Quantified potential for residential building renovations approaching NZE standards in EU

Deliverable D.5.3

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DOCUMENT AUTHORS AND AUTHORISATION	
Lead	Holger Wallbaum (Chalmers)
Contributor(s)	Javier Casco Company, Claudio Nägeli, Mohamad Kharseh (Chalmers)
Reviewed by	Justus von Geibler (Wuppertal Institute), Miguel Fontela Martinez (Exeleria), Steven Fawkes (EnergyPro)
Authorised by	Izabela Kurkowska (Project Manager)

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Executive summary

The goal of this deliverable is to evaluate the energy saving and greenhouse gas emission reduction potential of the European building stock utilising the renovation measures implemented in the three pilot sites of the DREEAM project. In the first chapter of this report, the modelling strategy is explained. Following that a chapter about the model results on a European scale is provided.

An Excel-based building stock model (BSM), originally developed at ETH Zurich, Prof. Holger Wallbaum [1, 2, 3, 4] and later used in the BEEM-UP project [5] has been expanded and adapted to meet the requirements of the DREEAM project. Data for residential buildings and energy supply mixes in the EU27 countries has been updated in the model. Calculations for energy production with solar photovoltaic (PV) cells have been included as well.

Typically, a country's **building stock** is categorised by a number of construction periods or building cohorts (e.g. grouped by year of construction 1961 to 1975). Buildings from the same construction periods and style usually show similar properties of size, building envelope quality, etc. For modelling purposes, each cohort is represented by an **archetype** building, which it is assumed has representative properties for its **cohort**. This archetype building then serves as a model building for calculating space heating and hot water demand, and energy production with the installation of solar photovoltaic (PV) panels.

Energy demand is determined by a steady-state, heating period space heat demand calculation, based on EN 13790. Hot water demand is calculated following the methodology of the software PHPP (www.passiv.de). The model calculates energy demand for the respective archetype buildings before and after refurbishment. Energy production with PV panels is calculated in a steady-state monthly basis only after refurbishment.

The refurbishment scenarios that are applied to the archetype buildings in the model are based on the pilot site refurbishments of the DREEAM project. The archetype buildings are based on multi-family building cohorts included in the TABULA Project [6], as well as several other cohorts from different countries implemented in the BEEM-UP Project [5].

The results, in kWh/m^2·year, are multiplied with the cohort's total floor area (m^2), giving total energy demand per year, i.e. TWh/year. Summing up all of a country's cohorts gives the total demand for the respective building type. These results are then multiplied with respective conversion factors to provide results for energy demand, greenhouse gas emissions, and primary energy demand.

The document in hand contains a selection of model results. These results are based on four different cases based on the renovation measures implemented in the three pilot sites of the DREEAM project and using the current and future European space heating and domestic hot water production mix.

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1 Description of the used model

1.1 Modelling approach

An Excel-based building stock model (BSM), originally developed at ETH Zurich, Prof. Holger Wallbaum [1, 2, 3, 4] and later used in the BEEM-UP project [5] has been expanded and adapted to meet the requirements of the DREEAM project. From building stock data for residential buildings and energy supply mixes in the EU27 countries the model calculates energy demands of the existing building stock and energy savings of a renovated stock.

A country's **building stock** is categorised into a number of **building types** (e.g. apartment block, office), construction periods or building cohorts (e.g. year of construction 1961 to 1975). Buildings from the same construction periods and style usually show similar properties of size, building envelope quality, etc. For modelling purposes, each cohort is represented by an **archetype** building, which it is assumed has representative properties for its **cohort**. This archetype building then serves as a model building for calculating space heat and hot water demand [1, 2, 3, 4].

A country's energy demand is determined by a steady-state, heating period space heat demand calculation, based on the European Standard EN 13790 (Energy performance of buildings -- Calculation of energy use for space heating and cooling). Hot water demand is calculated following the methodology of the software PHPP (www.passiv.de). The BEEM-UP model does an energy demand calculation for the respective archetype buildings before and after refurbishment.

Energy production with PV panels is calculated on a steady-state monthly basis after refurbishment and will be explained further in more detail.

The model incorporates three different building types: Multi-family houses (MFH), apartment blocks (AB), and terraced houses (TH).

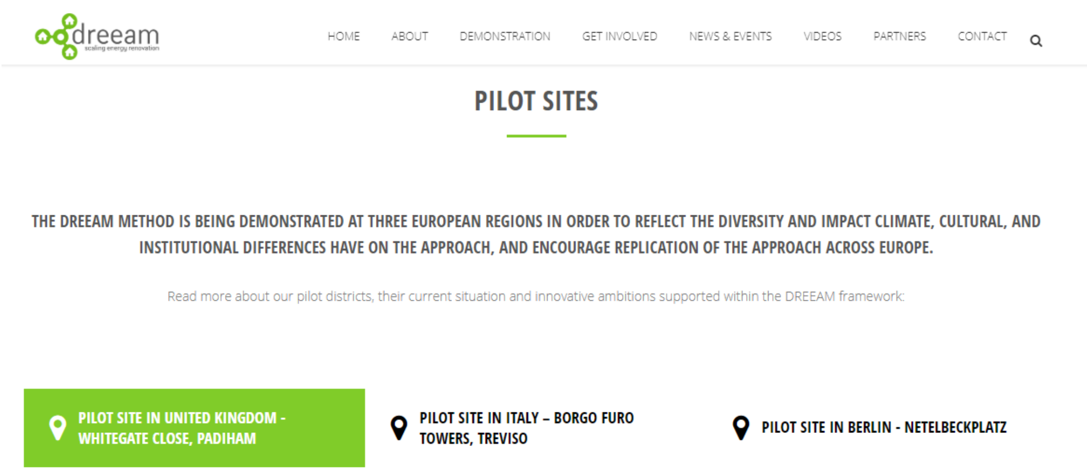


Figure 1. DREEAM website (www.dreeam.eu) on pilot sites in UK, Italy, and Germany.

The refurbishment scenarios that are applied to the archetype building are based on the pilot site refurbishments implemented in the DREEAM project. Please refer to Deliverables D2.2 to D2.4 for further information.

