.

1.2 Energy efficiency

While discussing the efficiency of heating systems, one need to realise that you will end up with different results depending on the interpretation of the boundaries for the system in view. Different stake holders would set the boundaries from different perspectives. The end user of a heating system would naturally define the efficiency as the useful heat in relation to the amount of energy that needs to be purchased. This is however not sufficient when energy systems are studied from a broader perspective, as energy losses and emissions from different types of heating systems appear at different stages in the energy chain. An electric boiler might seem very efficient from the perspective of the consumer, but taking into account for distribution losses and losses at point of electricity generation and even further up the energy chain, it is evident that electric heating is not as efficient as the customer might perceive. In order to obtain an impartial comparison of the energy efficiency for different types of systems, it is essential to address the primary energy efficiency. This study will encompass the energy chain including, extraction, refinement and transportation of the primary energy source as well as conversion, final distribution and final conversion at appliance level. All energy losses upstream the heating appliance will, for practical reasons,
be represented by a resulting efficiency factor. Resulting upstream efficiency for the different technologies that will be considered in this study has been compiled and may be found in Appendix II.

Figure 1 Definition of the system boundary

1.3 Net change in CO$_2$- emissions
In following paragraphs an expression for the net change of CO$_2$-emissions will be derived by use of a simplified example. Albeit the example is given for a replacement of an oil boiler, analogous expressions for replacement of other heat sources will be found simply by an alteration of the emission and annual efficiency factors.
1.4 Green house gas emissions due to combustion of heating oil

The building in Figure 2 requires the net energy demand for heating denoted $E_{\text{building}}$. This is the useful heat supplied by the heating system, in this case an oil boiler operating at an estimated annual efficiency, $\eta_{\text{oil}}$.

![Diagram of a building with a heating system](image)

Figure 2 The annual heating demand for the building above is, denoted $E_{\text{building}}$. The oil boiler consumes the energy, $E_{\text{oil}}$ and operates at an annual efficiency, $\eta_{\text{oil}}$. The useful heat provided by the oil boiler is given by, $E_{\text{oil}} \cdot \eta_{\text{oil}}$.

The environmental impact, in terms of green house gas emissions, $e_{\text{imp,oil}}$, due to combustion of heating oil and upstream efficiency, $\eta_{\text{up,oil}}$, may be expressed as:

$$e_{\text{imp,oil}} = \frac{E_{\text{oil}} \cdot \eta_{\text{up,oil}}}{\eta_{\text{oil}}} , \text{ or } e_{\text{imp,oil}} = \frac{E_{\text{building}} \cdot \eta_{\text{up,oil}}}{\eta_{\text{oil}} \cdot \eta_{\text{up,oil}}} (\text{kg}) \quad (1)$$
2. Green house gas emissions related to the use of heat pumps

With the exception of a few technologies, the majority of all life cycle assessments carried out on systems for space conditioning or generation of electricity by combustion, confirm that most of the environmental impact stems from the appliance/plant in operation (IEA 2002, Spath, Mann 2000, Halozan et al 1999). Environmental evaluations of heat pump applications need to take into account for indirect emissions related to the generation of electricity that is used to operate the heat pump, as well as direct emissions of the refrigerant. A lot of research has been made on the establishment of an integrated method to calculate the contribution of green house gas emissions from refrigeration and heat pump applications. The most well established method, TEWI (Total Equivalent Warming Impact), was developed at Oak Ridge National Laboratory in the early nineties. A TEWI calculation integrates direct and indirect green house gas emissions over the whole lifetime into a single number expressed in terms of CO$_2$ mass equivalents. Even though the TEWI concept is well known and accepted it has been developed to evaluate individual units or a defined number of units. It is at current stage difficult to apply the concept in evaluations of very large number of units, which is the case when a whole country is being studied. In the Ground-Reach project we will restrict our analyses to the green house gas emissions related to the generation of electricity.

Like many other types of renewable heating systems, heat pumps are sometimes most economical if they are designed for part load, i.e. bivalent system. This fact raises the demand for an auxiliary heating system, aux$_{hp}$ to be run in parallel or in series with the heat pump. This practice is more pronounced in the Nordic countries than other parts of Europe, where heat pumps tend to be designed for the peak heating demand, i.e. monovalent system. The annual performance of the heat pump system is called seasonal performance factor ($SPF_{hp}$). In case of a bivalent system, a factor, $exen$, is used to denote the relation between the energy provided by the heat pump and the annual heat demand for the building.

$$E_{building} = exen \cdot E_{building} - (1 - exen).$$

For a monovalent heat pump system $exen$ equals to unity.

