Explore sustainable European futures

WP2 – Buildings module documentation (including households and services)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 730459.

Project Acronym and Name	EU Calculator: trade-offs and pathways towards sustainable and low-carbon European Societies - EUCalc
Document Type	Documentation
Work Package	WP2
Document Title	Module documentation
Main authors	Judit Kockat, Sophia Wallerand
Partner in charge	BPIE
Contributing partners	EPFL
Release date	(preliminary version for expert review)
Distribution	*All involved authors and co-authors agreed on the publication.*

Short Description
This report describes - *the sources and hypotheses used to build the historical database;* - *The calculation logic and scope of the module;* - *The lever choices and ambition levels.*

Quality check	
Name of reviewer	**Date**
Luis Costa	May 23rd 2019

Statement of originality:

This deliverable contains original unpublished work except where clearly indicated otherwise. Acknowledgement of previously published material and of the work of others has been made through appropriate citation, quotation or both.

Table of Contents

List of abbreviations

1 Introduction

Greenhouse gas emissions from buildings contribute one of the four biggest shares in Europe. Figure 1 [1] shows that the direct emissions of the residential and the commercial make up already 13% of the GHG emissions. Most of these direct emissions stem from space and water heating which consumes 79.2% of the energy delivered to buildings [2]. The indirect emissions from producing electricity and district heating for buildings are still allocated to energy supply in Figure 1. When considering them buildings account for 36% [3] of the European GHG emissions.

The potential to save energy and GHG in buildings starts to take effect as the negative GHG emission growth rate in figure 2 shows. The potential has been assessed to be large[6], however numerous barriers need to be overcome[5].

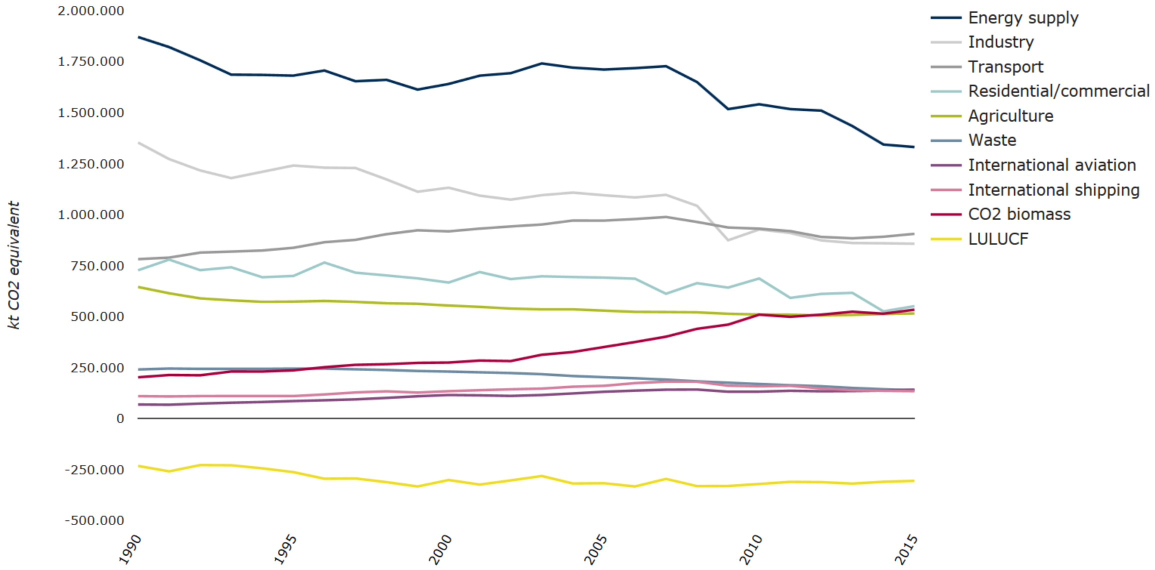

Figure 1 - GHG emissions by aggregated sector source: EEA 2018 IND-37-en[1]

What do we mean by Greenhouse gas (GHG) emissions from buildings? Buildings host people and may provide an environment that is liveable, healthy and even comfortable. Heating, cooling, ventilation and lighting systems generate this environment by burning fuel and by using electricity. The amount of energy consumed for generating a comfortable environment depends mostly on the design and the quality of the building. Hence, the GHG emissions related to conditioning the space and air in buildings are interpreted to be caused by buildings.

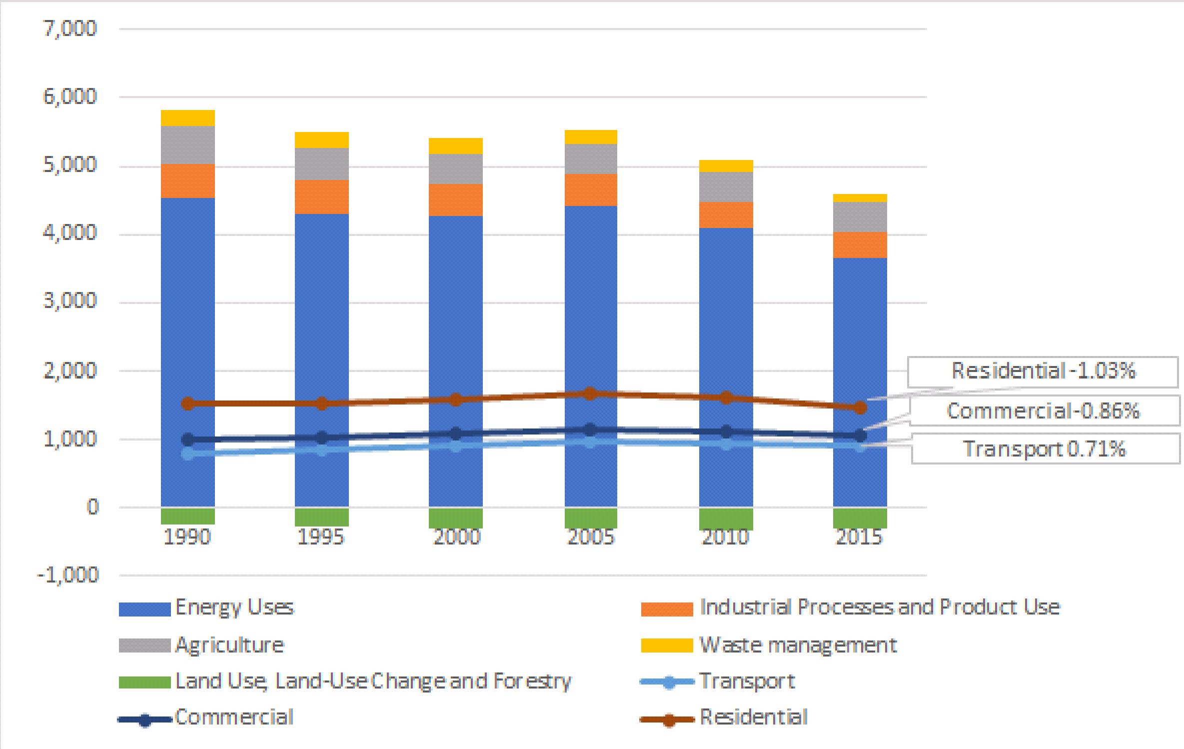

Figure 2 - accumulated GHG emissions by aggregated sector source: EEA [4]

Beyond providing a suitable environment buildings are used by people to host many activities. Some of these activities may consume energy and cause GHG emissions, for example working, cooking and entertainment.

As energy balances commonly aggregate sectors, the energy demand and GHG emissions for households and the service sector include not only indoor environment conditioning but also appliances (i.e. fridges, washing machines, dishwashers), information and communication technology (ITC) and cooking. These so-called energy uses depend more on the behaviour of the people than on the quality of the buildings. However, for households they are included in the building module. For the service sector these additional energy consumption is very dependent on the business, for example a restaurant will have a much higher energy demand for cooking than an office, which will have a much lower heating demand than a swimming pool, which will have a much lower electricity demand for ITC than a hospital. As a simplification this building module includes service sector energy demand and GHG emissions for appliances, ITC and cooking as an aggregate[1].

2 Trends and evolutions of the buildings sector

[1] The energy uses beyond heating are not yet implemented for the service sector. This will be done in an effort to map the energy balances.

3 Questions addressed by the module

Theme	Information/Question		Ambition	Progress
What are the types of impacts we want to take into account in the model?	Products & materials	• Buildings stock for renovation, new built and destructions, and their material and resources requirements	Yes	Implemented
		• Incl. coverage of biomaterials with link to land/food, this is covered in the manufacturing module	Yes	Implemented
	Resources	• Demand for appliances, production is covered in the manufacturing module	Yes	Implemented
	Energy	• Energy consumption by vector, including the perspective for district heating and the impact of fuel switch /electrification	Yes	Implemented
		• Fuel costs	Yes	Implemented in the energy module
	Emissions	• Direct emissions of the sector	Yes	Implemented
		• Is there an emission shift with the Energy use for material production	Yes, indirect emissions from industry & power module	Not Implemented
	Economy	• Cost and economic impact of the different scenarios (e.g. jobs)?	Yes, combined with employment module	Yes
	Other	• Biodiversity? • Health (Emissions Air Quality)	Not biodiversity. Yes, combined with air quality module	Yes
What is the impact of existing solutions to decarbonize the sector?	• Impact of heated floor area optimization		Yes	Implemented
	• Building envelope (walls, roof, windows) improvement - Impact of envelope energy efficiency (renovations rate and depth, new build rate and performance, and destructions)		Yes	Implemented
	• Systems and technology improvements - Impact of heating technologies innovation (e.g. district heating)		Yes	Implemented
	• Fuel switch to biomass/electrification		Yes	Implemented
What is the impact of potential breakthrough (techn. or societal)?	• Qualified Workforce demand bottle necks for retrofit • Material demand bottle necks for retrofit & construction • Resources and materials need for appliances (as rare earth materials in electronics; white as cooling fluids in fridges; gases in lights)		No Yes, with industry Yes, with industry and mining	Not implemented Implemented Implemented
What are the impacts of the sector on the others?	• Impact on industrial production and land use, e.g. material switch from concrete to wood		Yes, with industry and agriculture module	Implemented
	• Impact on electricity balancing (What is the DSM impact on power networks?)		Yes	Not implemented
	• Impact on waste industry: waste material of destroyed buildings (e.g. recycled glass, steel)		No	Not implemented
What are the impacts of other sectors on this one?	• Impact of demographic development (energy, cost, GHG)		Yes, population growth	Implemented
	• Impact of lifestyle (such as heating behaviour, floor area uptake, consumption) on energy, cost, GHG)		Yes, together with lifestyle module	Implemented

Table 1. Questions addressed (heating in buildings)

4 Calculation logic and scope of module

4.1 Overall calculation logic for heating in the buildings' module

The buildings module is based on a bottom-up approach to compute energy consumption and GHG emissions from the household and service sector. This calculation is based on historical data[2] and on projections until 2050 (the different projection levels are described in the lever specifications sections in this document).

The main outputs of the buildings' module are:

- The direct GHG emissions originating in buildings from households and services;
- The energy demand in buildings from households and services;
- The need for construction and renovation of buildings and the number of appliances required;
- The need for district heating infrastructures;
- The total costs of the buildings.

Buildings' and appliances' indirect emissions are addressed by other WPs (e.g. Power module assesses the emissions related to the electricity production and the upstream emissions of fossil fuels, and manufacturing assesses the emissions related to the manufacturing of the buildings, appliances and infrastructures)[3].

The calculation logic adopted here consists in the following steps:

1. the building stocks' energy performance with respect to its insulation quality is measured in energy need (also called useful energy) in kWh/m²
2. the heating behaviour of the occupant (in °C);
3. the technology share for each heating system and fuel (in 0%);
4. the energy efficiency of each technology for each heating system (in KWh_{therm}/kWh_{fuel});
5. the emission intensity of each type of fuel used in the various technologies (gCO_2e/MJ);
6. the needs for district infrastructures depending on the district heating share (e.g: km of pipes);
7. the costs for the purchase (CAPEX), operation and maintenance O&M (OPEX) and fuel consumption of infrastructures (e.g. EUR/heating system).

The different buildings, user behaviour and technologies of buildings and types of fuels are further described below.