The results, in kWh/m^{2}year, are then multiplied with the cohort's total floor area (m^2), giving total energy demand per year, i.e. TWh/a. Summing up all of a country's cohorts gives the total national demand for the selected building types. These results are multiplied by respective conversion factors, that take into consideration the heating systems used in the renovation scenario, to provide results for energy demand, greenhouse gas emissions, and primary energy demand. The factors were either directly extracted or calculated from the ecoinvent v2 database [7]. Finally, the tool provides the aggregated results of all implemented and activated cohorts.

The results presented in this deliverable represent almost the entire European multi-family house building stock. The whole dataset comprises a floor area of 9,464,612,836 m^2 (i.e. approximately 9,465 million m^2).

The countries covered by this deliverable are shown in Table 1. A visualization of these countries can be seen in Figure 2. As can be seen, 27 out of the 28 European Union countries are covered in this deliverable, with the exception of Croatia, due to the unavailability of the cohort data. It must be noted that the United Kingdom has only been implemented partially, as only the data for England is available. However, England represents circa 85% of the total population of the UK [8], thus, the data can be considered representative for the whole territory.

The Croatian multi-family building stock consists of approximately a floor area of 50 million m^2 [9]. This represents the 0.5 % of the processed floor area, which is similar to the percentage of the population of Croatia in the European Union (roughly 0.8 %).

Table 1. Countries covered in DREEAM / D.5.4

Country	Code	D.5.4 model integration	Country	Code	D.5.4 model integration
Austria	AT	*Implemented*	**Latvia**	LV	*Implemented*
Belgium	BE	*Implemented*	**Lithuania**	LT	*Implemented*
Bulgaria	BG	*Implemented*	**Luxembourg**	LU	*Implemented*
Cyprus	CY	*Implemented*	**Malta**	MT	*Implemented*
Czech Republic	CZ	*Implemented*	**Netherlands**	NL	*Implemented*
Denmark	DK	*Implemented*	**Poland**	PL	*Implemented*
Estonia	EE	*Implemented*	**Portugal**	PT	*Implemented*
Finland	FI	*Implemented*	**Romania**	RO	*Implemented*
France	FR	*Implemented*	**Slovakia**	SK	*Implemented*
Germany	DE	*Implemented*	**Slovenia**	SI	*Implemented*
Greece	GR	*Implemented*	**Spain**	ES	*Implemented*
Hungary	HU	*Implemented*	**Sweden**	SE	*Implemented*
Ireland	IE	*Implemented*	**United Kingdom**	UK	*Implemented, only data for England*
Italy	IT	*Implemented*	**Croatia**	HR	*Not implemented. Cohort data not available.*
Europe (generic)	EU	*Implemented (as the sum of all implemented cohorts)*			

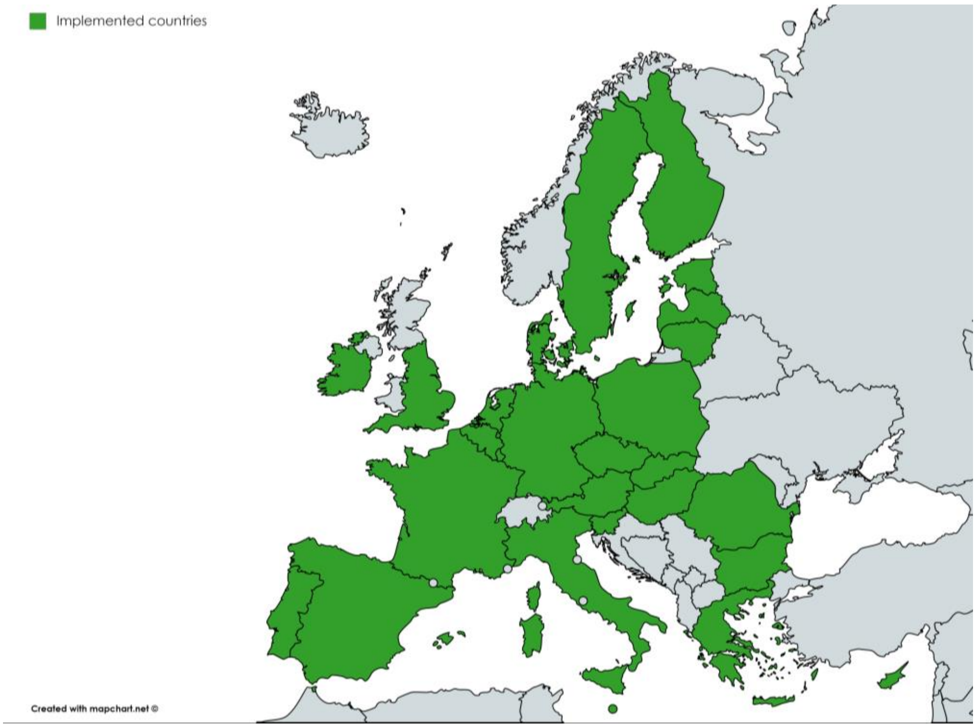


Figure 2. Visualization of the implemented countries in this deliverable.

1.1.1 Solar PV modelling

The solar PV energy production potential is calculated from the available monthly radiation data used for the energy demand calculations according to the following expression:

$$Energy\ produced = \sum_{i=1}^{12} A_{PV} \cdot r \cdot H_i \cdot PR \cdot n_i \quad (1)$$

Where:

A_{PV} is the total solar panel area of the archetype, in m^2

r is the module efficiency

H_i is the average daily solar global radiation in a horizontal orientation in the month i, in kWh/(m²·d)

PR is the performance ratio of the installation

n_i is the number of days orientation in the month i.

It should be noted that the input for the solar PV calculations is the average daily solar global radiation on the horizontal plane. However, the tilt for the PV panels in every installation rarely coincides with the horizontal plane and is usually optimized for energy production.

According to the research of Jacobson & Jadhav [6], the annual ratio between the incident radiation in a horizontal plane and the optimally tilted plane for maximizing this parameter is 1.19. Thus, this factor is to be used to correct the energy produced and have a better estimation of the actual energy production potential.

The area for the PV panel is set according to the ratio between the PV panel area and the total roof area in every renovation scenario. As well, the performance ratio of the installations has been estimated at 70 %.

1.2 Databases, assumptions and simplifications

1.2.1 Cohort data and national floor areas

The data used is mainly taken from two different sources: TABULA and BEEM-UP.

The TABULA project provides detailed datasets for building cohorts and the specific values of the archetype buildings. The building cohorts are classified according to their building type – apartment block (AB), multi-family (MFH), single-family (SFH) or terraced house (TH) – and construction period.