Figure 3 The annual heating demand, $E_{building}$ for interior space and domestic hot water heating is provided by the heat pump and if required by an auxiliary heat source, aux$_{hp}$. A factor $exen$ is used to denote the relation between the energy provided by the heat pump and the annual heat demand for the building. Thus the auxiliary heat source is providing $E_{building} \cdot (1 - exen)$. For a monovalent heat pump system $exen$ equals to unity.
The overall environmental impact of heat pump operation, in analogy with oil heating, to take into account for all upstream losses for the electricity and the auxiliary heating device, i.e. distribution losses and losses related to the generation of electricity as well as losses related to extraction and refinement. A final expression for the environmental impact of the heat pump system including the auxiliary heat source may be deducted (Appendix III) and yields in:

\[ e_{\text{imp}_{hp}} = \frac{E_{\text{building}}}{\text{SPF}_{hp}} \cdot \frac{\text{exen}}{\eta_{el}^{up}} \cdot \text{ef}_{el} + E_{\text{building}} \cdot (1 - \text{exen}) \cdot \frac{\text{ef}_{aux}}{\eta_{aux} \cdot \eta_{aux}^{up}} \] (kg) \hspace{1cm} (2)

This general expression may be used for all types of electric heat pumps.

The net change of CO\(_2\)-emissions when an oil boiler is replaced by a heat pump system is given by:

\[ \Delta e_{\text{imp}_{oil-hp}} = e_{\text{imp}_{oil}} - e_{\text{imp}_{hp}} \] (kg) \hspace{1cm} (3)

Using the expression above gives:

\[ \Delta e_{\text{imp}_{oil-hp}} = \frac{E_{\text{building}} \cdot \text{ef}_{oil}}{\eta_{oil} \cdot \eta_{oil}^{up}} \cdot \left( \frac{E_{\text{building}} \cdot \text{exen} \cdot \text{ef}_{el}}{\text{SPF}_{hp} \cdot \eta_{el}^{up}} + \frac{E_{\text{building}} \cdot (1 - \text{exen}) \cdot \text{ef}_{aux}}{\eta_{aux} \cdot \eta_{aux}^{up}} \right) \] \hspace{1cm} (4)

By use of equation (1) and (4), a final expression for the relative change of CO\(_2\)-emissions may be deducted. The deduction for equation 2 and 5 is described in more detail in Appendix III.

\[ \text{Relative emission savings} = 1 - \left( \frac{\text{exen} \cdot \text{ef}_{el} \cdot \eta_{oil}^{up} \cdot \eta_{oil}}{\text{SPF} \cdot \eta_{el}^{up} \cdot \eta_{oil} \cdot \eta_{oil}^{up} \cdot \eta_{oil}} + (1 - \text{exen}) \cdot \frac{\text{ef}_{aux} \cdot \eta_{oil}^{up} \cdot \eta_{oil} \cdot \eta_{oil}^{up} \cdot \eta_{oil}}{\eta_{aux} \cdot \eta_{aux}^{up} \cdot \eta_{aux}} \right) \] (-) \hspace{1cm} (5)

\[ h_{\text{conv}_{oil-hp}} = 1 - \left( \frac{\text{exen} \cdot \text{ef}_{el}}{\text{ef}_{oil} \cdot \eta_{el}^{up} \cdot \eta_{oil} \cdot \eta_{oil}^{up} \cdot \text{SPF}_{hp}} + (1 - \text{exen}) \cdot \frac{\text{ef}_{aux} \cdot \eta_{oil}^{up} \cdot \eta_{oil} \cdot \eta_{oil}^{up} \cdot \eta_{oil}}{\eta_{aux} \cdot \eta_{aux}^{up} \cdot \eta_{aux}} \right) \] (-) \hspace{1cm} (6)

Introducing a conversion factor, \( h_{\text{conv}_{oil-hp}} \):
Within the brackets, the conversion factor consists of two parts. One is related to heat pump operation, whereas the other is related to the auxiliary heat source. For a monovalent heat pump system, i.e. the heat pump is designed to provide 100% of the annual heat demand, \( \text{exen} \) is equal to 1 and evidently the part related to the auxiliary heat source will be superfluous.

As can be seen in equation (6) both parts within the brackets of the conversion factor consists of similar factors, i.e. one factor indicating the share of the annual heating demand provided by the heat source, one giving the relation between the emission factors, one giving the relation between the upstream losses and finally one factor giving the relation between the efficiencies of the heating devices.

Analogous conversion factors may be found for any case, simply by using the relevant indexes in equation (4).