[2] Historical data are also described in deliverable D2.1.
[3] WP5: Electricity and Fossil Fuels, WP3:Production and Manufacturing http://www.european-calculator.eu/research-approach-wps/

4.2 Scope definition

The buildings module comprises the calculation energy demand for heating residential and non-residential buildings, for household appliances, and for additional district heating that supplements heat from combined heat and power and industry waste heat. Elements are to be added to calculate the energy demand for lighting, cooking, cooling and hot water.

Greenhouse gas emissions are calculated whenever the energy transformation happens within the building or within additional district heating plants. This excludes greenhouse gas emissions from electricity generation and from combined heat and power plants. Greenhouse gas emissions from prior value chains, such as the production of cement or insulation material or steel for district heating pipelines, are calculated in other modules such as industry/manufacturing. Another example is the production of wood or biogas for heating which is calculated in agriculture and land-use.

An analysis of different levels of indirect emissions is planned and designed.

4.3 References

[1]European Environment Agency 2018. GHG Emissions by Aggregated Sector. IND-37-en, CSI 010 , CLIM 050: 1. https://www.eea.europa.eu/data-and-maps/indicators/greenhouse-gas-emission-trends-6/assessment-2, cited on 29.05.2019.

[2] Eurostat 2019. Energy consumption in households. retrieved from ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households, cited on 22.05.2019.

[3] European Commission 2019. Energy performance of buildings. retrieved from ec.europa.eu/energy/en/topics/energy-efficiency/buildings, cited on 29.05.2019.

[4] European Environment Agency 2019. Data viewer on greenhouse gas emissions and removals, sent by countries to UNFCCC and the EU Greenhouse Gas Monitoring Mechanism (EU Member States). retrieved from www.eea.europa.eu/data-and-maps/data/data-viewers/greenhouse-gases-viewer. cited on 30.05.2019.

[5] Bürger, Veit. 2012. *Overview and Assessment of New and Innovative Integrated Policy Sets That Aim at the NZEB Standard*. ENTRANZE. retrieved from www.entranze.eu/files/downloads/D5_4/Entranze_D5.4_05-2012_final.pdf. cited on 30.05.2019.

[6] Kranzl, Lukas et al. 2014. Policies to Enforce the Transition to NZEB : Synthesis Report and Policy Recommendations from the Project. retrieved from www.entranze.eu/files/downloads/D5_7/D5_7_ENTRANZE_synthesisrecommendations_v14.pdf. . cited on 30.05.2019.

5 Heating and Cooling in Buildings

5.1 Scope definition Heating and Cooling in Buildings

Table 2 defines the scope of the heating in buildings part of the buildings' modules in terms of:

- The different types of buildings considered;
- The technologies included in the model;
- The types of fuels and vectors of energy taken into account.

Table 2 Scope definition for heating in buildings

Levers	Granularity	
Homes • Living space per person • Heating, cooling and hot water use • Lighting and appliances use • City or countryside **Buildings** • Insulation • District heating share • Technology and fuel share • Heating and cooling efficiency • Appliances efficiency	2 building types 5 non-residential	• Single family homes, multiple family homes • Offices, schools, hospitals, educational buildings, health buildings
	4 End uses	• Space and water heating, • Space cooling • Lighting • Appliances white (fridge, freezer, washing machines, dryer, dishwasher) and black (TV, computer, mobiles)
	9 energy sources and the mix of their heating technology	• Heating-oil, coal, natural-gas, electricity, district-heating, solar-heat, ambient-heat, geothermal, waste-heat
	2 Fuel sources	• Conventional fossil fuel, Biofuel,
	3 Costs	• Fuel, CAPEX (buildings, district heating infrastructures and heating systems), OPEX (existing buildings and infrastructures)

5.2 Interactions with other modules

5.2.1 Lifestyle concerning heating and cooling

The lifestyle module provides the floor area for residential buildings based on the lever "Living space per person" and the fraction of cooled living space to the buildings module.

- lfs_floor-space_cool[1000m2]
- lfs_floor-space[1000m2]

This data, provided by the lifestyle module, is the base for the energy demand calculation for the households meaning the residential buildings. It has an impact on all building results: activity, energy consumption, construction and renovation demand and emissions.

The lifestyle module provides the indoor temperature for residential buildings based on the lever heating and cooling behaviour to the buildings module.

- lfs_heatcool-behaviour[C]

This data, provided by the lifestyle module, is the base for the energy demand calculation for the households meaning the residential buildings. It has an impact on the building energy consumption and emissions.

5.2.2 Manufacturing

The building module delivers the demand for new buildings and buildings renovation to the industry module. This construction demand is separated for residential and non-residential to allow consideration of the different size, geometry, material demand and the different lifetimes. Additionally, the infrastructure demand for district heating is included and delivered in the form of kilometres of pipeline needed.

Output to Industry

- bld_non-res-build[m²]
- bld_reno-non-res-build[m²]
- bld_res-build[m²]
- bld_reno-res-build[m²]
- bld_pipes[km]

BPIE provides to Industry module the number of these three appliances types to calculate the quantity of materials required for new appliances.

- bld_fridges[num]
- bld_freezer[num]
- bld_wash-machines[num]
- bld_dishwashers[num]
- bld_dryer[num]
- bld_tv[num]
- bld_comp[num]
- bld_smartp[num]

Input from technology

BPIE provides the efficiency data to the technology module which is then fed back into the building module to calculate the delivered energy.

- tec_eff-gas-low[kWht/kWhc]
- tec_eff-gas-condens[kWht/kWhc]
- tec_eff-oil-low[kWht/kWhc]
- tec_eff-oil-condens[kWht/kWhc]
- tec_eff-coal[kWht/kWhc]
- tec_eff-biomass[kWht/kWhc]
- tec_eff-solarthermal[kWht/kWhc]
- tec_eff-heatpump[kWht/kWhc]

5.2.3 Supply

The building module delivers the demand for electricity and fossil fuels to the supply module. The electricity demand for appliances and heat is separated to allow for demand side management considerations.

- bld_energy-demand_liquid-ff-oil[TWh]
- bld_energy-demand_gas-ff-natural[TWh]
- bld_energy-demand_heat_electricity[TWh]
- bld_energy-demand_solid-ff-coal[TWh]

- bld_energy-demand_appliances_electricity[TWh]

5.2.4 Agriculture

The building module delivers the demand for solid, liquid and gaseous biomass (bioenergy) to the agriculture module. The demand for woodlog and pellets is separated to allow the consideration of the different production processes.

- bld_biomass_solid-woodlog [TWh]
- bld_biomass_solid-pellets [TWh]
- bld_biomass_liquid [TWh]
- bld_biomass_gas [TWh]

- Climate

The climate module delivers temperature, wind and solar radiation data to the building module. These climate parameters affect the energy demand of the buildings. The building module delivers the emissions of CH4, N2O and CO2 the emissions part of the climate module.

- bld_emissions-CH4[Mt]
- bld_emissions-CO2[Mt]
- bld_emissions-N2O[Mt]

5.3 Detailed calculation trees

The calculation logic for heating that is described in the following sections is applied to both, residential and non-residential buildings.

The energy delivered to the buildings for heating depends on three sets of factors:

1. the population development and the floor space demand per person (one part of the activity level)
2. the mix of different ages and geometries of buildings existing in the countries as well as the climate, behaviour and insulation-based heat losses, this forms a second part of the activity level and contains the passive technologies in the buildings
3. the heating technologies are part of the active elements in a building and encompass the fuel type (e.g. biomass, gas) and the technology mix (e.g. heat pump) and the efficiency of the systems

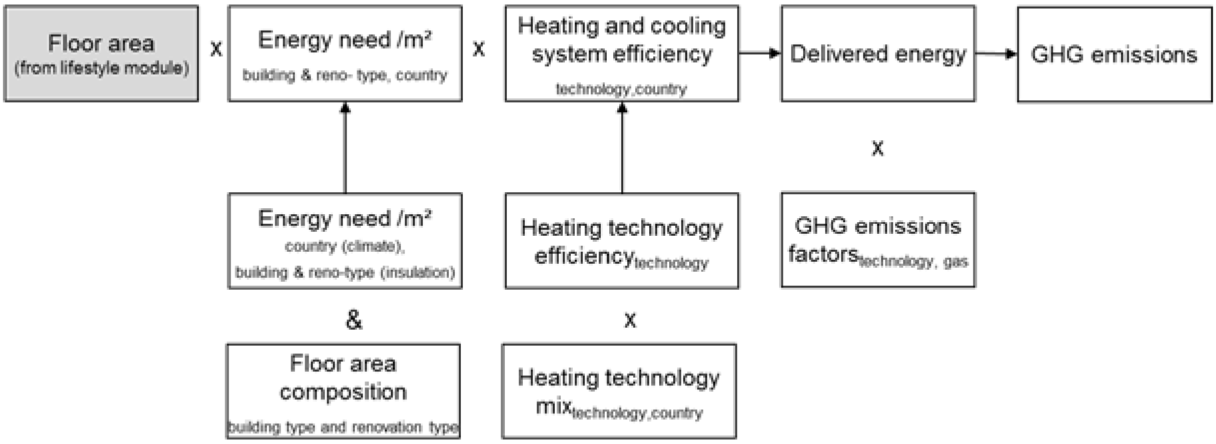

Figure 3 - Calculation logic of heating within the buildings' module.

The following subsections describe the details of the three subsets.

5.3.1 Floor area demand in residential and non-residential buildings

<u>Inputs</u>

- Total residential floor area: provided by the lifestyle module
- Total non-residential floor area estimation: from Building Stock Observatory/ Odyssee Mure, (Fleiter et al. 2016)
- Building mix: split of floor area into building types (e.g. single-family home, multi-family home): from Building Stock Observatory/ Odyssee Mure

<u>Processing</u>

The total floor area of a building stock for a country in a specific year shall be defined as $a_{country,year}$. It is composed of buildings that shall be categorized in different building types (b_type):

Table 1 building types with their acronyms and outputs

Acronym	Building type name
Sfh	Single Family House
Mfh	Multi-Family House
Offices	Offices
Hotels	Hotels and Restaurants
Trade	Services and trade
Education	Education buildings
Health	Health buildings
Other	Other buidings

The buildings of the different types contribute to the total floor area:

$$a_{country,year} = \sum_{btype=1}^{n} a_{btype}.$$

With $btype \coloneqq \{btype_{residential}, btype_{non-residential}\}$, where

$btype_{residential} \coloneqq \{sfh, mfh\}$ and

$btype_{non-residential} \coloneqq \{offices, trade, hotels, health, edcuation, other\}$.

Accordingly, the floor area disaggregates into residential and non-residential floor area that can each be split into the building type floor areas.

$$a_{country,year} = \{a_{residential,year}, a_{non-residential,year}\}$$

$$a_{country,year} = \left\{ \sum_{btype=1}^{n} a_{residential,btype,year}, \sum_{btype=1}^{n} a_{non-residential,btype,year} \right\}$$

Residential

The total residential floor area development is provided by the lifestyle module for the past and the future. This includes the observed time series from 1990-2015 and the future time series until 2050, which depends on the population lever.

As buildings of different types have different energy performance it is necessary for the energy demand calculation to split the floor area into the building types. The building stock observatory provides the floor area split for 2015, necessary to calculate the share of each building type by floor area $\frac{a_{residential,btype,2015}}{a_{residential,2015}}$, i.e.:

$$a_{country,residential,btype,year} = a_{residential,year} * \frac{a_{residential,btype,2015}}{a_{residential,2015}}$$

Observed time series

The total residential floor area development in the past is provided by the lifestyle module. The floor area is split into single family homes (SFH) and multi-family homes (MFH) by building stock observatory data.

Future time series

The future development is taken from lifestyle and split by building type following the current split from the building stock observatory.

Non-residential

The non-residential floor area by building type is provided in the building stock observatory for the past. The building types are offices, services and commercial, education buildings, health buildings, hotels and restaurants. This includes the observed time series from 1990 to 2015. The future time series until 2050 will be estimated by applying the residential floor area growth rate to all building types. The underlying assumption is that with increasing population the non-residential sector grows at the same rate, i.e. number of restaurants, schools, hospital etc.

$$a_{non-residential,btype,year} = a_{non-residential,btype,2015} * \frac{a_{residential,year}}{a_{residential,2015}}$$

Observed time series	Future time series
The total non-residential floor area past development split by building type is provided in the building stock observatory.	The future development of the total non-residential floor area is assumed to follow the trend for residential buildings. The split by building type follows the current split from the building stock observatory.