The datasets include all the data necessary for space heat demand calculations, such as heated areas, sizes and U-values of the different building elements, solar transmittance of the glazed elements, average air change rates, and other necessary variables for the calculations. It also provides climate data and national floor areas and/or number of buildings or dwellings of the different cohorts.

The model used was designed to enable optimal use of TABULA data to model a country's building stock. But, since not all the countries implemented in the model were in the scope of the TABULA project, not all the data needed was available at the necessary level of detail. Whenever this data was not available from TABULA, the data from the BEEM-UP project was taken.

Since the input for the BEEM-UP model is the national floor areas, in the cases where only the number of buildings or dwellings was provided, the floor area was estimated with the reference floor area of the cohorts.

An overview of important assumptions and simplifications made per country, in order to complete the required dataset is shown in Table 2. A total of 292 cohorts from all the listed countries are considered.

When it comes to the calculations of DHW, the data needed for the different cohorts comes entirely from the BEEM-UP project. This data includes DHW consumption per household, pipe dimensions, and the rest of the variables necessary to perform the calculations under the PHPP methodology.

The number of people per building archetype is calculated in the same manner as the BEEM-UP project: from the division of the heated area and the floor area per capita in the cohort using data from [11].

Table 2. Summary of used data sources, assumptions and made simplifications

Country	Building size classes included	Database comment
Austria	MFH, AB	National floor areas (TABULA) of MFH include TH's floor areas (cohorts referred to as MFH).
Belgium	MFH	National floor area calculated based on a number of dwellings, reference floor area and 114m^2 per MFH housing unit (same assumption as in BEEM-UP project, source: ENTRANZE, BPIE, Odyssee). Segmentation of construction periods (cohorts MFH.01-MFH.05) estimated based on TABULA.

Bulgaria	TH, MFH	National Floor Area calculated based on the reference floor area and number of buildings. A number of buildings for MFH includes the data for AB. The reference floor area has been averaged with the data from AB when available. Data for TH includes data for SFH the reference floor area has been averaged with the data from SFH. The National Floor Area for this cohort has been divided by 4 so that the area of SFH is not taken into consideration. The source of this assumption is the "Distribution of population by dwelling type, 2016" provided by Eurostat (online data code: ilc_lvho01). Time intervals in cohorts do not coincide with the time intervals from the data provided by Tabula. The data has been adapted linearly to fit the intervals.
Cyprus	TH, MFH	TABULA provides a complete dataset for the building size classes included.
Czech Republic	MFH	National floor area (TABULA): National floor areas of AB are included in MFH cohorts. TH national floor areas are included in SFH and therefore not implemented.
Germany	TH, MFH, AB	TABULA provides a complete dataset for the building size classes included.
Denmark	TH, AB	TABULA provides a complete dataset for the building size classes included.
Estonia	MFH	As implemented in BEEM-UP project: National floor area and U-values based on BPIE. Reference floor area, building component areas and building specifications (except U-values) taken from Poland.
Spain	MFH, AB	Cohort data based on TABULA. National floor area calculated based on the reference floor area and number of buildings. A number of buildings from the 2011 national census made by INE (linearly segmented to Tabula cohort construction periods).
Finland	MFH	As implemented in BEEM-UP project: National floor area and U-values based on BPIE. Component areas from VTT Technical Research Centre of Finland. Remaining missing values taken from Sweden (Tabula).
France	TH, MFH, AB	TABULA provides a complete dataset for the building size classes included.
Greece	MFH	National floor areas of four different climate zones were aggregated to one national climate zone. Calculations are based on a weighted average of the climate data. Implication: The national cohort is represented by specifications of climate zone B (accounts for 62% of total MFH floor area). This neglects the effect of the specifications of climate zone C, which accounts for 28% of the total MFH floor area.
Hungary	MFH	TABULA provides a complete dataset for the building size classes included.
Ireland	TH, AB	National floor area per cohort calculated from reference floor area and a number of housing buildings (TABULA). The national floor area of some cohorts was linearly segmented because construction periods for the provided data were not the same as for the building specifications.
Italy	MFH	The TABULA total floor area per MFH cohort was fitted to the MFH total floor area of Italy given by BPIE. This way the values are reasonably spread over the different cohort construction periods. It was taken into account that 50% of the buildings are situated in the Climatic Middle Zone and only this climate zone is implemented in the model. All other values are based on TABULA.
Lithuania	MFH	As implemented in BEEM-UP project: Total national floor area (BPIE) was segmented into construction periods according to Latvia's ratios. U-values (Latvia, BPIE), reference floor area and building component areas (Poland, TABULA). (Almost no data available)
Luxembourg	MFH	As implemented in BEEM-UP project: National floor area (linearly segmented over construction periods), U-values and reference floor area based on Luxembourg's statistical office. Component areas and other building specifications are taken from Belgium (TABULA).
Latvia	MFH	As implemented in BEEM-UP project: National floor area and U-values was taken from BPIE. Reference floor area, building component areas and other building specifications taken from Poland (TABULA).

Malta	MFH	As implemented in BEEM-UP project: National floor area and U-values based on BPIE (U-values only available for SFH). Reference floor area, building component areas and other building specifications taken from Italy (TABULA). Heating base temperature: Heat demand is calculated in case that the daily average external temperature is below a certain value. Within TABULA, 12°C is used as a standard value, so this threshold is used as well in the BEEM-UP model, except for Malta. According to the used methodology and the given climate data, there would be no heating days and therefore no space heat demand. Since the heat energy demand in Malta is not zero, the threshold value for Malta was changed to 13°C.
Netherlands	TH, MFH	National floor area calculated based on a number of dwellings, reference floor area and 114m² per MFH housing unit (same assumption as in Belgium). The national floor area of some cohorts was linearly segmented because construction periods for the provided data were not the same as for the building specifications.
Poland	TH, MFH, AB	TABULA provides a complete dataset for the building size classes included. The national floor area of some cohorts was linearly segmented because construction periods for given national floor areas were not the same as for the building specifications.
Portugal	MFH	As implemented in BEEM-UP project: Total national floor area (BPIE) linearly segmented by the cohort's construction periods. U-values from BPIE. Building component areas and other specifications are taken from Spain (TABULA).
Romania	MFH	As implemented in BEEM-UP project: National floor area and U-values based on BPIE. Building component areas and other specifications are taken from Bulgaria (TABULA).
Sweden	MFH	TABULA provides a complete dataset for the building size classes included. Calculations only use climate zone 3.
Slovenia	TH, MFH, AB	TABULA provides a complete dataset for the building size classes included.
Slovakia	MFH	As implemented in BEEM-UP project: National floor area and U-values based on BPIE. Building component areas and other specifications are taken from the Czech Republic (TABULA).
United Kingdom	TH, MFH, AB	TABULA provides a complete dataset for the building size classes included. Data for England.

