

# Evaluation and Monitoring for the EU Directive on Energy End-Use Efficiency and Energy Services

## EMEEES bottom-up case application 7: Domestic Hot Water – Heat Pumps

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30 April 2009


evaluate energy savings<sup>EU</sup>

coordinated by



**Wuppertal Institute**  
for Climate, Environment  
and Energy

supported by

**Intelligent Energy**  Europe

## The Project in brief

The objective of this project is to assist the European Commission in developing harmonised evaluation methods. It aims to design methods to evaluate the measures implemented to achieve the 9% energy savings target set out in the EU Directive (2006/32/EC) (ESD) on energy end-use efficiency and energy services. The assistance by the project and its partners is delivered through practical advice, technical support and results. It includes the development of concrete methods for the evaluation of single programmes, services and measures (mostly bottom-up), as well as schemes for monitoring the overall impact of all measures implemented in a Member State (combination of bottom-up and top-down).

## Consortium

The project is co-ordinated by the Wuppertal Institute. The 21 project partners are:

Project Partner	Country
Wuppertal Institute for Climate, Environment and Energy (WI)	DE
Agence de l'Environnement et de la Maitrise de l'Energie (ADEME)	FR
SenterNovem	NL
Energy research Centre of the Netherlands (ECN)	NL
Enerdata sas	FR
Fraunhofer-Institut für System- und Innovationsforschung (FhG-ISI)	DE
SRC International A/S (SRCI)	DK
Politecnico di Milano, Dipartimento di Energetica, eERG	IT
AGH University of Science and Technology (AGH-UST)	PL
Österreichische Energieagentur – Austrian Energy Agency (A.E.A.)	AT
Ekodoma	LV
Istituto di Studi per l'Integrazione dei Sistemi (ISIS)	IT
Swedish Energy Agency (STEM)	SE
Association pour la Recherche et le Développement des Méthodes et Processus Industriels (ARMINES)	FR
Electricité de France (EdF)	FR
Enova SF	NO
Motiva Oy	FI
Department for Environment, Food and Rural Affairs (DEFRA)	UK
ISR – University of Coimbra (ISR-UC)	PT
DONG Energy (DONG)	DK
Centre for Renewable Energy Sources (CRES)	EL

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## 1 Summary

### 1.1 Title of the method

Heat pump water heaters for the residential sector

### 1.2 Type of EEI activities covered

End-use EEI action	
Sector	Residential, but also public, tertiary
Energy end-use	Heating of domestic hot water
Efficient solution	Installation of heat pumps leading to ESD energy savings and CO <sub>2</sub> emission reduction
EEI Facilitating measure	
Types of EEI facilitating measures	<ul style="list-style-type: none"> <li>• Financial incentives (all kinds of)</li> <li>• Information tools, focused campaigns, advice</li> <li>• Energy performance contracting</li> <li>• Obligations to install<sup>1</sup></li> </ul>

### 1.3 Detailed definition of EEI activities covered

Installation of heat pumps (HPs) for provision of hot water in residential, public and tertiary buildings, leading to CO<sub>2</sub> emission reduction. The *a priori* applicable facilitating measures are: all kinds of financial incentives, information campaigns, energy performance contracting and possible mandatory measures (cf. footnote 1). In this method we focus on facilitating measures, where EEI programme participants (physical persons or institutions) need to apply individually to obtain support.

The HP heating of domestic hot water (DHW) has to be considered as two technical solutions:

- Stand-alone heat pump (when it can meet the peak demand)
- Heat pump supplementing other heating source (otherwise)

In both cases, energy savings have to be referred to the other (baseline) source, either replaced, or supplemented by HP. The *a priori* “other” heat sources are:

<sup>1</sup> If such an obligation is introduced (cf. Spanish Renewable Energy Plan 2005-2010), the proposed method based on Level 3 data collection through harmonised questionnaires will still apply. Some data in the questionnaires would be replaced by regulations that would have to be specified in the appropriate technical guidelines.

1. Fossil fuel sources

- a) gas boilers (GB),
- b) oil boilers (OB),
- c) coal boilers (CB),

2. Renewable sources

- d) biomass boilers (BMB),
- e) solar collectors (SC),

3. Grid-delivered energy

- f) district (grid) heating (DH) (fossil fuel, geothermal, biomass, etc.),
- g) resistance heating (RH),

or any combinations of (a-g) above. Below, sources (a-g) will be referred to as “*erstwhile sources*”, by which we shall mean the alternative (to HP) or supplemented (substituted) by the HP system.

#### 1.4 General specifications

##### **Conditions for energy savings to be eligible (e.g. compliance with a quality charter or minimum level of energy performance):**

- Installation of the heat pump water heater system in the premises of the EEI programme participant.
- Compliance with the respective EU norms (EN14511:2004 “Electrically driven heat pumps”, EN12309-2:2000 “Gas absorption heat pumps”)
- Furthermore, it would be justified to introduce as another condition (but this requires at least a decision by the European Commission with the ESD Committee:  
Eligibility of the energy savings, if the Total Equivalent Warming Impact (TEWI)<sup>2</sup> of the heat pump system is lower than the TEWI of the *erstwhile* source.

One should note that, as opposed to solar collectors or biomass boilers, the latter criterion is of utmost importance, as otherwise, promotion of heat pumps could be counterproductive for mitigating climate change, i.e., it might lead to increased CO<sub>2</sub> emissions.

<sup>2</sup> For a more detailed explanation of the TEWI concept, see the the Appendix I and references quoted therein.

**Conditions requiring level 2 and 3 efforts for a particular point or for the whole evaluation (e.g. special conditions on a parameter responsible of major uncertainties):**

The proposed method combines all three Levels (1, 2 and 3). The focus is on Level 3, i.e. on the EU harmonised mandatory questionnaire provided by the EEI programme participant with the relevant pre-installation data (e.g. hot water consumption determined by the number of occupants, erstwhile source characteristic, etc.). The other parameters, such as ambient temperature variations for air-to-water HPs, solar fraction for HP+SC combination, grid water temperature, etc., shall be taken at Level 2. Additionally, the volume of *per capita* DHW consumption will be taken at Level 2 (national average) or Level 1 default values (to be decided by the consortium).

### 1.5 Formula for unitary gross annual energy savings

For this method, the unit used in the formula for the unitary gross annual energy savings is an EEI programme participant (a family living in a given house; public/tertiary building of a specified function; etc.).

The unitary gross annual energy savings are given by the equation (S1), used also in section 3, step 1

$$\Delta E_U^{(HP)} = (D - \Delta E_{SC} - \Delta E_{BM} - \Delta E_{FF}) \cdot (1/\eta_{FF} - 1/\eta_{HP}) \quad (S1)$$

If the condition we propose in chapter 1.4 is accepted, this will hold only for

$$TEWI_{HP} < TEWI_{FF} \quad (S1.1)$$

The notation used is:

$$D = n \cdot v \cdot (T_1 - T_0) \cdot \rho \cdot \chi \quad (S1.2)$$

(D is annual heat demand for domestic hot water),

and:

n	number of occupants or users of the building
v	average annual <i>per capita</i> hot water consumption [m <sup>3</sup> /cap/year]
T <sub>1</sub> , T <sub>0</sub>	temperature of hot and cold water, respectively

$\rho$	density of water $\rho = 995,64 \text{ kg/m}^3$ , corresponding to 30°C (i.e. average value between 10 and 50 °C)
$\chi$	specific heat of water, $\chi = 4190 \text{ J/kgK}$
$\Delta E_U^{(HP)}$	annual heat supply provided by an installed heat pump;
$\Delta E_{SC}$	annual heat provided by a solar collector (if installed);
$\Delta E_{BM}$	annual heat provided by a biomass boiler (if installed);
$\Delta E_{FF}$	annual heat derived from fossil fuel boiler (if installed) to meet the heat demand when renewable heat sources are insufficient; it also includes heat purchased from the grid. In the latter case, the corresponding emission factors will have to be used, if e.g. DH is geothermal or biomass;
$\eta_{FF}$	efficiency of the erstwhile fossil fuel boiler
$\eta_{HP}$	efficiency of the heat pump
TEWI	Total Equivalent Warming Impact – defined in Appendix I.