Table 1 Overview of data sets for the observed and future time series

Subsector	Data set	Observed time series	Future time series
Residential	Total floor area	Obtained from lifestyle	Obtained from lifestyle
	Split by building type	Building Stock Observatory (BSO) data	2015 split from BSO data
	Split by building age	No split for now	No split for now
Non-residential	Total floor area	BSO data	Follows the development for residential floor area
	Split by building type	BSO data	2015 split from BSO data
	Split by building age	No split for now	No split for now

Outputs

Residential total floor area split by	bld_floor-area_residential[Mm²],
· Single Family House	bld_floor-area_residential_sfh[Mm²]
· Multi-Family House	bld_floor-area_residential_mfh[Mm²]
Non-residential total floor area split by	bld_floor-area_non-residential[Mm²],
· Offices	bld_floor-area_non-residential_offices[Mm²]
· Hotels and Restaurants	bld_floor-area_non-residential_hotels[Mm²]
· Services and trade commercial	bld_floor-area_non-residential_trade[Mm²]
· Education buildings	bld_floor-area_non-residential_education[Mm²]
· Health buildings	bld_floor-area_non-residential_health[Mm²]
· Other buildings	bld_floor-area_non-residential_other[Mm²]

Sources

Fleiter, Tobias et al. 2016. "Mapping and Analyses of the Current and Future (2020-2030) Heating/Cooling Fuel Deployment (Fossil/Renewables). Work Package 2: Assessment of the Technologies for the Year 2012." *Hg. v. EUROPEAN COMMISSION: DIRECTORATE-GENERAL FOR ENERGY. Online verfügbar unter*

ec.europa.eu/energy/en/studies/mapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel-deployment .

https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-performance-of-buildings/eubuildings

5.3.2 Energy need for heating in residential and non-residential buildings

The calculations in the building module are aligned with the guideline for cost optimality of minimum requirements (European Commission 2012, 11) and follows the terminology. From there we use the terms "energy need" and "delivered energy" within the calculation in the building module and the description in the following paragraphs as shown in figure 4. The calculation steps presented hereafter represent the steps one and three in figure 4*Figure 4*, the first one covers the energy need.

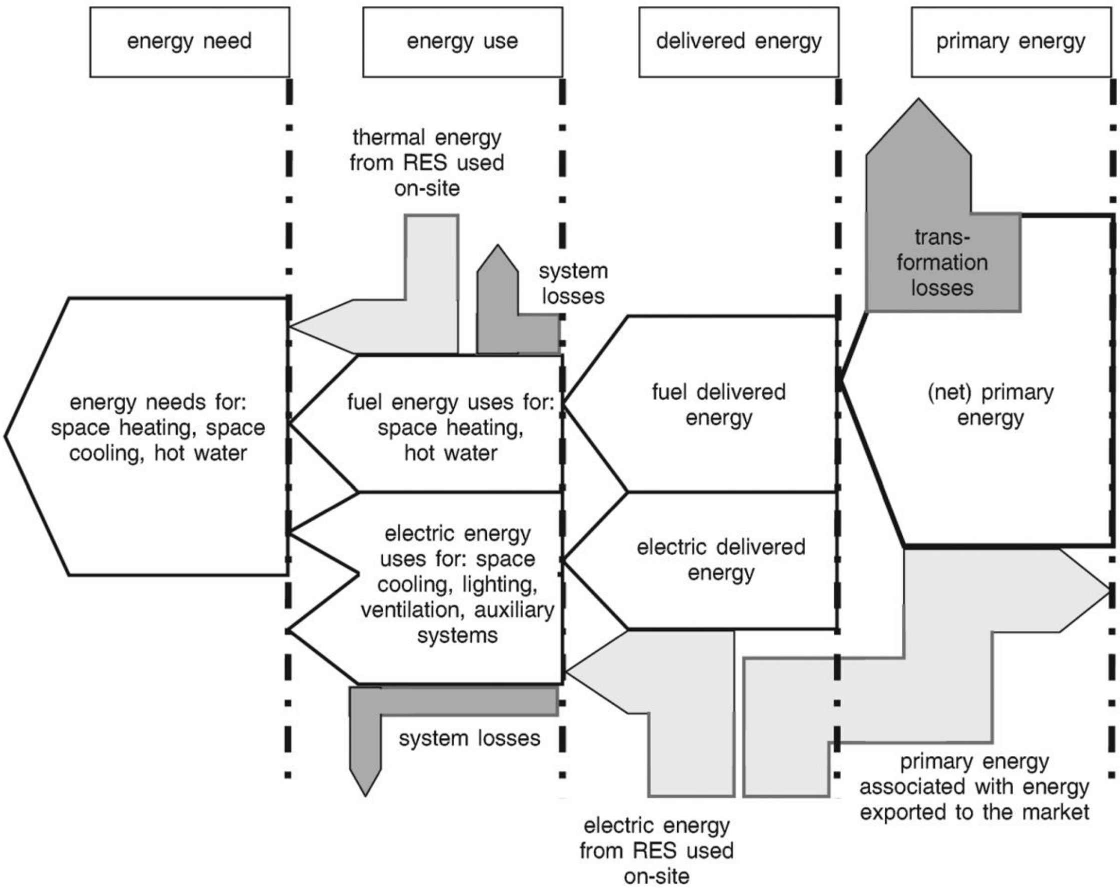

Figure 4 – Schematic illustration of the calculation scheme in the guideline for cost optimality of minimum requirements (European Commission 2012, 11)

The goal of this first step in figure 4*Figure 4* is to compute the building energy need by building type, such as single-family house (sfh), multi-family house (mfh), office, hotel, educational building.

The energy need depends on the fabric of buildings (including its level of insulation) which determines how efficient a building is at keeping heat and cold inside. The rate of heat lost from a building which is treated as one zone in the model depends on the difference in internal and external temperature, and the thermal 'leakiness' of buildings. The quality of the building envelope is critical to prevent those losses through thermal conduction and convection[4]. The design of the buildings allows for or cuts down on solar gains.

Hence, the energy need depends also on the climate. Outdoor temperature as well as wind determine the thermal losses, while solar gains depend on the solar radiation.

The energy need is calculated in a static model according to the monthly calculation method in the norm EN13790 eq. 4ff. It is handled separately from the delivered energy for different reasons:

- to isolate the contributions of insulation from heating system efficiency.
- to show the impact of renovation rate, which determines the amount of floor area renovated and the impact renovation depth, which is the quality and ambition of the renovation measure resulting in energy saved with each renovated square meter.
- to show the contribution of behavioural actions, such as heating behaviour

The outputs of this calculation step are of two types:

- Building energy need expressed in kWh/m². The main drivers for the energy need are the difference in internal and external temperature, and the thermal 'leakiness' of buildings. The 'leakiness' is quantified by the 'Heat Loss Coefficient' (HLC) which takes account of both fabric losses and ventilation losses. Another driver for the total energy need is the floor space demand per person and the desired indoor temperature, both are to a degree[5] user choices.
- Cost of renovation measures in MEUR: a certain average energy need across the building stock can be achieved through a combination of how many buildings are renovated as well as how ambitiously they are renovated. These different combinations lead to different costs, as the cost are higher for deeper renovations, but they enable higher energy savings.

5.3.3 Delivered energy: Heating systems, fuel mix and efficiencies

The heating technologies and encompass the fuel type (e.g. biomass, gas) and the technology mix (e.g. heat pump) and the efficiency of the systems. As active components of the building they transform the energy delivered to the building and supply the heat to the rooms where it is needed.

The calculation step from energy need to delivered energy represents the step of equipping a building with system for heating and cooling. The basis for this calculation are the heating

[4] Thermal conduction is the transmission of heat through solid media, such as walls, roofs but also windows. Convection is the transport of the heat with a medium such as air or water and it can happen with ventilation and wastewater discharge.

[5] The floor area of a flat for renting for example is usually also dependent on the offered sizes and the market prices, not only on the preferences on the decision maker.

and cooling systems[6] their use and efficiency[7] in the different countries in Europe according to the energy mix from Eurostat[3] and the technology mix determined by the Mapping Analysis[2]. The calculation includes GHG emissions based on fuel and technology specific factors.

With the technology and fuel share lever the user can influence the future fuel mix, see detailed description in section 3.5.2. A coherence of the overall fuel mix is ensured by the energy and land-use modules, i.e. respecting biomass and solar potentials and alignment to electricity supply.

The efficiency lever allows the user to drive the efficiency innovation and diffusion, see section 3.5.3.

The official statistics on heat generation and fuel shares[1] show that 0.05% of the gas in the natural gas network in Germany is biomethane. This assumption for the share of biomethane is distributed throughout Europe.

5.3.4 References

[1] Destatis Genesis-Online Database, retrieved from www.destatis.de/DE/Themen/Branchen-Unternehmen/Energie/Erzeugung/Tabellen/elekrizitaet-waermeerzeugung-energietraeger-monatsbericht.html, Statistisches Bundesamt Deutschland, cited on 22.05.2019.

[2] Fleiter, Tobias et al. 2016. "*Mapping and Analyses of the Current and Future (2020-2030) Heating/Cooling Fuel Deployment (Fossil/Renewables). Work Package 2: Assessment of the Technologies for the Year 2012.*". prepared for European Commission under contract N°ENER/C2/2014-641. retrieved from ec.europa.eu/energy/en/studies/mapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel-deployment, cited on 22/05/2019.

[3] Eurostat, Energy consumption in households, retrieved from ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households , cited on 22.05.2019.

5.4 Description of levers and ambition levels

5.4.1 Lever list and description

Table 3 – List of levers for heating, district heating and appliances

	Lever	Brief description	Content

[6] The system for indoor heat distribution is not considered, as it does not impact the amount of heating needed in the buildings, if you describe the building in a one zone model. The cost for distribution systems vary with a high bandwidth, therefore uncertainty is high.
[7] The efficiency is given as a ratio between the final energy demand kWhfin and the end use heat demand kWhheat.

1.	**Living space demand per person [in lifestyle]**	This lever controls the average living space per person.	The living space demand per person affects the energy consumption. The more floor area is heated in total the higher the energy demand. Reducing the average size of dwellings for example by sharing kitchens and common areas will impact emission levels.
2.	**Building envelope**	This lever controls the average heat loss which is reduced by insulation and affects the energy need per floor area.	Heating and cooling accounts for around 30% of all the energy demand of buildings. The amount of energy needed to heat or to cool buildings can be reduced significantly by improving external walls, floors, roofs, ceilings, windows and doors so that the building is better insulated. This means that less heat energy can escape from the inside of the building during cold weather, and less heat energy from outside can get in if you are cooling it[8]
3.	**Indoor temperature [in lifestyle]**	This lever controls the average room temperature during warm and cold times of the year.	Heating and cooling represent a big proportion of the energy demand of buildings. The energy demand will increase when indoor temperatures significantly deviate from outdoor temperatures.
4.	**Material use [in industry]**	This lever controls the material used to construct or insulate a building and manufacture the HVAC systems.	The carbon emissions and energy input associated with products such as steel, wood or insulation can be reduced by 3 ways: (i) reduction of required material during manufacturing, which can be done through improvements in the design, (ii) switching to less carbon-intensive materials and (iii) using more recycled material to reduce energy & emissions.
5.	**Heating and cooling (ventilation) system efficiency**	This lever controls the average energy loss in heating, cooling and ventilation systems and district heating generation.	HVAC systems have recently become more energy efficient. Increase in the energy efficiency lowers the emissions impact.
6.	**District heating share**	This lever controls the level of heating energy demand covered by district heating.	District heating can facilitate decarbonisation buildings in dense urban areas even with decreasing heat density. Buildings in dense urban areas are particularly hard to fully release from their energy need partly due to historic or special restrictions.
7.	**Technology and fuel share**	This lever controls the mix of technologies used for spare heating, space cooling, hot water, cooking and lighting and district heating.	A variety of different technologies are used in buildings for space heating, water heating and cooking. These technologies can have very different efficiencies and emissions associated with them. Today, the most common forms of heating in urban areas are combined heat and power (CHP), district heating, and gas boilers. In rural areas, solid fuel boilers are most common. In the future, new technologies could be used which have much lower emissions, for example heat pumps (which use electricity to move latent heat energy from the outside of the building to the inside) and solar hot water systems. This lever allows you to change the proportion of buildings using these new forms, and therefore to reduce emissions. Similarly, this lever also increases the proportion of cooling systems that use more efficient and lower carbon technology. The technologies for space cooling within the model are air conditioning, chillers and solar cooling.