1.2.2 National energy mixes

The model used requires a considerable input regarding energy mixes for the different modelled countries, which needed to be updated. Table 3 shows the required input and the source of the updated data.

Table 3. Sources of data for updated national energy mixes.

Data set	Source
Electricity mixes	Supply, transformation and consumption of electricity - annual data [nrg_105a]. Data for 2016. Eurostat [10].
District heating mixes	Mapping and analyses of the current and future (2020 - 2030) heating/cooling fuel deployment (fossil/renewables). Data for 2012. European Commission [11].
Space heat and domestic hot water mixes	Profiles and Baselines for heating and cooling energy demands in 2015 for EU28 countries. Heat Roadmap Europe [13].

Since the main purpose of this deliverable is to estimate the potential of the European building stock, the EU average energy mix for SH and DHW is used as an input on the renovated SH and DHW mix. This means that in all studied renovation cases, the calculation will take into consideration these energy mixes, regardless of the technology that provides the energy for SH and DHW on the specific pilot site which is taken as a reference.

These mixes are shown in Table 4, and they are calculated from the updated space heat and domestic hot water mixes [13]. As well, the baseline heating and hot water mix for the buildings sector for 2050 according to the project Heat Roadmap Europe [14] will be used to assess the effect of the national energy mixes. In this scenario, both oil and coal boilers have been phased out. This mix is also included in Table 4.

Table 4. Renovated space heat and hot water energy mixes.

Energy carrier/ assigned technology	Renovated Space Heat Energy Mix	Renovated Hot Water Energy Mix	Renovated Space Heat & Hot Water Energy Mix Heat Roadmap Europe [14]
Oil	14%	19%	0%
District heat	9%	11%	14%
Gas	43%	44%	50%
Electricity	8%	16%	18%
Wood	20%	4%	6%
Coal	5%	1%	0%
Heat pump	1%	1%	11%

1.2.3 Effect of the energy mix

By defining the "energy mix" for SH and DHW one does not only determine which fuel is used but also what technology provides the energy demand. Therefore, the "energy mixes" include the shares of district heat, electricity, and heat pumps too.

This assigned set of energy carriers and types of technology is subsequently combined with the set of heating systems. The impact factors for district heating and electricity are calculated individually per country, based on the national energy mixes.

1.2.4 Heating and ventilation systems

The final energy consumption depends on the chosen heating systems and the corresponding system efficiencies. The chosen set of systems is applied to all cohorts and countries. The presented model results, therefore, neglect the fact, that different countries are equipped with different systems, operating at lower or higher efficiencies.

The chosen set of systems for the renovated state was determined by using the systems implemented in the different pilot sites. For gas boilers, the data for the new gas boilers in Treviso and Padiham has been used. As well, the data for the new immersion heaters for Padiham, and the solar thermal system for preheating the water in Treviso have been added to the model.

The efficiency for oil and wood boilers has been improved, to account for efficiency gains due to a refurbishment. It is assumed that for the other technologies either no new installations take place or that they have the same efficiency as before.

Ventilation systems also need to be assigned. This has been done based on the ventilation systems of the different pilot sites, in cases where this has been renovated. The new ventilation system of the

Padiham pilot site consists of a mechanical ventilation unit, and the ventilation for Treviso includes a heat recovery system.

1.2.5 Transferability and previously installed PV

In the model, it is possible to introduce a transferability coefficient, in order to account for market barriers and other limitations in applicability. This factor reduces the impact of a given measure by 0 to 100%. For instance, certain insulation types may be applicable to only a part of a cohort's buildings or older buildings can only be refurbished very limited when they are under monumental protection.

Nevertheless, for the purpose of this deliverable this factor is set to 100%, illustrating the overall potential of the refurbishment scenario.

As well, it is important to note that this study does not take into consideration the currently installed PV panels in residential buildings and accounts for the overall potential of the installation of PV panels in the EU.

2 Model results

The modelling tool used was designed to analyse the energy saving potential within the existing building stock in European countries. The analysis is based on the experiences and results from the three DREEAM pilot sites. It must be noted that this analysis covers only technological aspects and does not cover behavioural, economic or political factors.

This chapter presents a selection of model results on a European scale. Four different cases have been calculated (see chapter 2.1, table 5). As well, a sensitivity analysis of the solar PV conditions is presented.

2.1 Scenario and option choices

The report in hand presents the model outputs of four selected cases. The cases provide the main results for the three scenarios, based on the DREEAM pilot sites, and for distribution of the renovation measures according to a distribution that takes into consideration the similarity of the building characteristics and weather conditions. The cases are presented in Table 5.

As it was mentioned in section 1.1, these refurbishment scenarios are based on the pilot site refurbishments of the DREEAM project. Please refer to Deliverables D2.2 to D2.4 for further information on the measures implemented in each site.

Note that the selected technologies that provide the energy for SH and DWH for all the different renovation scenarios consist on the new technologies used in the three different pilot sites. As well, for other technologies that have not been covered in the DREEAM project, namely oil and wood-fired boilers, more modern versions have been selected. This has been done in order to cover the different alternatives of the SH and DWH energy mixes (refer to Table 4).

Table 5. Chosen settings of the four presented result cases.

	Refurbishment scenario
Case I	Allocation according to the similarity of building characteristics and weather conditions to pilot sites
Case II	IT Treviso – Pilot site
Case III	DE Berlin – Pilot site
Case IV	UK Padiham – Pilot site

A sensitivity analysis on the solar conditions for PV will be presented for the first case. In addition, in order to assess the influence of the SH and DHW mixes, another scenario with the baseline heating and hot water mix for the buildings sector for 2050 according to the project Heat Roadmap Europe [14] is presented.

The allocation of sites for the first case is based on the proximity of the countries to the pilot sites, as well as the similarity of the building characteristic and the weather conditions. As a result, the cohorts in the countries located in southern Europe, namely Portugal, Spain, Italy, Slovenia, Greece, Malta and Cyprus have been allocated the Treviso site; the ones in Great Britain and Ireland have been allocated the Padiham site; and the rest of the cohorts have been assigned to the Berlin site.