Replacing electricity based heating with a heat pump:

\[
h_{\text{el-hp}}^{\text{conv}} = 1 - \left( \text{exen} \cdot \frac{\eta_{\text{el}}}{\text{SPF}_{\text{hp}}} + (1-\text{exen}) \cdot \frac{\eta_{\text{el}}}{\eta_{\text{aux}}} \cdot \frac{\eta_{\text{aux}}^{\text{hp}}}{\eta_{\text{aux}}} \right) \tag{7}
\]

Replacing a gas boiler with heat pump:

\[
h_{\text{gas-hp}}^{\text{conv}} = 1 - \left( \text{exen} \cdot \frac{\eta_{\text{gas}}}{\eta_{\text{el}}} \cdot \frac{\eta_{\text{gas}}^{\text{hp}}}{\text{SPF}_{\text{hp}}} + (1-\text{exen}) \cdot \frac{\eta_{\text{gas}}}{\eta_{\text{aux}}} \cdot \frac{\eta_{\text{aux}}^{\text{hp}}}{\eta_{\text{aux}}} \right) \tag{8}
\]

\[\begin{array}{ccccccc}
\% & 100 & 90 & 80 & 70 & 60 & 50 & 40 & 30 & 20 & 10 & 0 & -10 \\
\eta & 0.01 & 0.04 & 0.08 & 0.12 & 0.16 & 0.2 & 0.24 & 0.28 & 0.32 & 0.36 & 0.4 & 0.44 & 0.48 & 0.52 & 0.56 & 0.6 & 0.64 & 0.68 & 0.72 & 0.76 & 0.8 & 0.84 & 0.88 \\
\end{array}\]

**Figure 4** Relative CO\(_2\) savings by heat pumps: Conditions used for the example above; gas boiler efficiency 95%, oil boiler efficiency 90%, monovalent heat pump operating with SPF 4.
3. Primary energy savings

As the previous expressions included upstream losses we may use the same equations to establish an expression for the relative savings of primary energy. The conversion factors for the relative savings of primary energy are given below.

By leaving out the quotient for the emission factors, we end up with a conversion factor for primary energy savings, \( h_{\text{oil-hp}}^{\text{primary energy}} \).

\[
\begin{align*}
    h_{\text{oil-hp}}^{\text{primary energy}} &= 1 - \left( \text{exen} \cdot \frac{\eta_{\text{up}}^{\text{oil}}}{\eta_{\text{up}}^{\text{el}}} \cdot \frac{\eta_{\text{ali}}}{\text{SPF}_{\text{hp}}} + (1 - \text{exen}) \cdot \frac{\eta_{\text{up}}^{\text{oil}}}{\eta_{\text{aux}}^{\text{up}}} \cdot \frac{\eta_{\text{ali}}}{\eta_{\text{aux}}} \right) (-) (9)
\end{align*}
\]

Replacing electricity based heating with a heat pump:

\[
\begin{align*}
    h_{\text{el-hp}}^{\text{primary energy}} &= 1 - \left( \text{exen} \cdot \frac{\eta_{\text{el}}^{\text{up}}}{\text{SPF}_{\text{hp}}} + (1 - \text{exen}) \cdot \frac{\eta_{\text{up}}^{\text{el}}}{\eta_{\text{aux}}^{\text{up}}} \cdot \frac{\eta_{\text{el}}}{\eta_{\text{aux}}} \right) (-) \quad (10)
\end{align*}
\]

Replacing a gas boiler with a heat pump:

\[
\begin{align*}
    h_{\text{gas-hp}}^{\text{primary energy}} &= 1 - \left( \text{exen} \cdot \frac{\eta_{\text{up}}^{\text{gas}}}{\eta_{\text{up}}^{\text{el}}} \cdot \frac{\eta_{\text{gas}}}{\text{SPF}_{\text{hp}}} + (1 - \text{exen}) \cdot \frac{\eta_{\text{up}}^{\text{gas}}}{\eta_{\text{aux}}^{\text{up}}} \cdot \frac{\eta_{\text{gas}}}{\eta_{\text{aux}}} \right) (-) \quad (11)
\end{align*}
\]

![Figure 5](image.png)  

*Figure 5* Relative savings of primary energy by heat pumps: Conditions used in the example above; gas boiler efficiency 95%, oil boiler efficiency 90%, monovalent heat pump operating with SPF 4.
3.1 End use energy savings

The step from primary energy savings to the actual energy savings for the end customer may be done by disregarding all upstream losses. The conversion factors for end use energy savings becomes:

\[
h_{\text{end use energy}} = 1 - \left( \text{exen} \cdot \frac{\eta_{\text{oil}}}{\text{SPF}_{hp}} + (1 - \text{exen}) \cdot \frac{\eta_{\text{oil}}}{\eta_{\text{aux}}} \right) (-) \quad (12)
\]