[8] http://tool.globalcalculator.org/gc-lever-description-v23.html?id=13/en

8.	**Appliances, cooking, lighting efficiency**	This lever controls the average rate of energy use for appliances, cooking and lighting.	A variety of different technologies are used in buildings for cooking, lighting and appliances. This lever allows you to use more electricity in cooking (rather than gas, oil or traditional biomass), and to introduce more efficient lighting options like LED bulbs.
9.	**Appliances, cooking, lighting behaviour and use [in lifestyle]**	This lever controls the average number of appliances per urban and rural household. It also controls average cooking and lighting demand.	The appliances modelled for this lever are refrigerators, dishwashers, clothes washers, clothes dryers and TVs. Miscellaneous appliances like laptops and DVD players are modelled separately. It also controls the number of lightbulbs per household, and energy demand for cooking.

5.4.2 Definition of ambition levels

The Table here under describes the 4 ambition levels used for the transport module.

Table 4 – Definition of ambition levels

Level 1	**Level 2**
This level contains projections that are aligned and coherent with the observed trends	This level is an intermediate scenario, more ambitious than business as usual but not reaching the full potential of available solutions.
Level 3 This level is considered very ambitious but realistic, given the current technology evolutions and the best practices observed in some geographical areas.	**Level 4** This level is considered as transformational and requires large additional efforts such as strong changes in the way society is organized, a very fast market uptake of deep measures, an extended deployment of infrastructures, major technological advances and breakthroughs (but without relying on new fundamental research), etc.

5.5 Lever specification

5.5.1 Building envelope

5.5.1.1 Lever description

This lever sets the energetic quality of the building envelope. When considering a building stock, the envelopes' qualities are changed by several processes: the renovation and the demolition which is replaced by new construction. Therefore, demolition rate and renovation rate are set by this lever. In addition, the new construction and the renovation can be conducted at different quality levels. Within this model we define three quality levels for new construction and renovation: shallow, medium and deep. How many buildings are constructed and renovated at each quality level will influence the quality of the building stock. Therefore, the quality mix for construction and renovation are also included in this lever. Consequently, the user will change the ambition for the following drivers, when using the building envelope lever:

- renovation rate,
- renovation quality mix,
- demolition rate,
- new building quality mix[9].

5.5.1.2 Rationale for lever and level choices

The drivers above were combined to

- … aggregate the drivers that influence the building envelope
- … combine the measures that increase the energy efficiency in a building
- … avoid overwhelming the user with too many choices.

The observed renovation rate lies at about 0.5 – 2.5% noted by [4] p.58, [5] p.3, [6] p.103, [7] p.10. As a maximum 3% are commonly used for the renovation rate and the whole building stock would be renovated between today and 2050 as noted by [1] p.90, [3] p.1, [2] p.4, [6] p.3. However, in expert opinion such a renovation rate is not likely to be achieved [8] p.10.

The renovation and construction mix determine the energy needed after the measures. The categories shallow, medium and deep aggregate the diversity of different energy qualities as follows. They are assigned one energy need value each while their share varies in the different pathways enabling a transparent representation of the distribution of different energy qualities. The representative energy needs are 100kWh/m² in the shallow category, 75 kWh/m² in the medium category and 50kWh/m² in the deep category.

The assumption that most renovations entail no measures exceeding the minimum requirements[10] is reflected in the share of shallow and medium renovations as well as minimum and nearzero in new built in the Level 1 pathway that continues the observed trend. As opposed to that the Level 4 scenario assumes the majority of

[9] The new building rate is a consequence of the demolition rate and of the evolution of the overall floor area need. The floor area needed is an input from the lifestyle module and depends on the growth of the population (this is also a lever) and on the m²/person (this is also a lever).

[10]

renovations to include very ambitious measures and a small share of medium ambitious envelope renovations.

5.5.1.3 Ambition levels & disaggregation method

EU-Levels

Name / Unit		1	2	3	4
annual renovation rate (%) [1]		1%	1.5%	2%	3%
renovation mix (%)	shallow	80%	20%	10%	0%
	medium	15%	60%	70%	30%
	deep	5%	20%	20%	70%
annual demolition rate (%)		0.1%	0.4%	0.7%	1%
new construction mix (%)[11]	minimum	80%	20%	10%	0%
	nearzero	15%	60%	70%	30%
	plusenergy	5%	20%	20%	70%

Disaggregation by country

Name / Unit	Disaggregation method	Exceptions/outlyers
annual renovation rate (%)	same assumptions for the percentage rates and mixes, but applied to building stocks that are detailed by country.	
renovation mix (%)		
annual demolition rate (%)		
new construction mix (%)		

5.5.1.4 Source references

[1] European Commission. 2018. In-depth analysis in support of the Commission communication COM(2018) 773. A Clean Planet for all - A European long-term strategic vision for a prosperous, modern, competitive and climate neutral economy. November 2018.
[2] Boermans, Thomas, K Bettgenhäuser, M Offermann, and S Schimschar. 2012. "Renovation Tracks for Europe up to 2050." *Ecofys Germany: Köln, Germany*.
[3] Bettgenhäuser, Kjell, Rolf de Vos, Jan Grözinger, and Thomas Boermans. 2014. "Deep Renovation of Buildings: An Effective Way to Decrease Europe's Energy Import Dependency." *ECOFYS Germany GmbH by order of Eurima, Germany, Project Number: BUIDE14901*.
[4] D'Agostino, Delia et al. 2016. "Synthesis Report on the National Plans for Nearly Zero Energy Buildings (NZEBs)." *Joint Research Center (JRC) publications*.
[5] Dean, Brian, John Dulac, Ksenia Petrichenko, and Peter Graham. 2016. "Towards Zero-Emission Efficient and Resilient Buildings.: Global Status Report."
[6] Buildings Performance Institute Europe (BPIE). 2011. *Europe's buildings under the microscope*. Buildings Performance Institute Europe. bpie.eu/publication/europes-buildings-under-the-microscope/.
[7] Hansen, Patrick. 2005. "Evaluierung Der CO 2 -Minderungsmaßnahmen Im Gebäudebereich." *BBR-Online-Publikation* June 2005: 46.

[11] shallow= minimum regulation; medium = nearly zero; deep = plus energy

[8] Sandberg, Nina Holck et al. 2016. "Dynamic Building Stock Modelling: Application to 11 European Countries to Support the Energy Efficiency and Retrofit Ambitions of the EU." *Energy and Buildings* 132: 26–38.
[9] Fleiter, Tobias et al. 2016. 09 Prepared for: European Commission under contract N°ENER/C2/2014-641 *Mapping and Analyses of the Current and Future (2020-2030) Heating/Cooling Fuel Deployment (Fossil/Renewables). Work Package 2: Assessment of the Technologies for the Year 2012*. European commission: Directorate-general for energy. ec.europa.eu/energy/en/studies/mapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel-deployment .
[10] Fleiter, Tobias et al. 2016. 09 Prepared for: European Commission under contract N°ENER/C2/2014-641 *Mapping and Analyses of the Current and Future (2020-2030) Heating/Cooling Fuel Deployment (Fossil/Renewables). Work package 1: Final energy consumption for the year 2012*. European commission: Directorate-general for energy. ec.europa.eu/energy/en/studies/mapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel-deployment.
[11] Odysee-Mure , *Heating consumption per m2 and Energy consumption by end-use*, retrieved from www.odyssee-mure.eu/publications/efficiency-by-sector/households/heating-consumption-per-m2.html and www.odyssee-mure.eu/publications/efficiency-by-sector/households/energy-consumption-by-end-use.html, cited on 22.05.2019.
[12] Eurostat , *Energy consumption in households*, retrieved from ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households, cited on 22.05.2019.
[13] Institut Wohnen und Umwelt et al. 2018. Monitoring Der KfW-Programme „ Energieeffizient Sanieren " Und „ Energieeffizient Bauen " 2016. Auftraggeber KfW Bankengruppe Gutachten. www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-alle-Evaluationen/Monitoringbericht_EBS_2016.pdf .
[14] Umwelt, Institut Wohnen und et al. 2018. Monitoring Der KfW-Programme „ Energieeffizient Sanieren " Und „ Energieeffizient Bauen " 2017. www.kfw.de/PDF/Download-Center/Konzernthemen/Research/PDF-Dokumente-alle-Evaluationen/Monitoring-der-KfW-Programme-EBS-2017.pdf .

.

5.5.2 Technology and fuel share for in-house heating and cooling technologies

That for each country the share for each technology shall be defined for each pathway. Therefore, we have simplified and aggregated all technologies for one fuel type in one sheet. This also means that we will have a mixed efficiency and a mixed cost value for all technologies that are covered by one energy carrier, for example gas.

5.5.2.1 Lever description

This lever controls the mix of technologies used to supply heating within the buildings. It is combined with the mix of technologies in district heating, see section 4.4.3.

5.5.2.2 Rationale for lever and level choices

The basis for the lever level definition is the initial fuel mix. For each fossil fuel, as the reduction share until 2050 is applied as shown in the table detailing "EU-Levels" below. The reduction in fossil fuels is balanced by an addition to any type of heat pumps (assuming to need only one fourth of the energy and including also geothermal and solar-thermal heat sources) and biomass.

The mix between heat pumps and biomass does not contribute to the ambition level for GHG savings as such. However, biomass is cheap to implement and causes unhealthy emissions such as particulate matter. The implementation of heat pumps can serve the balancing of the electricity system and can be used for heating and cooling. From a social perspective, heat pumps are more expensive in their installation and depend on a valuable and high-priced energy form electricity, where biomass is cost free in quite a lot of countries in Europe.

5.5.2.2.1 Disaggregation methodology rational

The basis for the fuel share at each lever level for the single countries is the initial fuel mix in the households[12] as given by Eurostat[1].

To obtain the fuel share in 2050 the reduction defined in the EU-Levels is applied to end up the value detailed in the table "Disaggregation by country" below.

5.5.2.3 Ambition levels & disaggregation method

The following paragraphs describe the assumptions for the lever level settings for the possible future mix of technologies.

EU-Levels

Name / Unit	1	2	3	4
share of gas	- 5%	-50%	-65%	-95%
share of coal	-30%	-80%	-90%	-95%
share of heating oil	-10%	-50%	-65%	-95%
substitution by heat pumps (including heat from air, solar-thermal and geothermal sources)	30%	40%	50%	70%
substitution by biomass	70%	60%	50%	30%

These assumptions are suggested to implement the fossil fuel phase out that is currently being discussed in some of the member states and that will spread across Europe with the ambition level.