$\Delta E_U^{(HP)}$  is determined by technical design taking into account the COP value, maximum heat output (Level 3) and Level 2 parameters, such as temperature of grid water and the standardised hot water temperature (Level 2 or Level 1).

D is determined by the number of occupants (or users of the building/facility) and the standardised (Level 1 or Level 2) annual *per capita* demand for hot water.

In equation S1  $\Delta E_{SC}$  and  $\Delta E_{BM}$  are mentioned explicitly, because it is assumed that their corresponding TEWI are always smaller than that of the HP<sup>3</sup>.

If condition S1.1 is accepted but not fulfilled,

$$\Delta E_U^{(HP)} = 0, \quad (\text{S1.3})$$

and heat demand D is met by  $\Delta E_{SC}$ ,  $\Delta E_{BM}$  and  $\Delta E_{FF}$ . This also means that if any of the latter has a lower TEWI, the HP energy savings will not be eligible even if the heat pump has been installed.

The TEWI will have to be calculated according to Appendix I for each country (Level 2) separately and for each erstwhile heating source (Level 3). This implies that for each case there will be a minimum COP of the HP system to

<sup>3</sup> This may not be the case for Norway with their fraction of hydro electricity. This and similar cases will have to be considered separately.

meet the eligibility criterion. The examples of the minimum (national) COP values for selected cases are given in the Appendix II.

### 1.6 Indicative default value for unitary gross annual energy savings (when relevant)

In the situation outlined above, setting any EU default values for unitary gross annual energy savings will not be relevant.

### 1.7 Formula for total ESD annual energy savings

If all correction factors are included, the formula for the total ESD annual energy savings will read:

$$\Delta E_{ESD,net}^{(HP)} = \Delta E_{ESD,gross}^{(HP)} * \left( 1 - \alpha_{fr} + \omega_{me} \right) * \xi_{dc} \text{ (equation S2)}$$

where the sum runs over all EEI programme participants.  $\alpha$  and  $\xi$  are in the interval (0, 1), and  $\omega \geq 0$ , and represent the free rider, double counting and multiplier effect, respectively.

### 1.8 Indicative default value for energy savings lifetime

The suggested value is to be taken from as a harmonised EU value according to CEN 15693:2007, as long as the European Commission has not published another set of harmonised or default values. After publication of such values by the Commission, they will be valid.

Energy savings lifetime: EU default/harmonised values	
EU default	
EU harmonised	17 years, taken from CEN 15693:2007

This value is based on

CEN 15693:2007

## 1.9 Main data to collect

Data needed in calculation for <u>EU</u> values (Level 1)	Corresponding data sources
Data 1 Hot water temperature	EU (or national) standard value, e.g. 55C or 60 C
Data 2 Specific CO <sub>2</sub> -equivalent emissions for a given fuel (e.g. natural gas, oil, biomass <sup>4</sup> for determination of TEWI)	For example, values used in ETS
Data 3 Harmonised average <i>per capita</i> hot water consumption	EU-common value or weighted average of national averages <sup>5</sup>
Data 4 Time intervals for averaging grid (cold) water temperatures	The proposal is: March 21 - September 22 (for “summer” season) and September 23 – March 20 (for “winter” season) <sup>6</sup>

Data to be collected <u>national values</u> (Level 2)	Corresponding data sources
Data 1 National emission factors	Official national data
Data 2 Monthly averages of ambient temperature (particularly important for air-to-water HPs)	Simulation based on meteorological files
Data 3 Grid water (cold water) temperature averaged over defined periods of time (e.g.months)	Data exist in many cases. If not, they are very easy to collect
Data 4 Average <i>per capita</i> hot water consumption (if Data 3 in Level 1 is not accepted)	See above
Data 5	Average real life COP of different types of heat pumps over the year; average energy efficiency of replaced erstwhile hot water boiler

Data to be collected <u>measure-specific</u> (or participants-specific) (Level 3)	Corresponding data sources
Data 1 Number of occupants (or users of building/facility)	EU harmonised questionnaire provided by an EEI programme participant

<sup>4</sup> If energy embedded in e.g. pellet production is attributed to fossil fuels

<sup>5</sup> **Note:** as seen in Fig. 2 of the case application 6 on solar water heaters, the differences between the national averages of hot water use are dramatic. This would mean that taking national averages would favour a lavish use of hot water, which should not be promoted. Therefore, a better solution would be to take as harmonised value the EU average (possibly weighted by the population numbers). One can also consider taking a fraction of that value (say 80%).

<sup>6</sup> One could also consider an equivalent to degree-days for the difference between hot water temperature and daily (or weekly) average cold water temperature.

Data 2 Erstwhile heat source characteristics (including solar fraction for combined HP+SC)	
Data 3 Building characteristics to include in-door hot water distribution system losses	

Apart from the data, the proposed method heavily relies on the EU harmonised calculation procedures (algorithms).

## 2 Introduction

### 2.1 Twenty bottom-up case applications of methods

Within EMEES, task 4.1 provided methodological materials in the internal working paper “Definition of the process to develop harmonised bottom-up evaluation methods”, version 20 April 2007; an update has been published as an Appendix to the report on Bottom-up methods at [www.evaluate-energy-savings.eu](http://www.evaluate-energy-savings.eu). Based on this draft report, concrete bottom-up case applications were developed by EMEES partners within task 4.2, and reference values were to be specified within task 4.3.

This report deals with case application 7 “Domestic Hot Water – Heat Pumps” developed by AGH University of Science and Technology.

Eleven project partners have developed concrete bottom-up case applications for a specific type of technology or energy efficiency improvement measure or end-use action. All gave comments and input to the methods developed by the other organisations.

The 20 case applications developed are presented in the table below:

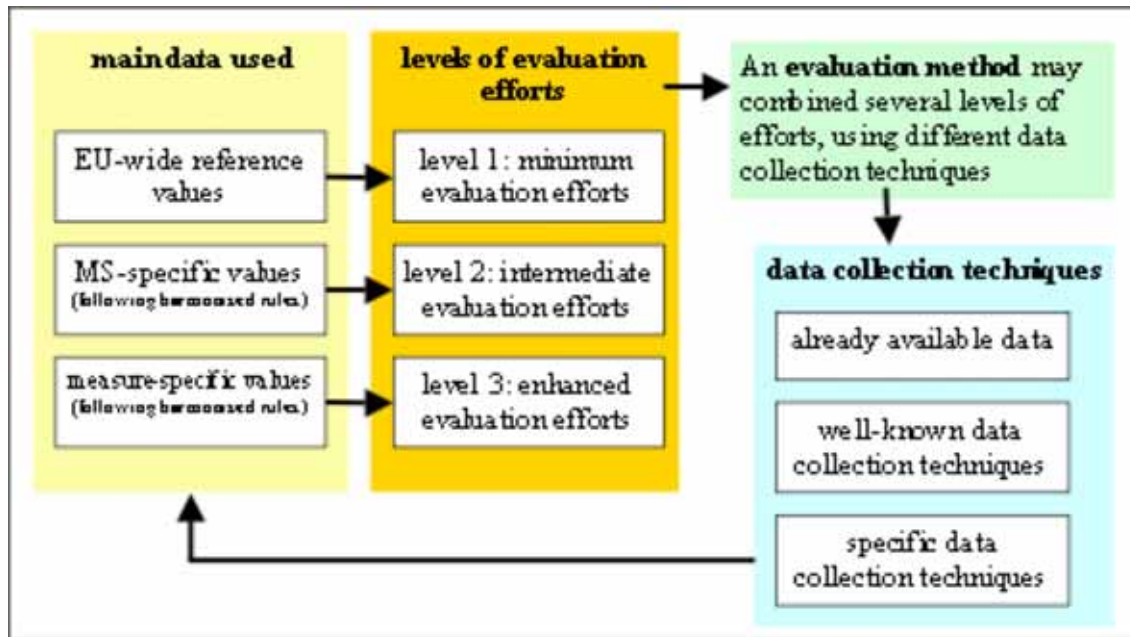
N°	End-use or end-use action, technology, or facilitating measure	Sector	Responsible organisation
1	Building regulations for new residential buildings	Residential	SenterNovem
2	Improvement of the building envelope of residential buildings	Residential	AEA
3	Biomass boilers	Residential	AGH-UST
4	Residential condensing boilers in space heating	Residential	Armines
5	Energy efficient cold appliances and washing machines	Residential	ADEME
6	Domestic Hot Water – Solar water heaters	Residential	AGH-UST
7	Domestic Hot Water - Heat Pumps	Residential	AGH-UST
8	Non residential space heating improvement in case of heating distribution by a water loop	Tertiary	eERG
9	Improvement of lighting systems	Tertiary (industry)	eERG
10	Improvement of central air conditioning	Tertiary	Armines

N°	End-use or end-use action, technology, or facilitating measure	Sector	Responsible organisation
11	Office equipment	Tertiary	Fraunhofer
12	Energy-efficient motors	Industry	ISR-UC
13	Variable speed drives	Industry	ISR-UC
14	Vehicle energy efficiency	Transport	Wuppertal Institute
15	Modal shifts in passenger transport	Transport	Wuppertal Institute
16	Ecodriving	Transport	SenterNovem
17	Energy performance contracting	Tertiary and industry end-uses	STEM
18	Energy audits	Tertiary and industry end-uses	Motiva
19	Voluntary agreements – billing analysis method	Tertiary and industry end-uses	SenterNovem
20	Voluntary agreements with individual companies – engineering method	Tertiary and industry end-uses	STEM

## 2.2 Three levels of harmonisation

In order to be as practicable as possible and to stimulate continued improvement, the harmonised reporting on bottom-up evaluation is structured on three levels (cf. figure 1).

Figure 1: Three levels of harmonisation



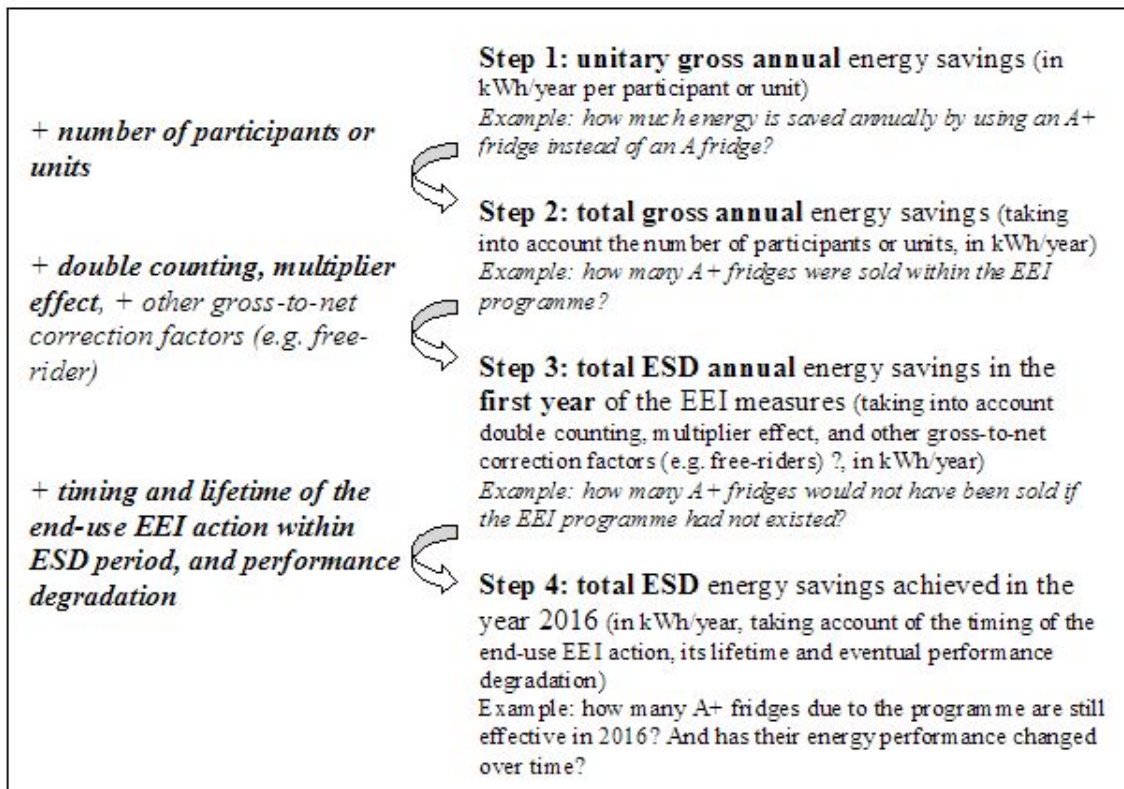
As a consequence, the EMEES case applications for bottom-up evaluation methods present:

- EU wide reference values, if applicable;
- Guidelines how Member States can use country-specific values following harmonised rules;
- Guidelines how measure- or action-specific (national) values can be developed, following harmonised rules.

### 2.3 Four steps in the calculation process

The harmonised rules for bottom-up evaluation methods are organised around four steps in the calculation process (cf. figure 2). These steps are presented in detail in the report for WP 4.1.

Figure 2: Four steps in the calculation process



The reports on the concrete bottom-up case applications follow the format of these four steps and they each hold six chapters plus some annexes:

1. summary
2. introduction
3. step 1: unitary gross annual energy saving
4. step 2: total gross annual energy savings
5. step 3: total ESD annual energy savings
6. step 4: total ESD energy savings for year “i”

## 2.4 Pilot tests

Additional to the development of the 20 bottom-up case applications, some of these cases were tested in practice in Work Package 8.