Replacing electricity based heating with a heat pump:

\[
h_{\text{end use energy}} = 1 - \left( \text{exen} \cdot \frac{\eta_{\text{el}}}{\text{SPF}_{hp}} + (1 - \text{exen}) \cdot \frac{\eta_{\text{el}}}{\eta_{\text{aux}}} \right) (-) \quad (13)
\]

Replacing a gas boiler with a heat pump:

\[
h_{\text{end use energy}} = 1 - \left( \text{exen} \cdot \frac{\eta_{\text{gas}}}{\text{SPF}_{hp}} + (1 - \text{exen}) \cdot \frac{\eta_{\text{gas}}}{\eta_{\text{aux}}} \right) (-) \quad (14)
\]

![Figure 6](image)

**Figure 6** End use energy savings by heat pumps: Conditions used in the example above; oil boiler efficiency 90%, gas boiler efficiency 95%, monovalent heat pump operating with SPF 4.
3.2 End use cost savings

Whether an electric heat pump installation will render in lower operating costs for the end consumer or not, depends on the appliance efficiency as well as the energy price ratios between electricity and the alternative systems. The relevant energy price ratio is simply the end user price of 1 kWh electricity in relation to the price of 1 kWh of the alternative. The step from end use energy savings to the actual savings of operating costs for the consumer may be done by including the energy price ratios for the systems studied. The conversion factors for savings of operating costs become:

\[
h_{\text{end use energy}}^{\text{end use energy}} = 1 - \left( \text{exen} \cdot \frac{\text{price}_{\text{el}}}{\text{price}_{\text{oil}}} \cdot \frac{\eta_{\text{oil}}}{\text{SPF}_{\text{hp}}} + (1 - \text{exen}) \cdot \frac{\text{price}_{\text{aux}}}{\text{price}_{\text{oil}}} \cdot \frac{\eta_{\text{oil}}}{\eta_{\text{aux}}} \right)
\]  
\[\text{Replacing electricity based heating with a heat pump:}\]

\[
h_{\text{el-hp}}^{\text{end use energy}} = 1 - \left( \text{exen} \cdot \frac{\eta_{\text{el}}}{\text{SPF}_{\text{hp}}} + (1 - \text{exen}) \cdot \frac{\text{price}_{\text{aux}}}{\text{price}_{\text{el}}} \cdot \frac{\eta_{\text{el}}}{\eta_{\text{aux}}} \right)
\]  
\[\text{Replacing a gas boiler with a heat pump:}\]

\[
h_{\text{gas-hp}}^{\text{end use energy}} = 1 - \left( \text{exen} \cdot \frac{\text{price}_{\text{el}}}{\text{price}_{\text{gas}}} \cdot \frac{\eta_{\text{gas}}}{\text{SPF}_{\text{hp}}} + (1 - \text{exen}) \cdot \frac{\text{price}_{\text{aux}}}{\text{price}_{\text{gas}}} \cdot \frac{\eta_{\text{gas}}}{\eta_{\text{aux}}} \right)
\]

![Graph](image)

**Figure 7** Relative cost savings for end consumer: Conditions used in the example above; oil boiler efficiency 90%, gas boiler efficiency 95%, monovalent heat pump operating with SPF 4.
3.3 Renewable energy provided by heat pumps

An extensive use of renewable energy is an absolute necessity in order to reach a sustainable energy system. This is already well acknowledged all over Europe and binding targets for the use of renewable energy have already been approved by the European Council, March 2007. The target is set for a minimum of 20% of renewable energy in total energy utilisation by 2020. The calculation of renewable energy provided by monovalent heat pumps is given by the equation below.

\[ E_{\text{ren}} = E_{\text{building}} \cdot \frac{(\text{SPF} - 1)}{\text{SPF}} \text{ (kWh)} \] (18)

4. Applying the methodology on a Country

The theoretical model described in previous paragraphs can be used in order to determine how the greenhouse gas emissions will be affected if ground source heat pumps are introduced on a large scale in different countries. While applying the methodology on a country a number of assumptions related to the efficiency of the stock of heating appliances need to be introduced. Available energy statistics for the heating sector need to be acquired for each country that is to be studied. The calculations will be based on a statistical format which is represented by the end use of energy for the different energy sources.