Disaggregation by country

Country	2015	1	2	3	4
Austria	electricity 7% gas 22% coal 0% oil 20% renewables 20%	electricity 7% gas 21% coal 0% oil 18% renewables 18%	electricity 9% gas 11% coal 0% oil 10% renewables 10%	electricity 10% gas 8% coal 0% oil 7% renewables 7%	electricity 14% gas 1% coal 0% oil 1% renewables 1%

12 The assumptions of the fuel mix for heating in households is also applied to non-residential buildings.

Belgium	electricity 3% gas 49% coal 1% oil 36% renewables 36%	electricity 4% gas 47% coal 1% oil 33% renewables 33%	electricity 8% gas 25% coal 0% oil 18% renewables 18%	electricity 10% gas 17% coal 0% oil 13% renewables 13%	electricity 18% gas 2% coal 0% oil 2% renewables 2%
Bulgaria	electricity 9% gas 4% coal 13% oil 0% renewables 0%	electricity 9% gas 4% coal 9% oil 0% renewables 0%	electricity 10% gas 2% coal 3% oil 0% renewables 0%	electricity 10% gas 1% coal 1% oil 0% renewables 0%	electricity 11% gas 0% coal 1% oil 0% renewables 0%
Croatia	electricity 2% gas 21% coal 0% oil 5% renewables 5%	electricity 2% gas 20% coal 0% oil 5% renewables 5%	electricity 3% gas 10% coal 0% oil 3% renewables 3%	electricity 4% gas 7% coal 0% oil 2% renewables 2%	electricity 6% gas 1% coal 0% oil 0% renewables 0%
Cyprus	electricity 34% gas 0% coal 0% oil 57% renewables 57%	electricity 35% gas 0% coal 0% oil 51% renewables 51%	electricity 37% gas 0% coal 0% oil 28% renewables 28%	electricity 39% gas 0% coal 0% oil 20% renewables 20%	electricity 44% gas 0% coal 0% oil 3% renewables 3%
Czech Republic	electricity 4% gas 27% coal 18% oil 1% renewables 1%	electricity 5% gas 26% coal 13% oil 1% renewables 1%	electricity 7% gas 13% coal 4% oil 0% renewables 0%	electricity 9% gas 9% coal 2% oil 0% renewables 0%	electricity 12% gas 1% coal 1% oil 0% renewables 0%
Denmark	electricity 3% gas 16% coal 0% oil 4% renewables 4%	electricity 3% gas 15% coal 0% oil 4% renewables 4%	electricity 4% gas 8% coal 0% oil 2% renewables 2%	electricity 5% gas 6% coal 0% oil 2% renewables 2%	electricity 6% gas 1% coal 0% oil 0% renewables 0%
Estonia	electricity 1% gas 8% coal 1% oil 3% renewables 3%	electricity 1% gas 7% coal 1% oil 3% renewables 3%	electricity 1% gas 4% coal 0% oil 1% renewables 1%	electricity 2% gas 3% coal 0% oil 1% renewables 1%	electricity 3% gas 0% coal 0% oil 0% renewables 0%
Finland	electricity 26% gas 1% coal 0% oil 8% renewables 8%	electricity 26% gas 1% coal 0% oil 7% renewables 7%	electricity 26% gas 0% coal 0% oil 4% renewables 4%	electricity 26% gas 0% coal 0% oil 3% renewables 3%	electricity 27% gas 0% coal 0% oil 0% renewables 0%
France	electricity 13% gas 38% coal 0% oil 18% renewables 18%	electricity 13% gas 37% coal 0% oil 16% renewables 16%	electricity 16% gas 19% coal 0% oil 9% renewables 9%	electricity 18% gas 13% coal 0% oil 6% renewables 6%	electricity 22% gas 2% coal 0% oil 1% renewables 1%
Germany	electricity 2% gas 46% coal 1% oil 26% renewables 26%	electricity 2% gas 44% coal 1% oil 23% renewables 23%	electricity 6% gas 23% coal 0% oil 13% renewables 13%	electricity 8% gas 16% coal 0% oil 9% renewables 9%	electricity 14% gas 2% coal 0% oil 1% renewables 1%
Greece	electricity 7% gas 13% coal 0% oil 50% renewables 50%	electricity 8% gas 12% coal 0% oil 45% renewables 45%	electricity 11% gas 6% coal 0% oil 25% renewables 25%	electricity 13% gas 4% coal 0% oil 18% renewables 18%	electricity 18% gas 1% coal 0% oil 3% renewables 3%
Hungary	electricity 1% gas 51% coal 3% oil 0% renewables 0%	electricity 1% gas 48% coal 2% oil 0% renewables 0%	electricity 4% gas 26% coal 1% oil 0% renewables 0%	electricity 5% gas 18% coal 0% oil 0% renewables 0%	electricity 10% gas 3% coal 0% oil 0% renewables 0%
Ireland	electricity 4% gas 24%	electricity 5% gas 23%	electricity 9% gas 12%	electricity 12% gas 9%	electricity 19% gas 1%

	coal 21% oil 47% renewables 47%	coal 15% oil 43% renewables 43%	coal 4% oil 24% renewables 24%	coal 2% oil 17% renewables 17%	coal 1% oil 2% renewables 2%
Italy	electricity 0% gas 61% coal 0% oil 8% renewables 8%	electricity 1% gas 58% coal 0% oil 7% renewables 7%	electricity 4% gas 30% coal 0% oil 4% renewables 4%	electricity 6% gas 21% coal 0% oil 3% renewables 3%	electricity 12% gas 3% coal 0% oil 0% renewables 0%
Latvia	electricity 1% gas 8% coal 1% oil 3% renewables 3%	electricity 1% gas 7% coal 1% oil 3% renewables 3%	electricity 1% gas 4% coal 0% oil 1% renewables 1%	electricity 2% gas 3% coal 0% oil 1% renewables 1%	electricity 3% gas 0% coal 0% oil 0% renewables 0%
Lithuania	electricity 1% gas 9% coal 5% oil 1% renewables 1%	electricity 1% gas 9% coal 4% oil 1% renewables 1%	electricity 2% gas 5% coal 1% oil 1% renewables 1%	electricity 3% gas 3% coal 1% oil 0% renewables 0%	electricity 4% gas 0% coal 0% oil 0% renewables 0%
Luxembourg	electricity 4% gas 50% coal 0% oil 39% renewables 39%	electricity 5% gas 48% coal 0% oil 35% renewables 35%	electricity 9% gas 25% coal 0% oil 20% renewables 20%	electricity 11% gas 18% coal 0% oil 14% renewables 14%	electricity 19% gas 3% coal 0% oil 2% renewables 2%
Malta	electricity 34% gas 0% coal 0% oil 57% renewables 57%	electricity 35% gas 0% coal 0% oil 51% renewables 51%	electricity 37% gas 0% coal 0% oil 28% renewables 28%	electricity 39% gas 0% coal 0% oil 20% renewables 20%	electricity 44% gas 0% coal 0% oil 3% renewables 3%
Netherlands	electricity 2% gas 87% coal 0% oil 1% renewables 1%	electricity 2% gas 83% coal 0% oil 1% renewables 1%	electricity 6% gas 44% coal 0% oil 0% renewables 0%	electricity 9% gas 31% coal 0% oil 0% renewables 0%	electricity 16% gas 4% coal 0% oil 0% renewables 0%
Poland	electricity 1% gas 14% coal 45% oil 1% renewables 1%	electricity 2% gas 14% coal 32% oil 1% renewables 1%	electricity 5% gas 7% coal 9% oil 0% renewables 0%	electricity 7% gas 5% coal 5% oil 0% renewables 0%	electricity 11% gas 1% coal 2% oil 0% renewables 0%
Portugal	electricity 19% gas 1% coal 0% oil 8% renewables 8%	electricity 19% gas 1% coal 0% oil 7% renewables 7%	electricity 19% gas 1% coal 0% oil 4% renewables 4%	electricity 19% gas 0% coal 0% oil 3% renewables 3%	electricity 20% gas 0% coal 0% oil 0% renewables 0%
Romania	electricity 0% gas 28% coal 1% oil 0% renewables 0%	electricity 0% gas 27% coal 0% oil 0% renewables 0%	electricity 2% gas 14% coal 0% oil 0% renewables 0%	electricity 3% gas 10% coal 0% oil 0% renewables 0%	electricity 5% gas 1% coal 0% oil 0% renewables 0%
Slovakia	electricity 4% gas 27% coal 18% oil 1% renewables 1%	electricity 5% gas 26% coal 13% oil 1% renewables 1%	electricity 7% gas 13% coal 4% oil 0% renewables 0%	electricity 9% gas 9% coal 2% oil 0% renewables 0%	electricity 12% gas 1% coal 1% oil 0% renewables 0%
Slovenia	electricity 4% gas 12% coal 0% oil 15% renewables 15%	electricity 4% gas 11% coal 0% oil 14% renewables 14%	electricity 5% gas 6% coal 0% oil 8% renewables 8%	electricity 6% gas 4% coal 0% oil 5% renewables 5%	electricity 8% gas 1% coal 0% oil 1% renewables 1%
Spain	electricity 7% gas 24% coal 1% oil 31%	electricity 7% gas 23% coal 1% oil 28%	electricity 10% gas 12% coal 0% oil 15%	electricity 11% gas 9% coal 0% oil 11%	electricity 16% gas 1% coal 0% oil 2%

	renewables 31%	renewables 28%	renewables 15%	renewables 11%	renewables 2%
Sweden	electricity 31% gas 1% coal 0% oil 0% renewables 0%	electricity 31% gas 1% coal 0% oil 0% renewables 0%	electricity 31% gas 0% coal 0% oil 0% renewables 0%	electricity 31% gas 0% coal 0% oil 0% renewables 0%	electricity 31% gas 0% coal 0% oil 0% renewables 0%
Switzerland	electricity 7% gas 22% coal 0% oil 20% renewables 20%	electricity 7% gas 21% coal 0% oil 18% renewables 18%	electricity 9% gas 11% coal 0% oil 10% renewables 10%	electricity 10% gas 8% coal 0% oil 7% renewables 7%	electricity 14% gas 1% coal 0% oil 1% renewables 1%
United Kingdom	electricity 7% gas 76% coal 2% oil 9% renewables 9%	electricity 7% gas 72% coal 2% oil 8% renewables 8%	electricity 11% gas 38% coal 0% oil 5% renewables 5%	electricity 14% gas 27% coal 0% oil 3% renewables 3%	electricity 21% gas 4% coal 0% oil 0% renewables 0%

5.5.2.4 Source references

[1] Eurostat , Energy consumption in households, retrieved from ec.europa.eu/eurostat/statistics-explained/index.php/Energy_consumption_in_households, cited on 22.05.2019.

5.5.3 Heating and cooling efficiency

5.5.3.1 Lever description

This lever controls the average energy loss in heating, cooling and ventilation systems and district heating generation. HVAC systems are becoming more and more energy efficient. Increase in the energy efficiency lowers the emissions impact.

5.5.3.2 Rationale for lever and level choices

The efficiency of the systems within the building stock differ in age and technology, for example low temperature boilers versus condensing boilers. The efficiency of the whole system depends on the efficiency, insulation and configuration of several components of the heating system. How they are integrated in the individual building can be very different, the boiler however is most comparable. Therefore, the efficiency of the boiler is used to represent improvement of the efficiency of the heating system.

Almost all boilers should be replaced at least once between 2015 and 2050 as the substitution rate based on technical lifetime of a boiler is around 3.1%/a and thus the average lifetime approximately 25 years[1]. The efficiency of all the boilers in 2050 is thus dependent on the learning curve. If ambitious technologies are introduced quickly, then they will equipp most of the buildings. The average efficiency will be higher compared to a slow market diffusion. The higher average efficiency associated with level 4 means a faster distribution of ambitious heating system compared to other ambition levels.

5.5.3.2.1 Disaggregation methodology rational

The efficiency values for the boilers are assumed to be the same within Europe, as these products can easily be traded across borders. As a starting point the current efficiencies are used per country.