Pilot tests of the following case applications were performed by EMEEES partners in Italy, France, Denmark, and Sweden:

EMEEES case application	Sector	Italy	France	Denmark	Sweden
Building envelope improvement	Residential		X		
Energy-efficient white goods	Residential	X			
Biomass boilers in the residential sector	Residential		X		
Condensing Boilers	Residential	X	X		
Improvement of lighting system	Tertiary (industry)				X
High efficiency electric motors	Industry	X			
Variable speed drives	Industry	X			
Energy audits	Tertiary and industry end uses			X	
Energy performance contracting	Tertiary and industry				X

The following EEI measures were evaluated ex-post using the above-mentioned EMEEES bottom-up case applications:

Country	Subject	Sector(s) addressed
France	Condensing boilers, building envelope improvements and compact fluorescent lamps under the French White Certificates.	Residential
Italy	Schemes under the Italian White Certificates system	Residential, tertiary, industry
Sweden	Energy Efficiency Investment Programme for Public Buildings (2005-2008)	Public non-residential buildings
Denmark	Energy audits performed in Denmark between 2006 and 2008	Industry, tertiary

As a result of the pilot tests, some of the case applications tested were updated to reflect the findings of the tests.

### 3 Step 1: Unitary gross annual energy savings

#### 3.1 Step 1.1: General formula and calculation model

For this method on *Domestic Hot Water – Heat Pumps*, the unit is an EEI programme participant (a family living in a given house; public/tertiary building of a specified function; etc.).

unitary gross annual energy savings =

$$\Delta E_U^{(HP)} = (D - \Delta E_{SC} - \Delta E_{BM} - \Delta E_{FF}) \cdot (1/\eta_{FF} - 1/\eta_{HP})$$

(equation 1)

The notation used is:

$$\Delta E_U^{(HP)} = (D - \Delta E_{SC} - \Delta E_{BM} - \Delta E_{FF}) \cdot (1/\eta_{FF} - 1/\eta_{HP}) \quad (S1.2)$$

(D is annual heat demand for domestic hot water),

and:

n	number of occupants or users of the building
$\square$	average annual <i>per capita</i> hot water consumption [m <sup>3</sup> /cap/year]
T <sub>1</sub> , T <sub>0</sub>	temperature of hot and cold water, respectively
$\square$	density of water
	$\rho = 995,64 \text{ kg/m}^3$ , corresponding to 30°C (i.e. average value between 10 and 50 °C)
$\chi$	specific heat of water, $\chi = 4190 \text{ J/kgK}$
$\Delta E_U^{(HP)}$	annual heat supply provided by an installed heat pump;
$\Delta E_{SC}$	annual heat provided by a solar collector (if installed);
$\Delta E_{BM}$	annual heat provided by a biomass boiler (if installed);
$\Delta E_{FF}$	annual heat derived from fossil fuel boiler (if installed) to meet the heat demand when renewable heat sources are insufficient; it also includes heat purchased from the grid. In the latter case, the corresponding emission factors will have to be used, if e.g. DH is geothermal or biomass;
$\eta_{FF}$	efficiency of the erstwhile fossil fuel boiler
$\eta_{HP}$	efficiency of the heat pump
TEWI	Total Equivalent Warming Impact – defined in Appendix I.

$\Delta E_U^{(HP)}$  is determined by technical design taking into account the COP value, maximum heat output (Level 3) and Level 2 parameters, such as temperature of grid water and the standardised hot water temperature (Level 2 or Level 1).

D is determined by the number of occupants (or users of the building/facility) and the standardised (Level 1 or Level 2) annual *per capita* demand for hot water.

In equation S1  $\Delta E_{SC}$  and  $\Delta E_{BM}$  are mentioned explicitly, because it is assumed that their corresponding TEWI are always smaller than that of the HP<sup>7</sup>.

If condition S1.1 is not fulfilled,

$$\Delta E_U^{(HP)} = 0, \quad (S1.3)$$

and heat demand D is met by  $\Delta E_{SC}$ ,  $\Delta E_{BM}$  and  $\Delta E_{FF}$ . This also means that if any of the latter has a lower TEWI, the HP energy savings are not eligible even if the heat pump has been installed.

The TEWI will have to be calculated according to Appendix I for each country (Level 2) separately and for each erstwhile heating source (Level 3). This implies that for each case there will be a minimum COP of the HP system to meet the eligibility criterion. The examples of the minimum (national) COP values for selected cases are given in the Appendix II.

### 3.2 Step 1.2: Baseline

The baseline is the individual situation before the installation of a heat pump, determined basically by the erstwhile heat source, with taking into account Level 1 or Level 2 values when appropriate (as indicated in the table below).

There will be no difference between the baseline for all and additional energy savings. The baseline will also be dynamic automatically, if the individual baseline is taken. If national averages are used (e.g., for erstwhile boiler efficiency), they should be adapted to changes from time to time.

<sup>7</sup> This may not be the case for Norway with their fraction of hydro electricity. This and similar cases will have to be considered separately.

level 1	EU default values for calculation of the baseline: i) <i>Per capita</i> hot water consumption: 10 m <sup>3</sup> /year/cap ii) the EU-standard hot water temperature of 55C (or 60C – proposed for consideration) iii) potentially: efficiency values for erstwhe boiler taken from case application 4 on condensing boilers
level 2	guidelines ( <i>how to define a MS-specific baseline</i> ): data required: see section 1.9 and grid (cold) water temperature determined at Level 2
level 3	guidelines: ( <i>how to define a measure-specific baseline</i> ) EU harmonised questionnaire and a common computer model for processing the input data into ESD energy savings data required: see section 1.9

### 3.3 Step 1.3: Requirements for normalisation factors

(new) normalisation factor 1a – Seasonal averages of grid (cold) water	
level 1	Averaging cold water temperature over “winter” and “summer” season (see section 1.9).
level 2	n.a.
level 3	n.a.

(new) normalisation factor 1b – Degreedays (or degreeweeks) for domestic hot water	
level 1	n.a.
level 2	guidelines: ( <i>how to include the normalisation factor in calculation model or how to calculate a level 2 coefficient of normalisation</i> ) Either average cold water temperature averaged in two time intervals: March 21 - September 22 (for “summer” season) and September 23 – March 20 (for “winter” season). Else, one could consider use a number equivalent to degreedays, calculated for the difference between standarised hot water temperature and daily (or weekly) average cold water temperature. data required: as specified in 1.9
level 3	n.a.

### 3.4 Step 1.4 Specifying the calculation method and its three related levels

level 1	Mix of deemed and ex-post: The use of the EU common computer model evaluating ESD savings based on Level 2 and <u>aggregated</u> Level 3 data, with level 1 harmonised value for hot water use per year.
level 2	Mix of deemed and ex-post: national average values for some parameters (cf. section 1) based on the creation of national databases of: <ul style="list-style-type: none"> <li>• ESD savings results, corresponding to a particular EEI facilitating measure for evaluation, planning and possible improvement</li> <li>• input values, reported in the questionnaires for research and planning</li> </ul>
level 3	Enhanced engineering calculation, with the use of EU harmonised questionnaire

### 3.4.1 Conversion factors

n.a. (no special conversion factors needed, ESD Annex II is valid for the replaced fuels and for electricity)

### 3.4.2 Considering the direct rebound effect

*The direct rebound effect is not explicitly mentioned in the ESD. It is created by final energy consumers who increase the intensity of the use of energy-efficient equipment after an EEI measure, e.g., when the internal temperature of a building is increased after insulation. This reduces the energy savings achieved in comparison to the baseline of autonomous consumption changes. Consequently, including energy savings “eaten up” by the direct rebound effect in the total ESD annual energy savings would mean to include too high energy savings compared to the autonomous energy consumption changes. It has not yet been decided by the European Commission and the ESD committee, whether this effect shall be included in the total ESD annual energy savings or eliminated from them. In the latter case, the following requirements apply.*

In the proposed method, the direct rebound effect is automatically eliminated by referring the savings to an average annual *per capita* consumption of hot water defined at an EU-standard level. In this way, any savings that would otherwise be attributed to the excess of hot water above this ceiling will not be counted as ESD savings.