In the following, the method described will be applied to Sweden as a whole. The calculations below are based on available energy statistics [Statistics Sweden]. The end use of all the different sources of heating that exist on the market are expressed in TWh and given in the chart below.

\[ \text{Figure 8} \quad \text{The end use energy for residential heating in TWh for single-family houses in Sweden 2004. The total use amounts to 36.7 TWh.} \]
The environmental impact from heating of single family houses is given by the sum of the contributions from all energy sources:

\[ e_{\text{imp}, \text{tot}} = e_{\text{imp}, \text{oil}} + e_{\text{imp}, \text{dh}} + e_{\text{imp}, \text{el}} + e_{\text{imp}, \text{hp}} + e_{\text{imp}, \text{bio}} + e_{\text{imp}, \text{gas}} \]  

(19)

Where

- \( e_{\text{imp}, \text{oil}} = \text{CO}_2 \text{ mass equivalent for oil (kg)} \)
- \( e_{\text{imp}, \text{dh}} = \text{CO}_2 \text{ mass equivalent for district heating (kg)} \)
- \( e_{\text{imp}, \text{el}} = \text{CO}_2 \text{ mass equivalent for electricity excluding existing heat pumps (kg)} \)
- \( e_{\text{imp}, \text{hp}} = \text{CO}_2 \text{ mass equivalent for already existing heat pumps (kg)} \)
- \( e_{\text{imp}, \text{bio}} = \text{CO}_2 \text{ mass equivalent for biomass (kg)} \)
- \( e_{\text{imp}, \text{gas}} = \text{CO}_2 \text{ mass equivalent for gas (kg)} \)

The \( \text{CO}_2 \)-emissions for each source of energy is given by the product of the emission factors (\( ef_i \)) and the primary energy use:

\[ e_{\text{imp}, i} = \frac{E_i \cdot ef_i}{\eta_i^{\text{hp}}} \]  

(20)

Where

- \( E_i = \text{The total end use energy for an energy source (kWh)} \)
- \( ef_i = \text{Emission factor in CO}_2\text{-mass equivalent for an energy source (kg/kWh)} \)

The total \( \text{CO}_2 \)-emissions becomes:

\[ e_{\text{imp}, \text{tot}} = \sum \frac{E_i \cdot ef_i}{\eta_i^{\text{hp}}} \]  

(kg)  

(21)

As heat pumps are replacing existing heating, the total emissions becomes:

\[ e_{\text{imp}, \text{tot}} = \sum \left( \frac{E_i \cdot ef_i}{\eta_i^{\text{hp}}} \right) - \Delta e_{\text{imp}, \text{hp}} \]  

(kg)  

(22)

Where

- \( \Delta e_{\text{imp}, \text{hp}} = \text{The net change of CO}_2\text{-emissions as heat pumps are introduced.} \)
5. Scenario analysis

A wide introduction of ground source heat pumps in the European Union will evidently have a large impact on energy efficiency and the dependency of fossil fuel. The full potential of ground source heat pumps needs to be estimated by taking into account for the differences on the national markets. As the different countries at present are at entirely different levels, it is clearly not possible for all countries to use the same assumptions for the market developments. The scenarios that are to be used will allow for national deviations regarding the market development. Three general scenarios will be used and analysed by calculations based on national data for Sweden.

5.1 Scenario: “Reach out”

This scenario assumes that X% of all existing (based on the most recent available statistics) fossil and electricity based heating will be replaced by ground source heat pumps by 2020 and Y% by 2050. District heating will not be considered as an option for retrofit in the sector of single family houses. Within the timeframe between 2020 and 2050 it is assumed that the efficiency of the heat pump systems will increase by 25% (2020 SPF=4, 2050 SPF=5).

5.2 Scenario: “Jackpot”

This scenario assumes that X+10% of all existing fossil and electricity based heating will be replaced by ground source heat pumps by 2020 and Y+10% by 2050. District heating will not be considered as an option for retrofit in the sector of single family houses. Within the timeframe between 2020 and 2050 it is assumed that the efficiency of the heat pump systems will increase by 25% (2020 SPF=4, 2050 SPF=5) and that the generation of electricity will develop according to scenario “Role of Electricity” outlined by Eurelectric [Eurelectric, 2007](see Appendix IV).

5.3 Scenario: “Full impact”

This scenario will reveal the theoretical potential that may be achieved if 100% of all existing fossil and electricity based heating will be replaced by ground source heat pumps, all other conditions according to the Jackpot scenario.
6 References


Oeko-Institut, Global Emissions Model for Integrated Systems (GEMIS), Oeko-Institut, Germany (www.gemis.de).

The table below depicts the emission factors, for various types of energy sources, retrieved from GEMIS 4.2. As the emission factor include emissions occurring upstream it is given as the quotient of emission factor and upstream efficiency, \( \frac{ef}{\eta^{up}} \).