5.5.3.3 Ambition levels & disaggregation method

EU-Levels

Efficiency improvement	1	2	3	4
fossil	3%	5%	10%	18%
biomass	15%	17%	22%	31%

Disaggregation by country

Country	2015 [2-5]	1	2	3	4
Austria	gas 83%, coal 54%, oil 86%, renewables 55%	gas 86%, coal 56%, oil 89%, renewables 63%	gas 87%, coal 57%, oil 91%, renewables 64%	gas 91%, coal 59%, oil 95%, renewables 67%	gas 98%, coal 64%, oil 98%, renewables 72%
Belgium	gas 80%, coal 56%, oil 77%, renewables 65%	gas 83%, coal 57%, oil 79%, renewables 74%	gas 84%, coal 59%, oil 81%, renewables 76%	gas 88%, coal 61%, oil 84%, renewables 79%	gas 94%, coal 65%, oil 90%, renewables 85%
Bulgaria	gas 83%, coal 63%, oil 72%, renewables 59%	gas 85%, coal 65%, oil 75%, renewables 68%	gas 87%, coal 67%, oil 76%, renewables 69%	gas 91%, coal 70%, oil 80%, renewables 72%	gas 97%, coal 75%, oil 85%, renewables 77%
Croatia	gas 82%, coal 59%, oil 79%, renewables 58%	gas 85%, coal 61%, oil 81%, renewables 66%	gas 87%, coal 62%, oil 83%, renewables 68%	gas 91%, coal 65%, oil 87%, renewables 71%	gas 97%, coal 69%, oil 93%, renewables 76%
Cyprus	gas 82%, coal 60%, oil 76%, renewables 56%	gas 85%, coal 62%, oil 79%, renewables 64%	gas 87%, coal 63%, oil 80%, renewables 65%	gas 91%, coal 66%, oil 84%, renewables 68%	gas 97%, coal 71%, oil 90%, renewables 73%
Czech Republic	gas 85%, coal 60%, oil 79%, renewables 64%	gas 88%, coal 62%, oil 81%, renewables 73%	gas 89%, coal 63%, oil 83%, renewables 75%	gas 93%, coal 66%, oil 87%, renewables 78%	gas 98%, coal 71%, oil 93%, renewables 84%
Denmark	gas 77%, coal 60%, oil 74%, renewables 61%	gas 80%, coal 62%, oil 76%, renewables 70%	gas 82%, coal 63%, oil 78%, renewables 71%	gas 85%, coal 66%, oil 81%, renewables 75%	gas 91%, coal 71%, oil 87%, renewables 80%
Estonia	gas 83%, coal 60%, oil 75%, renewables 64%	gas 86%, coal 62%, oil 78%, renewables 73%	gas 88%, coal 63%, oil 79%, renewables 75%	gas 92%, coal 66%, oil 83%, renewables 78%	gas 98%, coal 70%, oil 89%, renewables 84%
Finland	gas 82%, coal 62%, oil 81%, renewables 56%	gas 85%, coal 64%, oil 83%, renewables 64%	gas 87%, coal 65%, oil 85%, renewables 65%	gas 91%, coal 68%, oil 89%, renewables 68%	gas 97%, coal 73%, oil 95%, renewables 73%
France	gas 83%, coal 54%, oil 87%, renewables 55%	gas 86%, coal 56%, oil 90%, renewables 63%	gas 87%, coal 57%, oil 91%, renewables 64%	gas 91%, coal 60%, oil 95%, renewables 67%	gas 98%, coal 64%, oil 98%, renewables 72%
Germany	gas 83%, coal 55%, oil 85%, renewables 55%	gas 86%, coal 57%, oil 87%, renewables 63%	gas 87%, coal 58%, oil 89%, renewables 64%	gas 91%, coal 60%, oil 93%, renewables 67%	gas 98%, coal 65%, oil 98%, renewables 72%
Greece	gas 81%, coal 59%, oil 76%, renewables 55%	gas 83%, coal 61%, oil 79%, renewables 63%	gas 85%, coal 62%, oil 80%, renewables 64%	gas 89%, coal 65%, oil 84%, renewables 67%	gas 95%, coal 69%, oil 90%, renewables 72%
Hungary	gas 84%, coal 60%, oil 79%, renewables 64%	gas 86%, coal 62%, oil 81%, renewables 73%	gas 88%, coal 63%, oil 83%, renewables 75%	gas 92%, coal 66%, oil 87%, renewables 78%	gas 98%, coal 71%, oil 93%, renewables 83%
Ireland	gas 82%, coal 62%, oil 79%, renewables 53%	gas 85%, coal 64%, oil 81%, renewables 61%	gas 86%, coal 65%, oil 83%, renewables 63%	gas 90%, coal 68%, oil 87%, renewables 65%	gas 97%, coal 73%, oil 93%, renewables 70%
Italy	gas 79%, coal 58%, oil 75%, renewables 56%	gas 81%, coal 60%, oil 77%, renewables 65%	gas 83%, coal 61%, oil 79%, renewables 66%	gas 87%, coal 64%, oil 83%, renewables 69%	gas 93%, coal 69%, oil 88%, renewables 74%

Latvia	gas 82%, coal 58%, oil 85%, renewables 62%	gas 85%, coal 60%, oil 88%, renewables 71%	gas 86%, coal 61%, oil 89%, renewables 72%	gas 90%, coal 64%, oil 93%, renewables 75%	gas 96%, coal 68%, oil 98%, renewables 80%
Lithuania	gas 85%, coal 61%, oil 79%, renewables 65%	gas 88%, coal 63%, oil 81%, renewables 74%	gas 89%, coal 64%, oil 83%, renewables 76%	gas 93%, coal 67%, oil 87%, renewables 79%	gas 98%, coal 72%, oil 93%, renewables 85%
Luxembourg	gas 84%, coal 60%, oil 79%, renewables 68%	gas 86%, coal 62%, oil 82%, renewables 77%	gas 88%, coal 63%, oil 83%, renewables 79%	gas 92%, coal 66%, oil 87%, renewables 83%	gas 98%, coal 71%, oil 93%, renewables 88%
Malta	gas 82%, coal 60%, oil 76%, renewables 67%	gas 85%, coal 62%, oil 79%, renewables 77%	gas 87%, coal 63%, oil 80%, renewables 79%	gas 91%, coal 66%, oil 84%, renewables 82%	gas 97%, coal 71%, oil 90%, renewables 88%
Netherlands	gas 82%, coal 60%, oil 80%, renewables 60%	gas 84%, coal 62%, oil 82%, renewables 68%	gas 86%, coal 63%, oil 84%, renewables 70%	gas 90%, coal 66%, oil 88%, renewables 73%	gas 96%, coal 71%, oil 94%, renewables 78%
Poland	gas 86%, coal 61%, oil 77%, renewables 70%	gas 89%, coal 63%, oil 79%, renewables 80%	gas 90%, coal 64%, oil 81%, renewables 82%	gas 94%, coal 67%, oil 84%, renewables 85%	gas 98%, coal 72%, oil 90%, renewables 91%
Portugal	gas 82%, coal 60%, oil 80%, renewables 55%	gas 84%, coal 62%, oil 83%, renewables 63%	gas 86%, coal 63%, oil 84%, renewables 64%	gas 90%, coal 66%, oil 88%, renewables 67%	gas 96%, coal 71%, oil 94%, renewables 72%
Romania	gas 82%, coal 63%, oil 79%, renewables 55%	gas 85%, coal 64%, oil 81%, renewables 63%	gas 87%, coal 66%, oil 83%, renewables 65%	gas 91%, coal 69%, oil 87%, renewables 68%	gas 97%, coal 74%, oil 93%, renewables 72%
Slovakia	gas 84%, coal 60%, oil 79%, renewables 66%	gas 87%, coal 62%, oil 81%, renewables 76%	gas 88%, coal 63%, oil 83%, renewables 78%	gas 92%, coal 66%, oil 87%, renewables 81%	gas 98%, coal 71%, oil 93%, renewables 87%
Slovenia	gas 84%, coal 60%, oil 79%, renewables 63%	gas 86%, coal 62%, oil 82%, renewables 73%	gas 88%, coal 63%, oil 84%, renewables 74%	gas 92%, coal 66%, oil 87%, renewables 77%	gas 98%, coal 71%, oil 93%, renewables 83%
Spain	gas 83%, coal 67%, oil 80%, renewables 58%	gas 86%, coal 69%, oil 82%, renewables 66%	gas 87%, coal 70%, oil 84%, renewables 68%	gas 91%, coal 74%, oil 88%, renewables 71%	gas 98%, coal 79%, oil 94%, renewables 76%
Sweden	gas 85%, coal 60%, oil 81%, renewables 56%	gas 87%, coal 62%, oil 83%, renewables 64%	gas 89%, coal 63%, oil 85%, renewables 65%	gas 93%, coal 66%, oil 88%, renewables 68%	gas 98%, coal 71%, oil 95%, renewables 73%
Switzerland	gas 82%, coal 60%, oil 76%, renewables 56%	gas 85%, coal 62%, oil 78%, renewables 64%	gas 87%, coal 63%, oil 80%, renewables 65%	gas 91%, coal 66%, oil 84%, renewables 68%	gas 97%, coal 71%, oil 89%, renewables 73%
United Kingdom	gas 82%, coal 61%, oil 79%, renewables 57%	gas 85%, coal 63%, oil 82%, renewables 65%	gas 86%, coal 64%, oil 83%, renewables 66%	gas 90%, coal 67%, oil 87%, renewables 69%	gas 97%, coal 72%, oil 93%, renewables 74%

5.5.3.4 Source references

[1] Hansen, Patrick. 2005. "Evaluierung Der CO 2 -Minderungsmaßnahmen Im Gebäudebereich." *BBR-Online-Publikation* June 2005: 46.

[2] Fleiter, Tobias et al. 2016. "Mapping and Analyses of the Current and Future (2020-2030) Heating/Cooling Fuel Deployment (Fossil/Renewables). Work Package 2: Assessment of the Technologies for the Year 2012.", *prepared for European Commission under contract N°ENER/C2/2014-641.* retrieved from ec.europa.eu/energy/en/studies/mapping-and-analyses-current-and-future-2020-2030-heatingcooling-fuel-deployment, cited on 22/05/2019.

[3] Wenzel, B., Nitsch, J., Pregger, T., Scholz, Y., Naegler, T., Sterner, M., Gerhardt, N., Oehsen, A.v., Pape, C., Saint-Drenan, Y.-M.(2010): Langfristszenarien und

Strategien für den Ausbau der erneuerbaren Energien in Deutschland bei Berücksichtigung der Entwicklung in Europa und global "Leitstudie 2010". Datenanhang II.
Deutsches Zentrum für Luft- und Raumfahrt DLR (Stuttgart); Fraunhofer Institutfür Windenergie und Energiesystemtechnik (Kassel); Ingenieurbüro für neue Energien (Teltow), Stuttgart, Kassel, Teltow. Accessed 9 September 2015.
[4] Schramek, E.-R. (Ed.) (2011): Taschenbuch für Heizung und Klimatechnik. einschließlich Warmwasser- und Kältetechnik, 75th ed. Oldenbourg Industrieverlag GmbH,München, 2391 pp.
[5] COWI, TI, DGC (2013): TechnologyData for Energy Plants. Individual Heating Plants and Energy Transport, Copenhagen, Denmark.
[6] COWI, TI, DGC (2012): Technology Data for Energy Plants. Generation of Electricity and District Heating, Energy Storage and Energy Carrier Generation and Conversion.

6 District Heating (DH)

6.1 Scope definition District Heating

CHP and industry waste heat are an input from the power and the industry modules thus it was not necessary to specifically model CHP and Industry waste heat plants inside the district heating module.

The emissions from district heating are, therefore, only those for additional district heating plants, which include different types of centralized boilers, a centralized heat pump system, solar- and geothermal sources.

The technologies used for district heating are of high level of maturity, resulting in a limited space for further development. That is why their efficiencies are assumed to remain constant over time [1]. The data can be found in section 6.3.1.

District cooling is not included in the DH module.

6.1.1 References

[1] Moret S, Codina Gironès V, Bierlaire M, Maréchal F. Characterization of input uncertainties in strategic energy planning models. Appl Energy. 2017 Sep 15;202(Supplement C):597–617.

6.2 Interactions with other modules

The district heating module receives the energy demand for district heating from the building module by building type. This construction demand is separated for residential and non-residential to allow consideration of the different size, geometry, material demand and the different lifetimes. Additionally, the infrastructure demand for district heating is included and delivered in the form of kilometres of pipeline needed.

6.2.1 Buildings

The district heating demand expressed as GWh per year depends on two aspects:

- the district heating share lever District heating share, and

- the total heating demand from Buildings module, including:

- bld_energy-need_residential_district_mfh[GWh], representing the energy demand of the residential multi-family houses
- bld_energy-need_residential_district_sfh[GWh], representing the energy demand of the residential single-family houses

6.2.2 Power

The district heating module receives the heat elc_chp_fossil_total [TWh] from the CHP plants in Power sector, and prioritizes its utilization in order to avoid the possible direct losses to atmosphere.

6.2.3 Manufacturing

In parallel to CHP, the industrial waste heat ind_supply_heat-waste [TWh/year] from manufacturing is also in priority among district heating technologies in the consideration of energy losses.

Apart from the CHP in power and the waste heat in industry, the utilization of other district heating technologies is determined by the lever "Technology and Fuel Share".

6.2.4 Avoided interfaces

There are further possible outputs to the industry and the electricity module. These outputs are the kilometer of district heating pipes annually constructed, the annual new capacity of additional district heating and the electricity demand for providing additional district heat[TWh].

These outputs would create a loop, because the district heating module already receives inputs from these modules.