### 3.4.3 From EMEES tasks 4.2 to 4.3: defining values and requirements

#### 3.4.3.1 Default values for energy consumption and/or related parameters

- *Per capita* hot water consumption: 10 m<sup>3</sup>/year/cap
- Standard hot water temperature ( $T_1$ ) of 55C (or 60C – proposed for consideration) and grid (cold) water temperature ( $T_0$ ) determined at Level 2

#### 3.4.3.2 Requirements to define level 2 and level 3 values

The method is mainly based on an individual level 3 calculation, with a harmonised calculation model and some level 1 input values possible (see section 3.4.3.1 above). For situations that are comparable, e.g., single family houses or flats with an individual heat pump in the same region or with a ground source heat pump, the evaluation of a large enough sample could lead to definition of national average values for the efficiency of both a range of erstwhile boilers and heat pumps (level 2).

Furthermore, if accepted, the basic eligibility criterion specified in section 1.5,

$$TEWI_{HP} < TEWI_{FF},$$

will define a threshold value of COP for the national (Level 2) emission factor and for a given erstwhile heat source (Level 3). The requirement is availability of the above data.

## 4 Step 2: Total gross annual energy savings

### 4.1 Step 2.1: Formula for summing up the number of actions

For this method, the unit used in the formula for the unitary gross annual energy savings is an EEI programme participant (a family living in a given house; public/tertiary building of a specified function; etc.). The formula for summing up the number of actions is:

$$\Delta E_{ESD, gross}^{(HP)} = \sum_j \Delta E_{U, j}^{(HP)} \quad (2)$$

where the sum runs over all EEI programme participants.

### 4.2 Step 2.2: Requirements and methods for accounting for the number of actions

The proposed methodology is based on the case-by-case data provided by individual participants, therefore the number of actions is readily available.

Those data are then entered into a database and supplemented there by the appropriate default/average values needed for Eq.(S1).

Subsequently, the evaluation of the total annual gross energy savings becomes straightforward (automatic) and easy, as it does not require any post-investment measurements or monitoring. The gross annual savings are then given by a sum over all participants.

The additional benefit of the proposed methodology, apart from the ESD reporting simplicity, is its potential usefulness for introducing corrections to the promotion schemes that may increase their efficiency.

## 5 Step 3: Total ESD annual energy savings

In this section, the correction factors required by the ESD and potential further correction factors are dealt with. Applying these factors will allow to calculate the total ESD annual energy savings from the gross annual energy savings calculated in step 2.

### 5.1 Step 3.1: Formula for ESD annual savings

If all correction factors are included, the formula for total net ESD annual energy savings, corrected for the free-rider,  $\alpha_{fr}$ , multiplier effect,  $\omega_{me}$ , and double-counting,  $\zeta_{dc}$ , factors will read:

$$\Delta E_{ESD,net}^{(HP)} = \Delta E_{ESD,gross}^{(HP)} * \left(1 - \alpha_{fr} + \omega_{me}\right) * \zeta_{dc} \quad (3)$$

where  $\alpha$ ,  $\omega$ ,  $\zeta$  are in the interval (0, 1). Their particular values are discussed below following the approach of case application 12 on electric motors.

### 5.2 Step 3.2: Requirements for avoiding double counting

EMEEES case application 12 suggests the following approach:

5.2.1 *“double counting can best avoided by cross-cutting available information in a central database of registered participants and the equipment (...) installed (...).”*

This approach would be perfectly feasible in the method proposed here. As we suggest, the Level 3 data should converge at the “National ESD Evaluation Centres” (one per MS, e.g., the authorities according to article 4(4) ESD), where corrections for  $\omega$  and  $\zeta$  could possibly be estimated. Otherwise, following again the case application 12:

5.2.2 (...) *How to address double counting when reporting results:*

- *Group (EEI) facilitating measures targeting the same type of end-use action in a single package, reporting one global result by end-use action, or*
- *Associate each targeted end-use with a particular facilitating measure or programme, allocating the corresponding energy savings only to this measure. “*

In this method the latter solution should be favored. If one of the facilitating measures is a financial support of any kind, it is most likely that all people intending to invest in an EEI measure, who have been reached by an

information, education or advice campaign will apply for such support, which practically means

$$\xi=1$$

Assuming additionally that  $\alpha$  and  $\omega$  roughly cancel with each other or/and are both small Eq.(3) will read

$$\Delta E_{ESD,net}^{(HP)} = \Delta E_{ESD,gross}^{(HP)} \quad (4)$$

which should be a sufficient approximation of the net ESD savings. For further remarks concerning  $\omega$  see step 3.4.

### 5.3 Step 3.3: Requirements for taking account of technical interactions

The technical interactions are accounted for in Eq.(1) and described in section 1.3 and quantitatively illustrated in Appendix 2. The evaluation will be possible on the basis of the data provided in the applicant's questionnaire.

### 5.4 Step 3.4: Requirements for multiplier energy savings

If the idea of the National ESD Evaluation Centres is accepted and implemented, the trend of the time variation of the number of EEI programme participants can be followed and extrapolated into the future, by numerical fitting of the observed data to an assumed analytical formula for the time dependence. They can be verified by ex-post evaluation through e.g. sales data analyses or surveys among representative samples of (non-)participants.

### 5.5 Step 3.5: Requirements for the free-rider effect

*The free-rider effect is not explicitly mentioned in the ESD. Free riders are final energy users who are counted when monitoring the effects of facilitating measures but would have taken the end-use actions promoted also without the facilitating measure. Consequently, including energy savings achieved by free riders in the total ESD annual energy savings would mean to include a part of the autonomous energy efficiency improvements. It has not yet been decided by the European Commission and the ESD committee, whether this effect shall be included in the total ESD annual energy savings or eliminated from them. In the latter case, the following requirements apply.*

The proposal is to make an *ex post* anonymous inquiry asking one “YES/NO” question whether the participant would have installed the heat pump without the EEI programme. Technically, it could be done by mailing a small questionnaire to a sample of participants (possibly to all, the cost wouldn’t be high) with an addressed and prepaid return envelope. The questionnaire could also include questions helping to evaluate the multiplier effect, e.g. : “if you moved to another house would you install a heat pump in absence of the programme?” “Why?”.

## 6 Step 4: total ESD energy savings for 2010 and 2016

The ESD text is interpreted so that only for those EEI measures that have not reached the end of their energy saving lifetime in the years of the intermediate (2010) and final (2016) targets, energy savings will be counted towards a Member State's intermediate or final energy savings target under the ESD.

### 6.1 Requirements for the energy saving lifetime

The value of 17 years is suggested for the energy saving lifetime. It is to be taken as a harmonised EU value according to CEN 15693:2007. It will be replaced, if the European Commission with the ESD Committee publishes a list of harmonised lifetimes.

### 6.2 Special requirements for early actions

*The definition of early actions may include two possibilities (to be clarified by the European Commission and the ESD Committee):*

- *early (EEI) facilitating measures, and only those energy savings that result from end-use actions that are implemented during 2008-2016, as a result of these facilitating measures that still have a lasting effect during 2008-2016, are eligible*

OR

- *early energy savings from end-use actions initiated between 1995 and 2008, with the end-use actions having a lasting effect in 2010 (for the intermediate target) or 2016 (for the overall target).*

If early energy savings are accepted, a contribution to the target in 2016 can only be counted if the energy saving lifetime is greater than 8 years plus the time between installation and 2008. This needs to be proven. The same holds, respectively, for the intermediate target in 2010.