2.2 Results

The following subsections show the model results for all 292 implemented model cohorts of the 27 countries for multi-family houses (including AB and TH), using different scenarios and settings as described in the previous section.

The presented set of indicators are; energy demand, final energy consumption and greenhouse gas emissions. The results are discussed in section 2.3, where the primary energy consumptions from the case I and case IV are shown as well.

2.2.1 The case I - Allocation according to the similarity of building characteristics and weather conditions to pilot sites

III. Total results

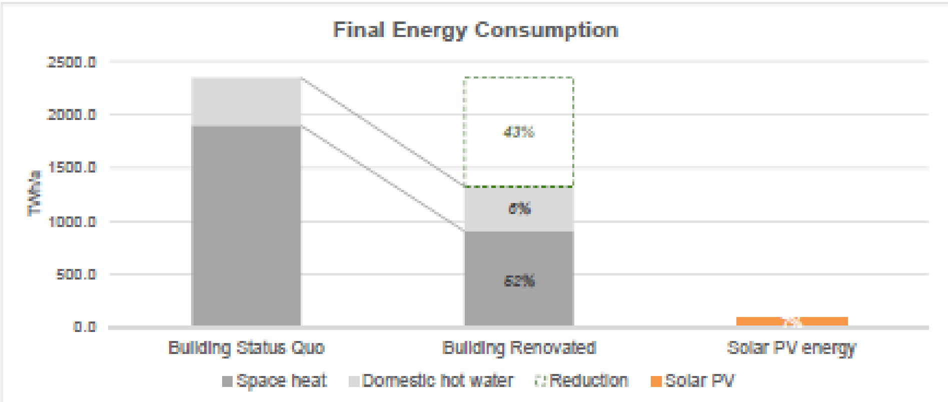
Results for all cohorts currently activated for calculation

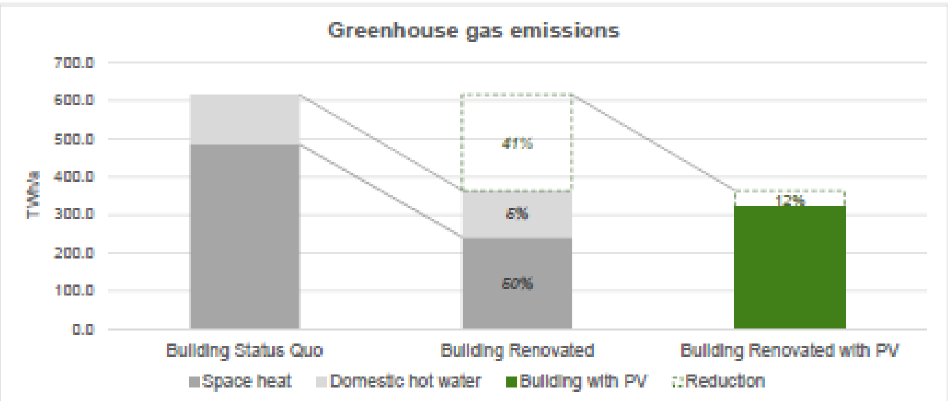
Total floor area 9,464,612,836 m²

	Building Status Quo	Building Renovated	Reduction Potential
Energy Demand	TWh/a	TWh/a	Δ
Space heat	1,518	745	50.9%
Domestic hot water	413	413	0.0%
Total	1,931	1,158	40.0%
Final Energy Consumption	TWh/a	TWh/a	Δ
Space heat	1,899	906	52.3%
Domestic hot water	446	420	5.9%
Total	2,345	1,325	43.5%
Solar PV energy production	TWh/a	TWh/a	
Energy produced	-	97	
Greenhouse gas emissions	Mtons CO_2-eq/a	Mtons CO_2-eq/a	Δ
Space heat	486	241	50.4%
Domestic hot water	130	123	5.5%
Solar PV production	-	-43	-
Total	616	320	48.0%

III. Graphic Results

Results for all cohorts currently activated for calculation





2.2.1.1 The case I – 2050 energy mix

III. Total results

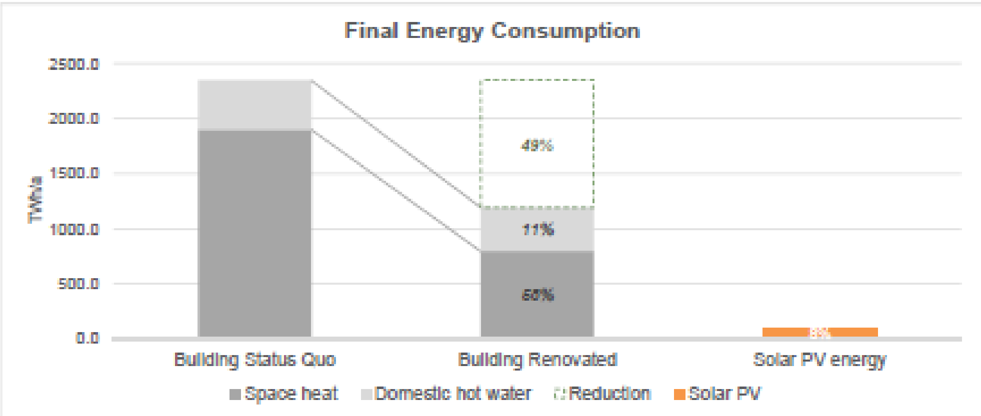
Results for all cohorts currently activated for calculation