As these are the smallest flows in the loop, these outputs are avoided. The demand for construction material for new pipes and capacity of additional district heating is assumed to be insignificant compared to the construction in the whole building and industry sector. The electricity demand for district heating is also assumed to be very small compared to the consumption of electricity in households and industry. A large share of district heating is today delivered by CHP and can potentially derived from industry waste heat in the future.[12]

6.3 Detailed calculation trees

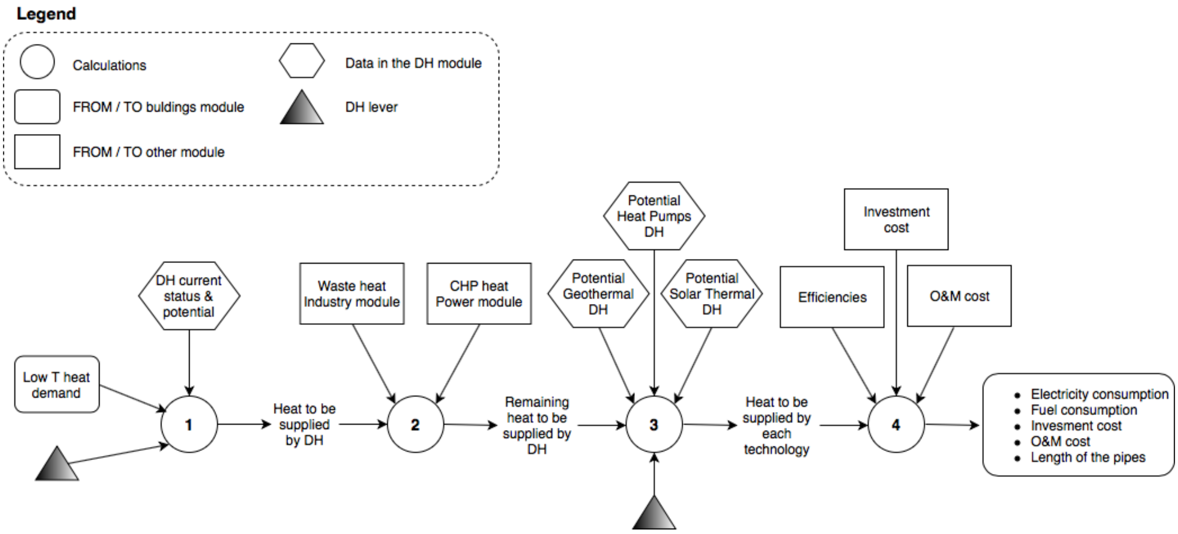

Figure 5 - Calculation logic of the district heating module.

Figure 5 depicts the submodule for DH as well as its interaction with the other modules of the model and its internal data. The interaction with its "parent module" (the Buildings module) are also captured.

A key point on the methodology development is the inputs defined by the DH share lever, detailed in section 4.4.2. This lever allows the user of the calculator to define the percentage of heat supplied by the DH system (1)The technologies providing the heat to the district heating network (3) can be changed with the technology and fuel lever, see section 4.4.3.

The procedure depicted in Figure 5 is conducted for each country. In the first step (1), the heating demand from the building modules is required, while the maximum potential of district heating (for each country) is stored in the DH module database. The third input is the lever position marking the share of district heating in the specific country (see detailed description section 4.4.3). From this, the total heat supplied by the DH is calculated. In step two (2), available waste heat from the industry and CHP systems is determined. The remaining heat needed by the DH is divided among various technologies. Their share is given by the lever position as defined in section 4.4.3.3. Once the share of technologies has been identified, their efficiencies, O&M and investment cost are determined, which is transferred back to the building module.

6.3.1 References

[12] Paardekooper, S., Lund, R. S., Mathiesen, B. V., Chang, M., Petersen, U. R., Grundahl, L., ... Persson, U. (2018). Heat Roadmap Europe 4: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps. Aalborg Universitetsforlag. https://vbn.aau.dk/ws/portalfiles/portal/288075509/HRE_Quantifying_the_low_impact_of_the_low_carbon_heating_and_cooling_roadmaps_Executive_Summary.pdf

6.4 Description of levers and ambition levels

6.4.1 Lever list and description

Table 6 – List of levers for (heating and) district heating

	Lever	Brief description	Content
	District heating share	This lever controls the level of heating energy demand covered by district heating.	District heating can facilitate decarbonisation buildings in dense urban areas even with decreasing heat density. Buildings in dense urban areas are particularly hard to fully release from their energy need partly due to historic or special restrictions.
	Technology and fuel share … in buildings … in district heating	This lever controls the mix of technologies in buildings used for space heating, space cooling, hot water, cooking and lighting and in district heating.	A variety of different technologies are used in buildings for space heating, water heating and cooking. These technologies can have very different efficiencies and emissions associated with them. Today, the most common forms of heating in urban areas are combined heat and power (CHP), district heating, and gas boilers. In rural areas, solid fuel boilers are most common. In the future, new technologies could be used which have much lower emissions, for example heat pumps (which use electricity to move latent heat energy from the outside of the building to the inside) and solar thermal systems. This lever allows you to change the proportion of buildings and district heating using these new forms, and therefore to reduce emissions. Similarly, this lever also increases the proportion of cooling systems that use more efficient and lower carbon technology. The technologies for space cooling within the model are air conditioning, chillers and solar cooling.

6.4.2 District heating share

A key point on the methodology development is the inputs defined by the district heating share lever. This lever allows the user of the calculator to define the percentage of low T heat supplied by the DH system.

The four levels of the lever for the district heating share are described in section "Ambition levels & disaggregation method" 4.4.2.3 below.

6.4.2.1 Lever description

This lever controls the level of heating energy demand covered by district heating (DH share).

6.4.2.2 Rationale for lever and level choices

Determination of the countries' district heating potential is notstraigh forward, as there is no study at European level that presents the district heating potentials for each country. The district heating potentials are obtained from a large set of references. These references mostly cover one country and are described in Table 3 in the deliverable D2.6. This approach has a limitation: the definition of the potential is not the same in all references. The potential of district heating depends on the heat demand density (kWh/m^2). The potential is calculated by defining a threshold for the heat demand density above which the installation of heat district networks starts to be economically attractive (e.g. 10 GWh/km^2 in Austria [1]). Hence the potential is calculated by summing the heating demands (space heating and hot water) of the buildings located in areas with a heat demand density above the chosen threshold.

The current demand on district heat, i.e. used for space heating and hot water in buildings, is obtained from Ref. [3] for each country with some exceptions which are shown in table 5, below[13].

Table 5 – Sources for current demand on low temperature heat

Country	Low T Heating Demand	Share DH
Switzerland	Obtained from Swiss-Energyscope calculator [4].	
Czech Republic	Sum of residential and tertiary in page 13 of [5].	[3]
Croatia	[6]	[6]
Spain	Sum of residential and tertiary in page 60 of [7].	[8]
Italy	[3]	[9]
Sweden	[3]	[10]
Finland	[3]	[11]

The results produced by the "Heat Roadmap Europe" (HRE) [1] project are used to define the evolution of the district heating share in the building sector for lever 3. Based upon which, ±10% shifts are defined for level 2(-10%) and level 4(+10%) respectively. This assumption contributes to a smooth transition between lever levels in 2035 (from 8.4%, 9.5%, 10.6% to 11.7%).

6.4.2.2.1 Disaggregation methodology rational

The principle methodology for disaggregation is summarized as follows:
DH share: Data of the district heating potential for each country (expressed in 0%) were obtained from a variety of references (presented in the Table 3 in the D2.6 content document).

6.4.2.2.2 Feedback from the stakeholder consultations

The calculation rationale has been intensely discussed with stakeholders for the Swiss Energy Scope [2]. New consultations have not been conducted.

6.4.2.3 Ambition levels & disaggregation method

The four levels of the lever are defined as follows:

[13] This is table 2 in deliverable D2.6

- Level 1 represents the business as usual case, implying DH ratio is in line with the historical trend which is assumed to be constant.
- Level 2 has the share of district heating 10% lower than the share reported in the "Heat Roadmap Europe" for each country.
- Level 3 has the same DH share identical to the "Heat Roadmap Europe" scenario.
- Level 4 has the DH share 10% higher than the share reported in the "Heat Roadmap Europe" scenario.

EU-Levels

Name / Unit	1	2	3	4
DH share EU 2050 (%)	**8.4**	**13.5**	**15.0**	**16.5**

Disaggregation by country

Name / Unit	Disaggregation method	Exceptions/outliers
DH share (%)	Based upon deliverable 2.6 data for 2015, keep the evolutional speed of DH share from 2015 to 2050 the same as that obtained in "Heat Roadmap Euro" in lever 3 for each country; Lever 2 and 4 could be determined based upon lever 3 by definition in 4.4.3.3.	Bulgaria, Croatia, Cyprus, Denmark, Estonia, Greece, Italy, Latvia, Lithuania, Luxemburg, Malta, Portugal, Slovakia, Slovenia, Spain, Switzerland (□ no data available)

Description of exceptions or alternative disaggregation methods

Name / Unit	Description of exception or alternative disaggregation method
DH share (%)	Assume that the evolution speed of the remaining fraction of potentials in those countries without available data are the same from 2015 to 2050 as the countries with available data.

6.4.2.4 Source references

[1] Nijs W, Ruiz Castelló P, Hidalgo González I. Baseline scenario of the total energy system up to 2050. JRC-EU-TIMES model outputs for the 14 MS and the EU. https://heatroadmap.eu/wp-content/uploads/2018/11/HRE4_D5.2.pdf

[2] Swiss-Energyscope calculator [Internet]. [cited 2015 Sep 7]. Available from: http://calculator.energyscope.ch/

[3] Pardo N, Vatopoulos K, Krook Riekkola A, Moya JA, Perez A. Heat and cooling demand and market perspective. Petten, The Netherlands: European Commission. Joint Research Centre Institute for Energy and Transport; 2012.

[4] Swiss-Energyscope calculator [Internet]. [cited 2015 Sep 7]. Available from: http://calculator.energyscope.ch/

[5] Assessment of the potential for high-efficiency combined heat and power generation and efficient district heating and cooling for the Czech Republic. Prague, Czech Republic: Ministerstvo Prumyslu a Obchodu; 2015 Dec.

[6] Croatia. Heat Roadmap Europe. A low-carbon heating and cooling strategy;

[7] Full Assessment of the Potential Use of High-efficiency Cogeneration and Efficient District Heating and Cooling Systems. Madrid, Spain: Ministerio de Industria, Energía y Turismo; 2016 Apr.

[8] Armest MA. Las redes de calor y frío en Espana. Energética XXI. 2013 Jun;133.

[9] Assessment of the National and Regional Potential for the Applicatin of High-efficiency Cogeneraitn and Efficient District Heating. Rome, Italy: Gestore Servizi Energetici; 2016 Dec.

[10] Friberg D, Brandsma E. Comprehensive assessment of the potential for exploiting high-efficiency cogeneration, district heating and district cooling. Eskilstuna, Sweden: Swedish Energy Agency; 2013.

[11] Vainio T, Lindroos T, Pursiheimo E, Vesanen T, Sipilä K, Airaksinen M, et al. High-efficiency CHP, district heating and district cooling in Finland 2010-2025. Finland: VTT Technical Research Centre of Finland;

[12] Paardekooper, S., Lund, R. S., Mathiesen, B. V., Chang, M., Petersen, U. R., Grundahl, L., ... Persson, U. (2018). Heat Roadmap Europe 4: Quantifying the Impact of Low-Carbon Heating and Cooling Roadmaps. Aalborg Universitetsforlag. https://vbn.aau.dk/ws/portalfiles/portal/288075509/HRE_Quantifying_the_low_impact_of_the_low_carbon_heating_and_cooling_roadmaps_Executive_Summary.pdf

6.4.3 Technology and fuel share in district heating

The DH technology mix is controlled by the lever "Technology and fuel share", which defines the technology mix for energy supply in buildings and the technology mix providing heat to the district heating network.

The four levels of the lever for the district heating technology mix are described in section "Ambition levels & disaggregation method" 4.4.3.3.

Across a broad range of literature review, an EU-supported project, "Heat Roadmap Europe" (HRE) [1] is chosen as the major reference in this section, which quantifies and implements changes at the national level for 14 EU member states accounting for approximately 85-90% of total heating and cooling in Europe. It is thus assumed one of the most authoritative and comprehensive models for district heating in Europe.

6.4.3.1 Lever description

This lever controls the mix of technologies which provide heat to the district heating network (DH technology mix).

6.4.3.2 Rationale for lever and level choices

The results produced by the "Heat Roadmap Europe" (HRE) [1] project are used to define the evolution of the DH technology mix in the building sector.

6.4.3.2.1 Disaggregation methodology rational

In order to simulate the technology mix pathway towards 2050, three baseline years are considered: 2015, 2030 and 2050. The heat contribution [TWh] for buildings by technology in the three years is retrieved from [1], including both district heating technologies and non-district heating technologies, based upon which the DH technology mixes in the three baseline years are deduced. An interpolation is then used for the years between the three baseline years. This method is applied in each member country and in EU28 as a whole.