The lifetime of the average heat pump exceeds 15 years. Therefore, savings due to installations realised before the 2010 ( $T_{2010}$ ) or 2016 ( $T_{2016}$ ) can be included by the Member States in their reported ESD savings, if early savings are admitted. In this case, they could be considered eligible as from

$$T < T_{i-17} \quad (6)$$

where  $i = 2010$ , or  $i = 2016$ , respectively.

### 6.3. How to treat uncertainties

In general, evaluation of savings involves uncertainties on all input parameters, except for physical constants or rigidly fixed default values. In the proposed method, the most relevant data are obtained directly from the EEI programme participant (Level 3), entered into national databases (Level 2), and then processed according to the EU harmonised (common) calculation procedures. Therefore, assuming coherence and uniformity of algorithms in the national centres across EU, the level of uncertainties in the calculation of savings will be relatively low, as compared with other evaluation methods.

Once the algorithm for calculation of  $\Delta E_{U,j}$  is agreed upon, the formula for  $\Delta E_{U,j}$  (Eq. S1) can be in principle written in an analytical form. Therefore the associated uncertainty can be expressed by the standard formula for propagation of errors:

$$\delta \left[ \Delta E_{U,j}(n, \nu, T_{hot} - T_{cold}) \right] = \left| \frac{\partial D}{\partial n} \delta n \right| + \left| \frac{\partial D}{\partial \nu} \delta \nu \right| + \left| \frac{\partial D}{\partial T_h - T_c} \delta(T_h - T_c) \right| + \delta E_{SC} + \delta E_{BM} + \delta E_{FF} = \rho \chi [ \nu \Delta T * \delta n + n \Delta T * \delta \nu + n \nu * \delta T_{cold} ] + \delta E_{SC} + \delta E_{BM} + \delta E_{FF} \quad (\text{Eq.7})$$

where:

$\delta n$ ,  $\delta T_{cold}$  can be taken as standard deviations of the respective probability distributions, while  $\delta \nu$  is 0, as  $\nu$  is a fixed default number.

Contrary to what may seem at a first glance, using Eq. 7 will be straightforward by using a single formula, accepted once for the whole EU .

Analogously, using the standard approach, the uncertainty of the total savings can be estimated as:

$$\delta\Delta E_{ESD, gross}^{(HP)} = \sqrt{\frac{\sum_j^{N_p} (\delta\Delta E_{U, j})^2}{N_p (N_p - 1)}} \quad (8)$$

where  $N_p$  is the number of EEI programme participants.

A bigger (low to medium) level of uncertainty may be related to some Level 2 parameters, such as ambient temperature variations, and grid water temperature.

Following the remarks in sections 3.4.2 and 5.2, the errors related to the direct rebound effect and the double counting effect in the proposed method are eliminated or reduced to a negligible level.

As to the evaluation of the uncertainty of the free-rider fraction (its magnitude and arbitrary nature of its assesment), it should be decided by the Commission, whether it is to be included or not.

Concerning the double counting, it is recommended, (cf. Section 5.2.2. above) to associate the heat pump instalation with the facilitating measure in which EEI programme participants must file individual applications (cf. case application 14), and allocate the corresponding energy savings only to this measure (cf. also case application 12).

## 7 References

- [1] CEN 15693:2007 “*Saving lifetimes of Energy Efficiency Improvement Measures in bottom-up calculations*”;
- [2] Forsen M. „*Heat Pumps. Technology and Environmental Impact*”, July 2005
- [3] Kapuscinski J., Rodzoch A. „*Geotermia niskotemperaturowaw Polsce – stan aktualny i perspektywy rozwoju*” (Low Temperature Geothermal Systems in Poland – Present Status and Perspective), Warsaw, October 2006;
- [4] “*Wartosci opalowe i wskaźniki emisji CO<sub>2</sub> w roku 2005 do raportowania w ramach Wspolnotowego Systemu Handlu Uprawnieniami do Emisji za rok 2008*”, (Report of the National Agency for the Emission Trading Scheme)  
[www.kashue.pl](http://www.kashue.pl);

## Appendix I: The TEWI Concept

*Following the same frame as the description of the method, and providing justifications and sources for each choice and default value, using existing data and examples of evaluation methods targeting the same subject wherever possible.*

Heat pumps require electrical energy to operate. Production of electricity in power plants is connected with GHG emission, therefore environmental evaluations of heat pump applications need to take into account the emissions related to electricity generation. One of the methods established to calculate the contribution of GHG emissions attributable to heat pumps is the Total Equivalent Warming Impact, TEWI, developed at Oak Ridge National Laboratory in the USA in the early nineties. The TEWI calculation integrates direct and indirect GHG emissions over the whole lifetime of a heat pump into a single number expressed in terms of CO<sub>2</sub> mass equivalents [Forsen, 2005].

$$TEWI_{HP} = \underbrace{(n \times L \times m \times GWP)}_{\substack{\text{direct emissions} \\ \text{due to leakage}}} + \underbrace{(n \times E_{annual} \times EF)}_{\substack{\text{indirect emissions} \\ \text{related to electricity} \\ \text{generation}}} + \underbrace{(L_{demolition} \times m \times GWP)}_{\substack{\text{direct emissions} \\ \text{at demolition}}, \quad (1A)$$

where

TEWI <sub>HP</sub>	Total Equivalent Warming Impact of a heat pump [kg CO <sub>2</sub> ]
n	equipment lifetime [years]
L	annual leakage rate [%]
m	refrigerant charge [kg]
GWP	global warming potential [kg CO <sub>2</sub> /kg refrigerant]
E <sub>annual</sub>	annual energy use [kWh/year]
EF	emission factor driving energy [kg CO <sub>2</sub> /kWh]
L <sub>demolition</sub>	refrigerant losses during demolition [%]

According to Forsen, emissions related to electricity generation constitute in Europe 97,8 %<sup>8</sup> on average, which is the largest contribution to GHG emissions attributable to HPs.

<sup>8</sup> Forsen assumed: heat demand = 24 MWh/year (heating), COP = 3 (seasonal performance factor), refrigerant charge = 1,8 kg, annual leakage rate = 2%, refrigerant losses at demolition = 15%, equipment lifetime = 15 years

Consequently, in further calculations, the direct emissions, due to leakage and those released during demolition, will not be taken into account. The annual value of TEWI becomes then:

$$TEWI_{HP} = E_{annual} \times EF = (HD \times EF)/COP, \quad (2A)$$

where:

HD	heat demand [kWh]
COP	coefficient of performance (seasonal performance factor)

On the other hand, calculation of TEWI for traditional boilers can be conducted according to the following formula:

$$TEWI_B = (3,6 \times HD \times \kappa)/\eta_b, \quad (3A)$$

where:

$\kappa$	CO <sub>2</sub> equivalent emission per unit energy of burned fuel [kg CO <sub>2</sub> /MJ]
$\eta_b$	boiler efficiency

In most cases, TEWI for heat pumps is much lower than for other heating systems (gas boilers, oil boilers, etc.). However, calculations made by Forsen show that application of heat pump systems needs not always to reduce GHG emission, as it is dependent on emission factor of power plants supplying the heat pump with electricity. In countries where electricity is generated in old, power plants, in which emission factor, EF, is high, the TEWI<sub>HP</sub> value may be higher than that of a conventional efficient gas (or oil) boiler.