The values for electricity Emission factors for electricity does not take into account for grid losses between the power plant and the end users. Thus the values retrieved from GEMIS have been recalculated by use of a general assumption of 4% grid losses. Even though this assumption is not valid for Europe as a whole, the error this will induce is small.

### Emission factors

<table>
<thead>
<tr>
<th>Energy source</th>
<th>( \frac{ef}{\eta^{up}} ) (kg/kWh)</th>
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<tbody>
<tr>
<td>Fuel oil</td>
<td>0.330</td>
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<tr>
<td>Natural gas</td>
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<td>Hard coal briquettes</td>
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<td>Elec. Finland</td>
<td>0.406</td>
</tr>
<tr>
<td>Elec. United Kingdom</td>
<td>0.554</td>
</tr>
</tbody>
</table>

**Results from GEMIS 4.2**
Table 2 Depict the upstream efficiencies for different heating systems used in this study. Values are retrieved from GEMIS 4.2. As the GEMIS database does not include gridlosses, the values have been recalculated by assuming 4% losses for all national grids.

**Table 2 Upstream efficiencies**

<table>
<thead>
<tr>
<th>Source of heating</th>
<th>Upstream efficiency, $\eta$%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel oil</td>
<td>84%</td>
</tr>
<tr>
<td>Natural gas</td>
<td>85%</td>
</tr>
<tr>
<td>Pellets</td>
<td>91%</td>
</tr>
<tr>
<td>Hard coal briquettes</td>
<td>90%</td>
</tr>
<tr>
<td>Electricity EU 25</td>
<td>34%</td>
</tr>
<tr>
<td>Electricity Austria</td>
<td>58%</td>
</tr>
<tr>
<td>Elec. Belgium</td>
<td>29%</td>
</tr>
<tr>
<td>Elec. Switzerland</td>
<td>47%</td>
</tr>
<tr>
<td>Elec. Germany</td>
<td>33%</td>
</tr>
<tr>
<td>Elec. Denmark</td>
<td>38%</td>
</tr>
<tr>
<td>Elec. Spain</td>
<td>37%</td>
</tr>
<tr>
<td>Elec. France</td>
<td>29%</td>
</tr>
<tr>
<td>Elec. Greece</td>
<td>37%</td>
</tr>
<tr>
<td>Elec. Italy</td>
<td>41%</td>
</tr>
<tr>
<td>Elec. Ireland</td>
<td>39%</td>
</tr>
<tr>
<td>Elec. Luxenburg</td>
<td>35%</td>
</tr>
<tr>
<td>Elec. Netherlands</td>
<td>36%</td>
</tr>
<tr>
<td>Elec. Norway</td>
<td>92%</td>
</tr>
<tr>
<td>Elec. Poland</td>
<td>36%</td>
</tr>
<tr>
<td>Elec. Sweden</td>
<td>44%</td>
</tr>
<tr>
<td>Elec. Finland</td>
<td>29%</td>
</tr>
<tr>
<td>Elec. United Kingdom</td>
<td>36%</td>
</tr>
</tbody>
</table>
This Appendix reveals the full deduction for some of the formulas used in the main report.

**Figure** A building has the energy demand $E_{building}$ for heating interior space and water. Of the energy demand, $exen$ is provided by the heat pump and $(1-exen)$ provided by an auxiliary heat source, denoted $aux_{hp}$. From the heat pump, the energy, $E_{building} \cdot exen$, is distributed to the building. The auxiliary heat source is providing $E_{building} \cdot (1-exen)$.

The annual energy demand for the building, $E_{building}$, in the figure above is covered by the annual heat output from the heat pump, $E_{hp}$, and, if required, the auxiliary heating system, $E_{aux}$.

$$E_{building} = E_{hp} + E_{aux}$$

$$E_{hp} = E_{building} \cdot exen$$

$$E_{aux} = E_{building} \cdot (1-exen)$$

The primary energy use for the heat pump includes all upstream losses for electricity, i.e. distribution losses and losses related to the generation of electricity as well as losses related to extraction/refinement, denoted $1/\eta_{up}^{el}$. With the emission factor for electricity $ef_{el}$ and primary energy use $E_{el} / \eta_{up}^{el}$, the CO$_2$-emission becomes:

$$\frac{E_{el} \cdot ef_{el}}{\eta_{el}^{up}} \text{ (kg)}$$

(1)

Using the seasonal performance factor SPF$_{hp}$ for the heat pump, the annual electricity demand is given by:

$$E_{el} = \frac{E_{building} \cdot exen}{SPF_{hp}} \text{ (kWh)}$$

(2)