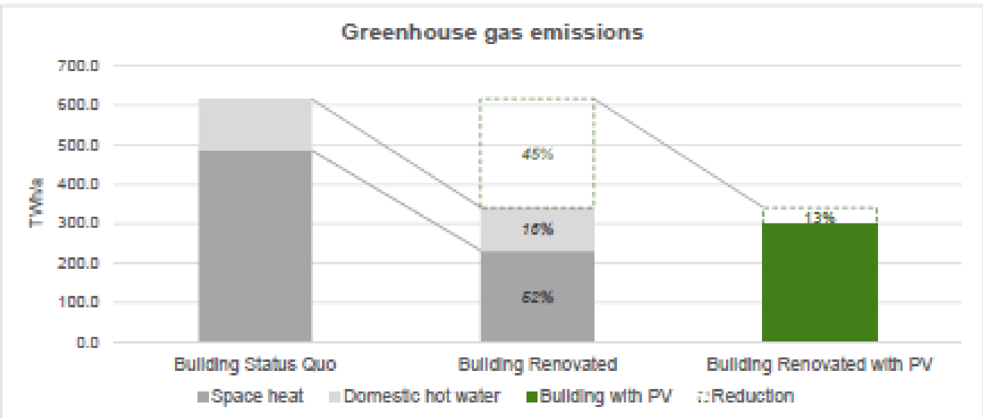
Total floor area 9,464,612,836 m²

	Building Status Quo	Building Renovated	Reduction Potential
Energy Demand	TWh/a	TWh/a	Δ
Space heat	1,518	745	50.9%
Domestic hot water	413	413	0.0%
Total	1,931	1,158	40.0%
Final Energy Consumption	TWh/a	TWh/a	Δ
Space heat	1,899	795	58.1%
Domestic hot water	446	399	10.6%
Total	2,345	1,194	49.1%
Solar PV energy production	TWh/a	TWh/a	
Energy produced	-	97	
Greenhouse gas emissions	Mtons CO_2-eq/a	Mtons CO_2-eq/a	Δ
Space heat	486	231	52.4%
Domestic hot water	130	110	15.7%
Solar PV production	-	-43	-
Total	616	298	51.7%

III. Graphic Results

Results for all cohorts currently activated for calculation





2.2.1.2 PV sensitivity analysis

In Table 6 a sensitivity analysis on the effect of the used roof area for solar PV panels is presented.

Table 6. Effect of the roof area used in the PV systems on different parameters.

PV case	Base case	Treviso pilot site	Berlin pilot site	Padiham pilot site	Ambitious area use
Roof area used	Distribution according to Case I	8.6%	12.0%	35.0%	50.0%
Energy produced [TWh/a]	97	58	80	235	334
Greenhouse emissions avoided [Mtons CO_2-eq/a]	43	27	37	109	156
Total GHG avoided	48.0%	45.3%	47.0%	58.7%	66.3%

2.2.2 The Case II - IT Treviso – Pilot site

III. Total results

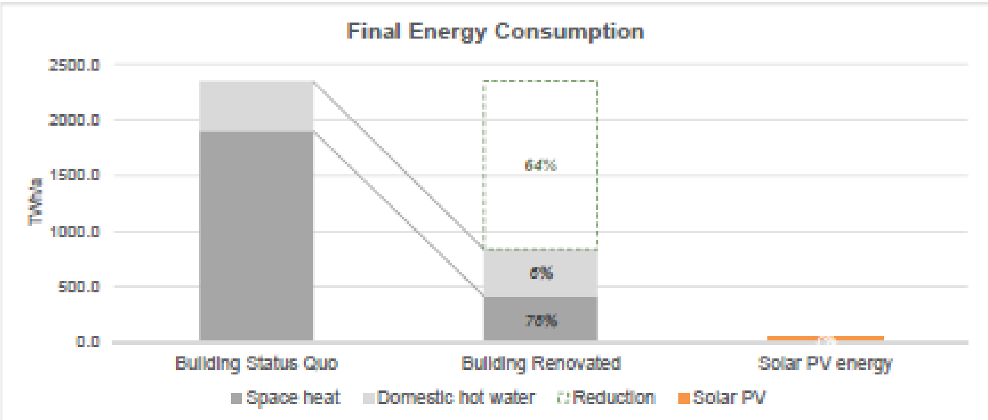
Results for all cohorts currently activated for calculation

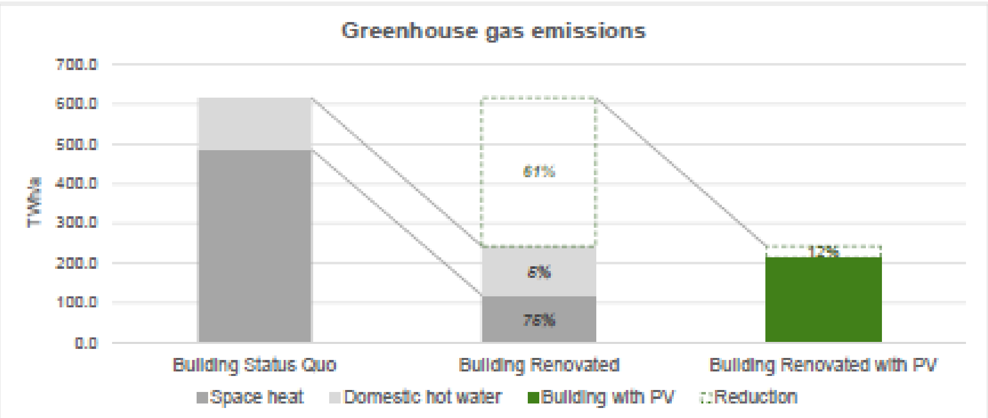
Total floor area 9,464,612,836 m²

	Building Status Quo	Building Renovated	Reduction Potential
Energy Demand	TWh/a	TWh/a	Δ
Space heat	1,518	307	79.8%
Domestic hot water	413	413	0.0%
Total	1,931	720	62.7%
Final Energy Consumption	TWh/a	TWh/a	Δ
Space heat	1,899	418	78.0%
Domestic hot water	446	420	5.7%
Total	2,345	839	64.2%
Solar PV energy production	TWh/a	TWh/a	
Energy produced	-	62	
Greenhouse gas emissions	Mtons CO_2-eq/a	Mtons CO_2-eq/a	Δ
Space heat	486	119	75.5%
Domestic hot water	130	123	5.3%
Solar PV production	-	-29	-
Total	616	213	65.3%