It is obvious that in countries like Norway, where almost 100 % of the electricity is produced in hydro power plants, the Total Equivalent Warming Impact is marginal. However, in countries where electricity generation is heavily dependent on fossil fuels, the TEWI value will be significantly higher. Therefore, the TEWI should be taken into consideration as eligibility criterion for installation of heat pump applications. It is already taken into account in e.g. Germany, Austria and Switzerland as one of the criteria of certification of heat pumps (eco-labelling) [Kapuscinski and Rodzoch].

Values of emission factors in the European countries are given in the table below.

Country	kg CO <sub>2</sub> /kWh <sub>el</sub>
Norway	0,005
Sweden	0,04
Switzerland	0,08
France	0,09
Austria	0,22
Finland	0,24
Belgium	0,29
European average	0,47
Spain	0,48
Hungary *	0,55
Italy	0,59
Germany	0,61
Turkey	0,62
Netherlands	0,64
Portugal	0,64
U.K.	0,64
Bulgaria *	0,683
Ireland	0,7
Denmark	0,84
Greece	0,98
Poland *	1,028
Luxemburg	1,08
Slovakia *	1,2

Source: Forsen 2005 and (\*) means private communication

For each Member State, according to their national emission factor, one can calculate a lower-bound value of COP, below which

$$TEWI_{HP} > TEWI_B$$

(i.e. installation of traditional high-efficient boiler would bring more emission reduction than installation of a heat pump system).

A comparison of Total Equivalent Warming Impact of various types of heat pumps (i.e. with different COP) with different types of the erstwhile heat sources (gas, oil, coal and biomass boilers) in selected European countries is shown in the figures of Appendix II.

## Appendix II

*Reference to existing requirements from other methods (or general requirements for all methods).*

A comparison of Total Equivalent Warming Impact, TEWI, of various types of heat pumps (i.e. with different COP) with different types of erstwhile heat sources (gas, oil, coal and biomass boilers) in selected European countries is shown in the figures below.

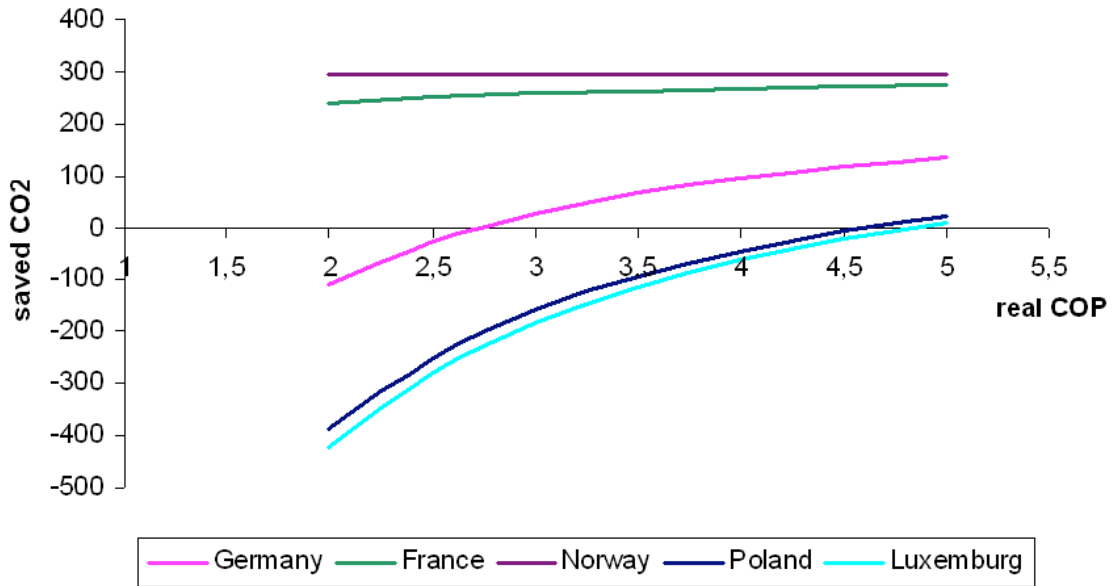
“CO<sub>2</sub> saved” was calculated as a difference between TEWI for the boiler and that for the heat pump.

$$CO_2 \text{ saved} = TEWI_B - TEWI_{HP} \quad [\text{kg CO}_2]$$

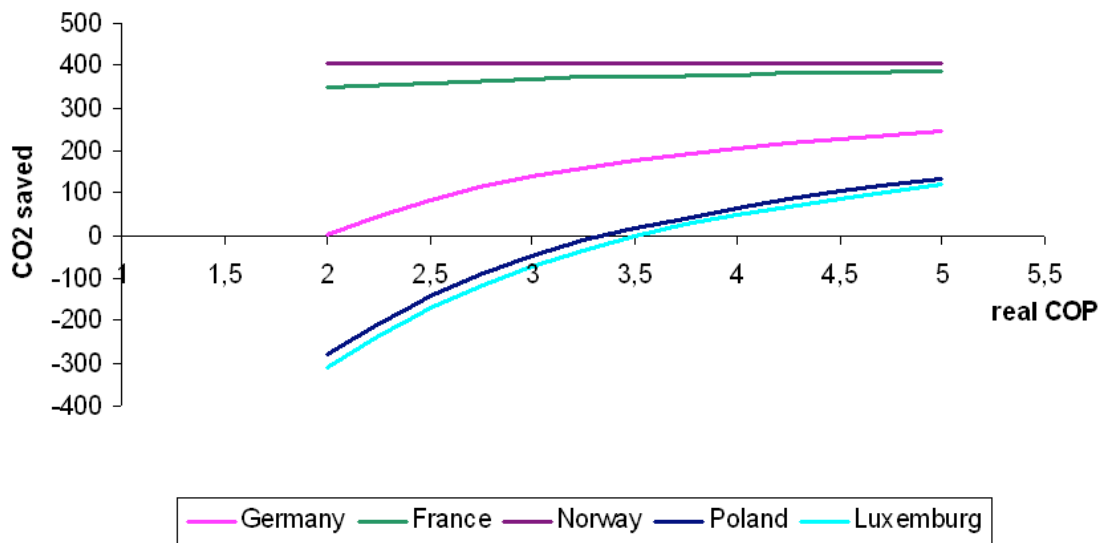
In this way, it is shown that, if “CO<sub>2</sub> saved” value is positive, the installation of heat pump system in a given country brings GHG emission reduction. The intersection point of the curves with the horizontal axis gives the minimum real life average COP value throughout the year (‘real COP’, by country), for which installation of heat pump system would be eligible.

It should be noted that these calculations are mainly valid for heat pumps producing domestic hot water, which run throughout the year, so the emission factor for their electricity consumption can be assumed to be similar to the average emission factors given in Appendix I. However, for heat pumps used for space heating, which run only during the heating season, their emission factor is likely to be higher, since their electricity consumption is more concentrating in peak or medium-peak hours.