Where $exen$ denote the relation between the energy provided by the heat pump and the annual heat demand for the building. Finally, the emissions related to the heat pump becomes:

$$\frac{E_{building} \cdot exen \cdot ef_{el}}{SPF_{hp} \cdot \eta_{el}^{up}} \text{ (kg)}$$

(3)
Appendix III

The CO2-emission from the auxiliary heat source is:

$$E_{\text{building}} \cdot (1 - \text{exen}) \cdot \frac{\text{ef}_{\text{aux}}}{\eta_{\text{aux}} \cdot \eta_{\text{aux}}^\text{up}} \quad (\text{kg}) \quad (4)$$

The total emissions for a heat pump system is given by the sum of the emissions from the heat pump and the auxiliary heat source:

$$e_{\text{imp}}_{\text{hp}} = \frac{E_{\text{building}}}{\text{SPF}_{\text{hp}}} \cdot \frac{\text{exen}}{\eta_{\text{el}}^\text{up}} \cdot \text{ef}_{\text{el}} + E_{\text{building}} \cdot (1 - \text{exen}) \cdot \frac{\text{ef}_{\text{aux}}}{\eta_{\text{aux}} \cdot \eta_{\text{aux}}^\text{up}} \quad (\text{kg}) \quad (5)$$

This general expression may be used for all types of electric heat pumps.

The net change of CO2-emissions when an oil boiler is replaced by a heat pump system is given by:

$$\Delta e_{\text{imp}}_{\text{oil-hp}} = e_{\text{imp}}_{\text{oil}} - e_{\text{imp}}_{\text{hp}} \quad (\text{kg}) \quad (6)$$

Using the expression above gives:

$$\Delta e_{\text{imp}}_{\text{oil-hp}} = \frac{E_{\text{oil}} \cdot \text{ef}_{\text{oil}}}{\eta_{\text{oil}}^\text{up}} \left( \frac{E_{\text{building}} \cdot \text{exen} \cdot \text{ef}_{\text{el}}}{\text{SPF}_{\text{hp}} \cdot \eta_{\text{el}}^\text{up}} + \frac{E_{\text{building}} \cdot (1 - \text{exen}) \cdot \text{ef}_{\text{aux}}}{\eta_{\text{aux}} \cdot \eta_{\text{aux}}^\text{up}} \right) \quad (7)$$

We have:

$$E_{\text{building}} = E_{\text{oil}} \cdot \eta_{\text{oil}} \quad (\text{kWh}) \quad (8)$$
Appendix III

The net change becomes:

\[ \Delta \text{imp}_{\text{oil}} = \frac{E_{\text{building}} \cdot \text{ef}_{\text{oil}}}{\eta_{\text{oil}} \cdot \eta_{\text{up}}} - \left( \frac{E_{\text{building}} \cdot \text{exen} \cdot \text{ef}_{\text{el}}}{\text{SPF}_{\text{hp}} \cdot \eta_{\text{el}}^{\text{up}}} + \frac{E_{\text{building}} \cdot (1-\text{exen}) \cdot \text{ef}_{\text{aux}}}{\eta_{\text{aux}} \cdot \eta_{\text{up}}} \right) \]  

(9)

The relative savings of emissions is given by:

\[ \text{Rel emission savings} = \frac{\text{imp}_{\text{oil}} - \text{imp}_{\text{hp}}}{\text{imp}_{\text{oil}}} \]  

(12)

Using (11) and (12) give:

\[ \text{Rel emission savings} = \frac{E_{\text{building}} \cdot \text{ef}_{\text{oil}}}{\eta_{\text{oil}} \cdot \eta_{\text{up}}} \left( \frac{E_{\text{building}} \cdot \text{exen} \cdot \text{ef}_{\text{el}}}{\text{SPF}_{\text{hp}} \cdot \eta_{\text{el}}^{\text{up}}} + \frac{E_{\text{building}} \cdot (1-\text{exen}) \cdot \text{ef}_{\text{aux}}}{\eta_{\text{aux}} \cdot \eta_{\text{up}}} \right) \]  

(10)

Rewriting (13) results in:

\[ \text{Rel emission savings} = 1 - \left( \frac{\text{exen} \cdot \text{ef}_{\text{el}} \cdot \eta_{\text{el}}^{\text{up}}}{\eta_{\text{oil}} \cdot \eta_{\text{el}}^{\text{up}}} \cdot \frac{\eta_{\text{oil}}}{\text{SPF}} + \frac{\text{exen} \cdot \eta_{\text{up}}}{\eta_{\text{aux}} \cdot \eta_{\text{up}}} \cdot \frac{\eta_{\text{oil}}}{\eta_{\text{aux}}} \right) \]  

(11)