III. Graphic Results

Results for all cohorts currently activated for calculation





2.2.3 The Case III - DE Berlin – Pilot site

III. Total results

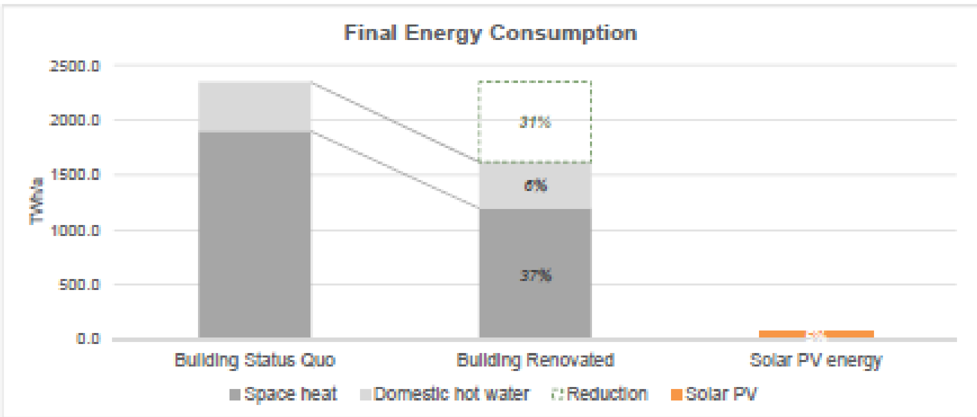
Results for all cohorts currently activated for calculation

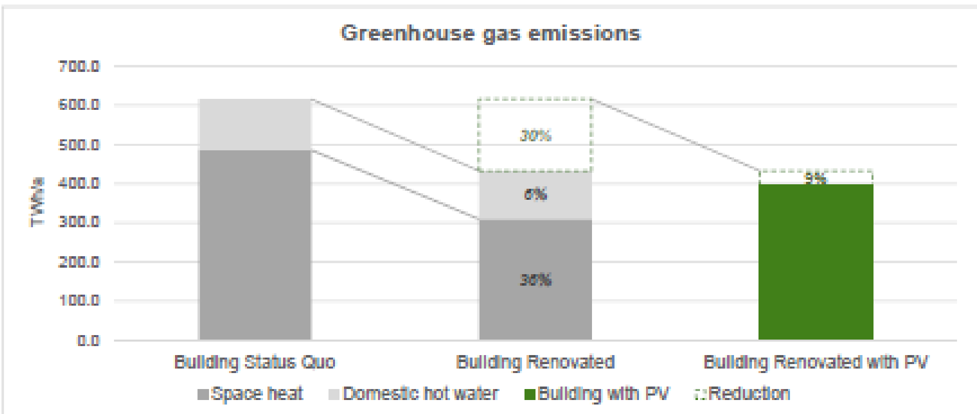
Total floor area 9,464,612,836 m²

	Building Status Quo	Building Renovated	Reduction Potential
Energy Demand	TWh/a	TWh/a	Δ
Space heat	1,518	1,011	33.4%
Domestic hot water	413	413	0.0%
Total	1,931	1,424	26.3%
Final Energy Consumption	TWh/a	TWh/a	Δ
Space heat	1,899	1,199	36.8%
Domestic hot water	446	420	5.9%
Total	2,345	1,619	31.0%
Solar PV energy production	TWh/a	TWh/a	
Energy produced	-	80	
Greenhouse gas emissions	Mtons CO_2-eq/a	Mtons CO_2-eq/a	Δ
Space heat	486	310	36.3%
Domestic hot water	130	123	5.6%
Solar PV production	-	-37	-
Total	616	395	35.8%

III. Graphic Results

Results for all cohorts currently activated for calculation





dreeam

2.2.4 The Case IV - UK Padiham – Pilot site

III. Total results

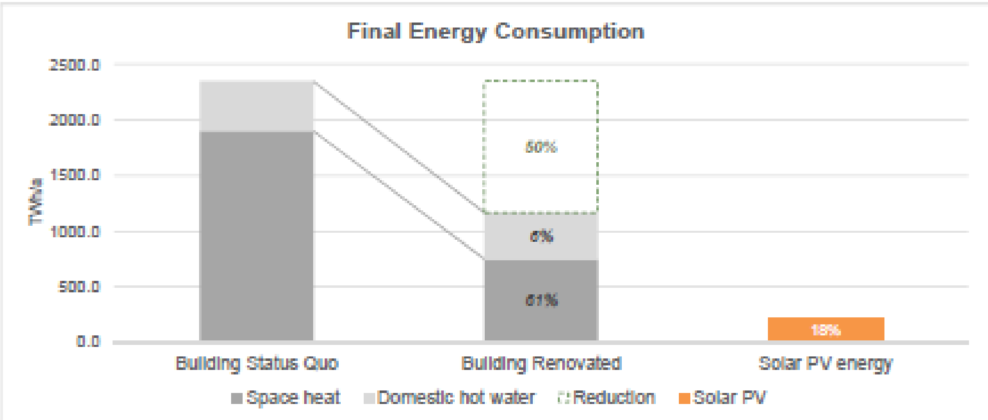
Results for all cohorts currently activated for calculation

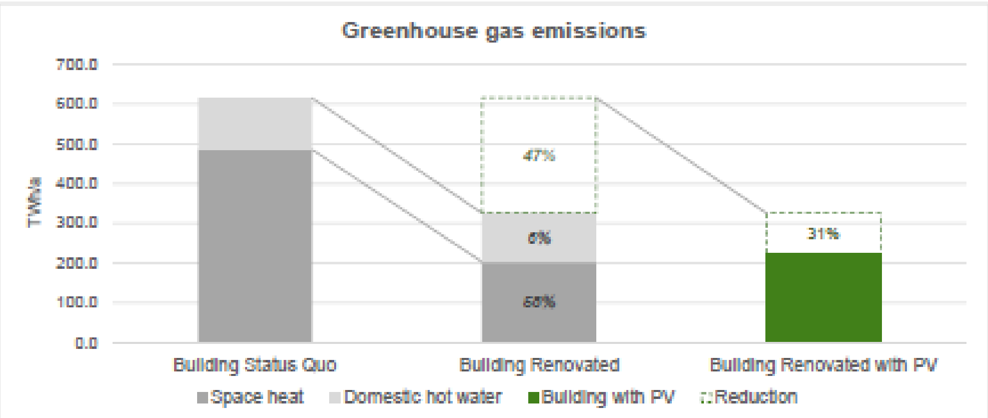
Total floor area 9,454,612,836 m²

	Building Status Quo	Building Renovated	Reduction Potential
Energy Demand	TWh/a	TWh/a	Δ
Space heat	1,518	599	60.5%
Domestic hot water	413	413	0.0%
Total	1,931	1,012	47.6%
Final Energy Consumption	TWh/a	TWh/a	Δ
Space heat	1,899	750	60.5%
Domestic hot water	446	420	5.9%
Total	2,345	1,169	50.1%
Solar PV energy production	TWh/a	TWh/a	
Energy produced	-	216	
Greenhouse gas emissions	Mtons CO_2-eq/a	Mtons CO_2-eq/a	Δ
Space heat	486	202	58.3%
Domestic hot water	130	123	5.6%
Solar PV production	-	-100	-
Total	616	225	63.5%

III. Graphic Results

Results for all cohorts currently activated for calculation





2.3 Discussion

The presented results show the notable energy and GHG emissions reduction potential for the European MFH (including AB and TH) building stock thanks to energetic refurbishments. There is an overall reduction potential between 30% and 60% of the building's energy demand. When it comes to PV systems, these can produce from 7% to 18% of energy demand, depending on the utilised roof area.