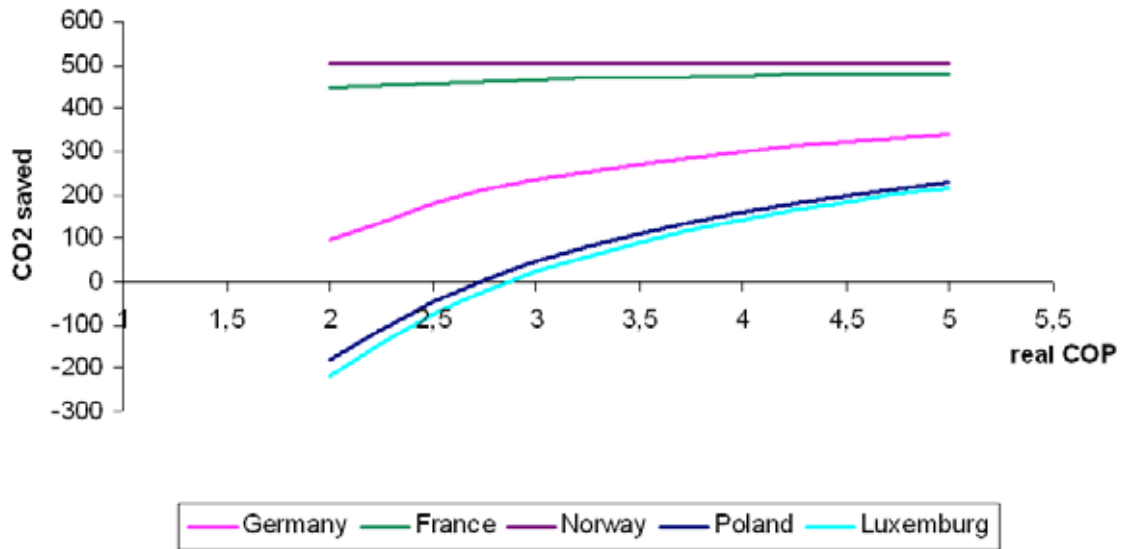
for gas boilers



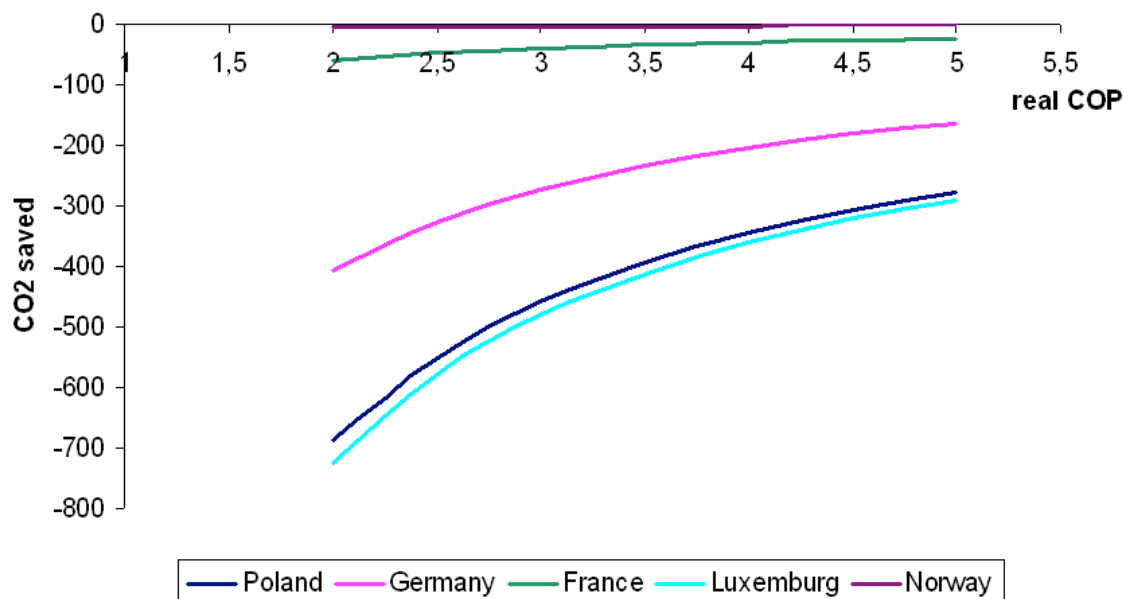
for oil boilers



for coal boilers



for biomass boilers



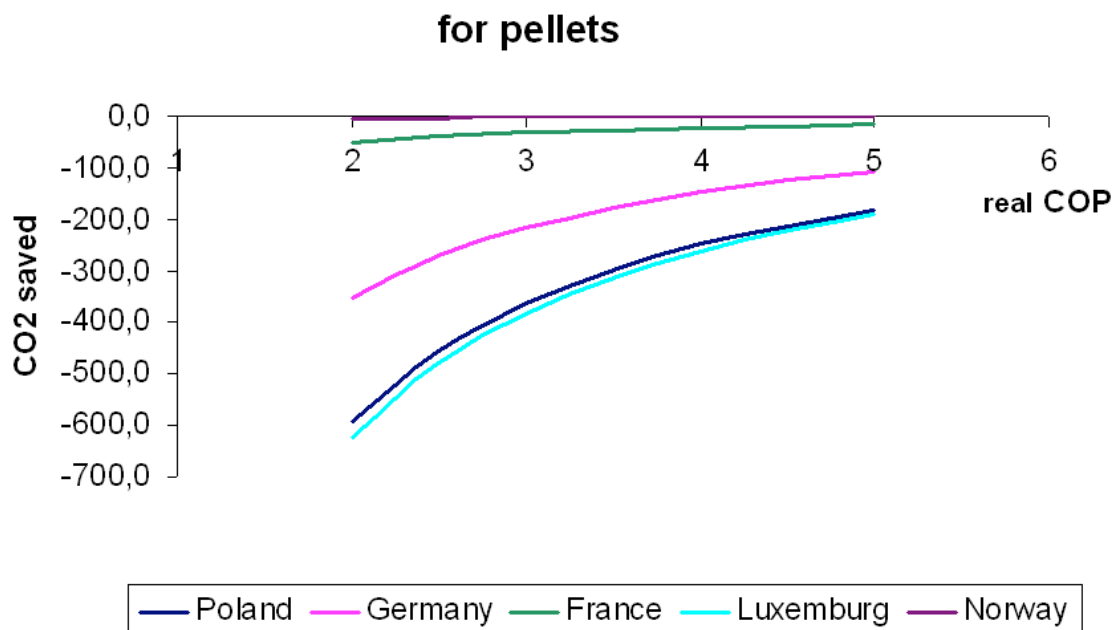
Note:

For all calculations in this comparison, the following assumptions were made:

- efficiency of all erstwhile boilers  $\eta_b = 0,9$

- the  $TEWI_{HP}$  and  $TEWI_B$  values were calculated according to equations (2A) and (3A) in Appendix I, respectively.
- The following  $\kappa$  values were assumed<sup>9</sup>
  - $\kappa_{gas} = 0,05582 \text{ kg CO}_2/\text{MJ}$
  - $\kappa_{oil} = 0,07659 \text{ kg CO}_2/\text{MJ}$
  - $\kappa_{coal} = 0,0945 \text{ kg CO}_2/\text{MJ}$
  - $\kappa_{biomass} = 0 \text{ kg CO}_2/\text{MJ}$

In the latter, it was assumed that biomass is emission-free. However, one may wish to take into account embedded energy in biomass processing (e.g. production of pellets), which may be attributed to fossil fuels. According to Drobnik 2007, (electrical) energy used for production of pellets is ca. 1 GJ per tonne of pellets. Bearing that in mind, the annual  $\text{CO}_2$  emissions attributable to pellets (for the assumed heat demand) differ between 0,46 kg (for Norway) and 99,51 kg (for Luxemburg). The results of the calculations are shown in the figure below.



<sup>9</sup> The assumed values are emission factors of fuels in the year 2005, used for reporting under Emission Trading Scheme in 2008 in Poland [4]