Introducing a conversion factor, \( h_{\text{oil}}^{\text{conv}} \)

\[ h_{\text{oil}}^{\text{conv}} = 1 - \left( \frac{\text{exen} \cdot \text{ef}_{\text{el}} \cdot \eta_{\text{el}}^{\text{up}}}{\eta_{\text{oil}} \cdot \eta_{\text{el}}^{\text{up}}} \cdot \frac{\eta_{\text{oil}}}{\text{SPF}_{\text{hp}}} + \frac{\text{exen} \cdot \eta_{\text{up}}}{\eta_{\text{aux}} \cdot \eta_{\text{up}}} \cdot \frac{\eta_{\text{oil}}}{\eta_{\text{aux}}} \right) \]  

(12)

Within the brackets, the conversion factor consists of two parts. One is related to heat pump operation, whereas the other one is related to the auxiliary heat source. For a monovalent heat pump system, i.e. the heat pump is designed to provide 100% of the annual heat demand, exen is equal to 1 and evidently the part related to the auxiliary heat source will be superfluous.

As can be seen in equation (12) both parts of the conversion factor consists of similar terms, i.e. one term indicating the share of the annual heating demand provided by the heat source, one giving the relation between the emission factors, one giving the relation between the upstream losses and finally one term giving the relation between the efficiency of the heating devices.
Appendix IV

Role of Electricity

Source PRIMES
Project Description

The GROUND-REACH project is expected to effectively assist EU policy towards both short and long term market penetration of ground coupled heat pumps, through analysing the market for ground coupled heat pumps and providing best practices, guidelines for local/regional authorities and key professional groups, conferences, meetings, website, brochure and other promotional tools. It will facilitate: A better understanding of ground coupled heat pumps merits and benefits and their importance towards Community policy objectives in relation to Kyoto targets and the buildings performance directive. An increased awareness and improved knowledge and perception of the ground coupled heat pumps technology among key European professional groups for short term market penetration.

The work is grouped in the following work packages:

WP#1 – Project management

WP#2 - Estimating the potential of ground coupled heat pumps for reducing CO₂ emissions and primary energy demand for heating and cooling purposes in the built environment: evaluation of available statistical information, definition of competing heating/cooling technologies, analysis of existing calculation tools, CO₂ emissions calculation.

WP#3 - Compiling and evaluating existing ground coupled heat pumps best practice information in Europe: identifying and updating information from all European member states, including case studies, and technical guidelines.

WP#4 - Analysing the contribution of ground coupled heat pump technologies to reach the objectives of the Buildings Performance Directive: Analysis of the technical, environmental and economic feasibility of ground coupled heat pump technologies; Guideline for supporting planners and architects in detailed technical aspects and in general questions; Standards review, evaluation and proposals.

WP#5 - Defining measures to overcome barriers for broader market penetration and setting up a long term dissemination plan: identification of market barriers including legal/regulatory, economical and technical, proposals for long term EU level interventions to overcome them, including a new directive on RES-Heat.

WP#6 - Launching a large scale promotional campaign at European level: brochure, poster, promotional text, presentations, interactive Internet site, setting-up the European Geothermal Heat Pump Committee, publications, international conference and exhibition, a series of regional meetings targeting key professional groups.

WP#7 - Common dissemination activities
Project partners

- KANE CRES
  Project Coordinator:
  Centre for Renewable Energy Sources (CRES)

- SVEP
  SVEP Information & Service AB (SVEP)

- ECOFYS
  Ecofys Netherlands b.v. (ECOFYS)

- EGEC
  European Geothermal Energy Council (EGEC)

- AEE
  The Energy Efficiency Agency (EEA)

- European Heat Pump Association (EHPA)

- BESEL
  BESEL S.A. (BESEL)

- Ademe
  Agence de l’environnement et de la Maîtrise de l’énergie (ADEME)

- University of Oradea
  (UOR)

- Escola Superior De Tecnologia De Setubal
  (ESTSetubal)

- Narodowa Agencja Poszanowania Energii S.A. (NAPE)

- BESEL
  BESEL S.A. (BESEL)

- COWI A’S (COWI)

- Fiz Karlsruhe
  Fachinformationszentrum Karlsruhe G mbH

- EnPro Engineers Bureau Ltd (ENPRO)

- Õsterreichisches Forschungs- und Prüfzentrum Arsenal Ges.m.b.H (ARSENAL)

- Geiteam
  Geoteam Technisches Büro für Hydrogeologie, Geothermie und Umwelt Ges.m.b.H (GEOTEAM)

- Bureau de Recherches Géologiques et Minières (BRGM)

- VITO
  Flemish Institute for Technological Research (VITO)

- TERA Energy S.r.l.
  (TERA)