The following should be considered, taking into account the previously mentioned model boundaries and assumptions. First of all, it should be kept in mind, that the shown savings are based on an ideal refurbishment transferability of 100%. That means refurbishments are successfully applied to all treated buildings without any limitation.

This is done in order to quantify the overall refurbishment potential of the EU MFH building stock. Taking into account several factors, such as historic building protection, economic restrictions, minor renovations, etc. this potential will be reduced.

The availability of roof area for the installation of solar PV panels is an important factor in the electricity output. Looking at the results from the sensitivity analysis for the case I, the case where 35% of the roof area is utilized, an additional 10% reduction in the GHG gases are obtained. Furthermore, when 50% of the roof area is used, a reduction of nearly 20% more in the GHG gases is achieved.

Unfortunately, in a realistic scenario, no more than 50% of the roof area could be used for these purposes. There are several factors that hinder the availability of roof area to install PV panels, such as roof orientation and tilt, placement of building services in the roof area, external shading, roof structure considerations, economic and policy constraints, etc.

The energy mix used for the renovation scenarios plays a significant role in the final energy consumption, as the overall efficiency of the system is improved. The overall increase in the energy savings for the 2050 baseline mix is 5% higher. There is also a 3% increase in the GHG savings. The increase in GHG savings is lower because of the PV panels. Therefore, using more environmentally friendly technologies can reduce the final energy consumption and GHG emissions notably.

As a conclusion, it can be said that even the least ambitious renovation scenario has a big impact on both the energy consumption and the GHG emissions. However, if the European reduction goals want to be met, there is a need to aim for thorough, deep renovations.

Abbreviations

AB	Apartment block
BSM	Building Stock Model
DHW	Domestic hot water
MFH	Multi-family house
SFH	Single-family house
SH	Space heat
TH	Terraced house
VBA	Visual Basic for Applications: Programming language used by Microsoft Office
PV	Solar photovoltaic

Glossary

Building component areas	Wall/roof/floor/window/door areas of the building envelope for energy demand calculations.
Building specifications	Values for energy demand calculations as; U-values, insulation thickness, transmission rates of components or additional thermal resistances.
Energy demand	Calculated energy demand of reference building / country / selected cohorts.
Final energy consumption	Calculated final energy consumption, based on calculated energy demands.
National floor area	Total floor area of a cohort within a country.
Reference floor area	Energy reference area (conditioned floor area, internal dimensions) of the archetype building of a cohort.

References

[1] N. Heeren, M. Gabathuler, H. Wallbaum, M. Jakob och G. Martius, ”Gebäudeparkmodell SIA Effizienzpfad Energie Dienstleistungs- und Wohngebäude,” 2009.

[2] N. Heeren, M. Jakob, G. Martius, N. Gross och H. Wallbaum, ”A component based bottom-up building stock model for comprehensive environmental impact assessment and target control,” *Renewable and Sustainable Energy Reviews,* vol. 20, pp. 45-56, 1 4 2013.

[3] N. Heeren, H. Wallbaum och M. Jakob, ”Towards a 2000 Watt society – assessing building-specific saving potentials of the Swiss residential building stock,” *International Journal of Sustainable Building Technology and Urban Development,* vol. 3, nr 1, pp. 43-49, 3 2012.

[4] H. Wallbaum, N. Heeren, M. Jakob och G. Martius, ”Gebäudeparkmodell Büro-, Schul- und Wohngebäude. Vorstudie zur Erreichbarkeit der Ziele der 2000-Watt-Gesellschaft für den Gebäudepark der Stadt Zürich,” 2010.

[5] Chalmers University of Technology & ETH Zurich, *BEEM-UP: Building Energy Efficiency for Massive market Uptake. Deliverable D.6.4: Adapted tool for building park modelling in EU countries. Contract number: ENER/FP7/260039/BEEMUP.,* 2014.

[6] Institut Wohnen und Umwelt GmbH, ”EPISCOPE - TABULA,” Institut Wohnen und Umwelt GmbH, 2016. [Online]. Available: http://episcope.eu/welcome/. [Använd March 2019].

[7] ecoinvent, ”ecoinvent,” 2007. [Online]. Available: http://www.ecoinvent.org/database/ecoinvent-version-2/. [Använd March 2019].

[8] World Population Review, ”United Kingdom Population,” World Population Review, 18 02 2019. [Online]. Available: http://worldpopulationreview.com/countries/united-kingdom-population/. [Använd 26 03 2019].

[9] Ministry for Protection of the Environment and Energy, ”Fourth National Energy Efficiency Action Plan of the Republic of Croatia for the Period from 2017 to 2019,” 2017.

[10] M. Z. Jacobson och V. Jadhav, ”World estimates of PV optimal tilt angles and ratios of sunlight incident upon tilted and tracked PV panels relative to horizontal panels,” *Solar Energy,* 2018.

[11] EUROPE'S BUILDINGS UNDER THE MICROSCOPE A country-by-country review of the energy performance of buildings, 2011.

[12] Eurostat, ”Eurostat,” 04 06 2018. [Online]. Available: https://ec.europa.eu/eurostat/web/main/home.

[13] ”Mapping and analyses of the current and future (2020-2030) heating/cooling fuel deployment (fossil/renewables),” 2016.

[14] Heat Roadmap Europe, ”Heat Roadmap Europe. A low-carbon heating and cooling strategy.,” 2019. [Online]. Available: https://heatroadmap.eu/heating-and-cooling-energy-demand-profiles/.

[15] W. Nijs, P. Ruiz Castelló och I. Hidalgo González, ”Baseline scenario of the total energy system up to 2050,” Heat Roadmap Europe. A low-carbon heating and cooling strategy., 2017.