6.4.3.2.2 Feedback from the stakeholder consultations

The calculation rationale has been intensely discussed with stakeholders for the Swiss Energy Scope [2]. New consultations have not been conducted.

6.4.3.3 Ambition levels & disaggregation method

The mix of technologies and fuels for supplying heat distributed by the district heating network is also based on the results presented in "Heat Roadmap Europe". The four levels of the lever are:

- Level 1 represents the business as usual case. The technology-fuel mixes remain constant in time.
- Level 2 has the same technology-fuel mixes as in the "Heat Roadmap Europe".
- Level 3 is based on the mixes from "Heat Roadmap Europe", but the percentages for coal and oil boilers are brought down to 0% by 2050, and they are replaced by natural gas and biomass boilers.
- Level 4 is based on the mixes from "Heat Roadmap Europe", but the percentages for coal and oil boilers are brought down to 0% by 2050, and they are replaced by centralised heat pumps, geothermal and centralised solar thermal systems.

EU-Levels

Name / Unit	1	2	3	4
DH centralized heat pump (HP) (%)	0	9	12	25
DH Biomass (%)	18	37	55	34
DH Oil (%)	0	0	0	0
DH Coal (%)	39	31	0	0
DH Gas (%)	43	21	29	28
DH Solar thermal (%)	0	3	4	9
DH Geothermal (%)	0	0	0	3[14]

[14] According to [3], Geothermal district heating systems are capital intensive: the principal liabilities are initial investment costs for production and injection wells, downhole and circulation pumps, heat exchangers, pipelines and distribution network, flow meters,

Disaggregation by country

Name / Unit	Disaggregation method	Exceptions/outliers
DH technology mix (%)	the same as Heat Road map for the lever 2, and Lever 3 and 4 could be determined based upon lever 3 by definition in 4.4.4.3.	Bulgaria, Croatia, Cyprus, Denmark, Estonia, Greece, Italy, Latvia, Lithuania, Luxemburg, Malta, Portugal, Slovakia, Slovenia, Spain, Switzerland (no data available)

Description of exceptions or alternative disaggregation methods

Name / Unit	Description of exception or alternative disaggregation method
DH technology mix (%)	Assume that the technology mix is the same as the European level (of available countries) for the countries without available data.

6.4.3.4 Source references

[1] Nijs W, Ruiz Castelló P, Hidalgo González I. Baseline scenario of the total energy system up to 2050. JRC-EU-TIMES model outputs for the 14 MS and the EU. https://heatroadmap.eu/wp-content/uploads/2018/11/HRE4_D5.2.pdf

[2] Swiss-Energyscope calculator [Internet]. [cited 2015 Sep 7]. Available from: http://calculator.energyscope.ch/

[3] J.W. Lund, 7.05 - Direct Heat Utilization of Geothermal Energy, in Comprehensive Renewable Energy, A. Sayigh, Ed. Oxford: Elsevier, 2012, pp. 171–188.

[4] D. Giardini, Geothermal quake risks must be faced, Nature, vol. 462, pp. 848–849, Dec. 2009.

7 Appliances

7.1 Scope definition Appliances

The appliances' submodule considers in the following appliances in residential buildings:

- Refrigerator
- Freezer
- Dish-washer
- Washing machine
- Dryer
- TV

valves and control equipment, and building retrofit. Additionally, geothermal has the risk of inducing earthquakes according to [4]. Therefore, it is less encouraged compared to other renewables for DH.

- PCs – Laptops
- Mobile phones – smartphones

Although VCRs, DVD players and videogame consoles co-existed, they were considered the evolution of an appliance serving partially the same purpose. Once DVD players became mainstream the VCR became almost obsolete. Although videogame consoles exist since the mid-70s', once they started using DVD discs as media, the use of DVD players declined, and they were replaced by videogame consoles. Similarly, smartphones were considered as the evolution of mobile phones, and although mobile phones still exist, their share in the market is insignificant.

7.2 Interactions with other modules

7.2.1 Lifestyle concerning appliances and lighting

The appliances module is providing buildings with the inputs listed below. The lever appliance-own adjusts the number of appliances per household, representing different levels of a sharing community (e.g. block of flats with shares washing machines). The lever of lighting and appliance use is a lever expressing the behavior of the users, representing different levels of user awareness about efficient use of domestic appliances. The usage of appliances per household is expressed in annual hours of operation. lever appliance ownership

- lever appliance use
- Number of Appliance per household
    - lfs_appliance-own_fridge[num]
    - lfs_appliance-own_freezer[num]
    - lfs_appliance-own_wmachine[num]
    - lfs_appliance-own_dryer[num]
    - lfs_appliance-own_dishwasher[num]
    - lfs_appliance-own_tv[num]
    - lfs_appliance-own_phone[num]
    - lfs_appliance-own_comp[num]
- Usage of appliance per household
    - lfs_appliance-use_fridge[h]
    - lfs_appliance-use_freezer[h]
    - lfs_appliance-use_wmachine[h]
    - lfs_appliance-use_dryer[h]
    - lfs_appliance-use_dishwasher[h]
    - lfs_appliance-use_tv[h]
    - lfs_appliance-use_phone[h]
    - lfs_appliance-use_comp[h]
- Percentage of today's lifetime that the appliance is kept by the consumer.
    - lfs_product-substitution-rate_fridge[%]
    - lfs_product-substitution-rate_freezer[%]
    - lfs_product-substitution-rate_wmachine[%]
    - lfs_product-substitution-rate_dryer[%]
    - lfs_product-substitution-rate_dishwasher[%]
    - lfs_product-substitution-rate_tv[%]
    - lfs_product-substitution-rate_phone[%]
    - lfs_product-substitution-rate_comp[%]

7.3 Appliances calculation trees

The calculation trees presented hereafter represent the steps one to three of figure 6 (Calculation logic of the residential appliances' module).

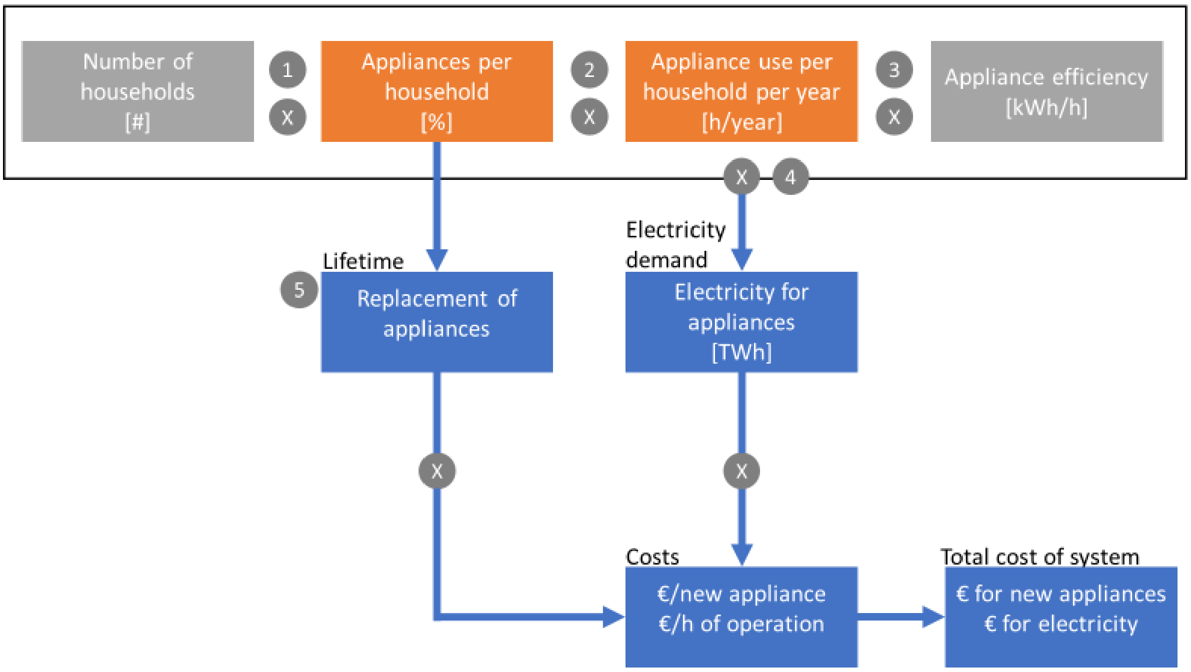

Figure 6 - Calculation logic of the residential appliances' module.

The goal of this step illustrated in figure 7 is to compute the electricity demand for operating the appliances of the residential sector and the number of new appliances that will be sold each year.

The available data are:

- The number of households per Member State [num]
- The percentage of each type of appliances per household per Member State [%]
- The use of each type of appliances per Member State expressed in hours of use per year [h]
- The efficiency of each type of appliance expressed in kWh per hour of use [kWh/h]

By multiplying the first two, the outcome is the number of each type of appliances per Member State which is an input required by the industry module. By multiplying this outcome with the hours of use of each type of appliance per Member State, the outcome is the total hours of operation for each appliance per Member State. This is provided by the Lifestyle module as an input. By multiplying this with the efficiency of each type of appliance, the outcome is the total electricity consumption per each appliance type per Member State in kWh. By summing up all the Member State we get the total electricity demand for appliances in the EU.

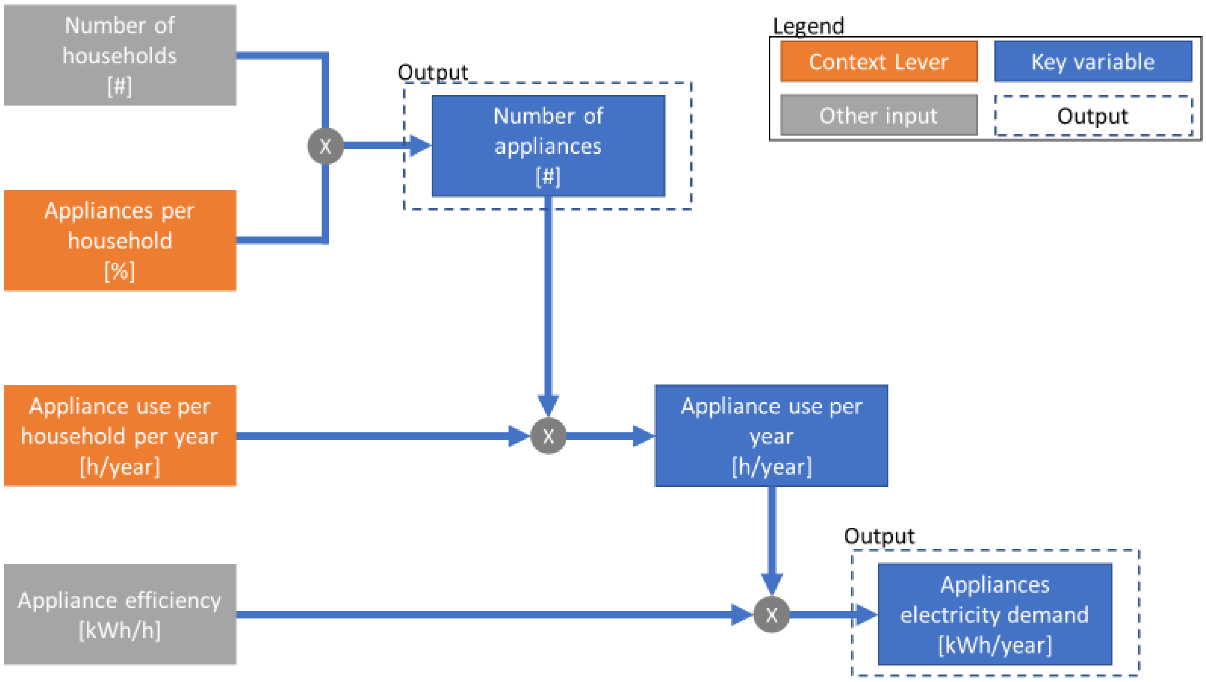

Figure 7 Calculation tree to determine the electricity demand from appliances

Step 5 of figure 6 defines the lifetime for each type of appliance in order to calculate the rate of replacement of appliances. The number of new appliances is an input to the industry module which needs to calculate the quantities of materials required to manufacture the new appliances. Only refrigerators, freezers and washing machines are covered by this process within the Industry module. The lifetimes for each appliance type are assumed to be constant as a simplification and are described in chapter 4.1.1 Lifetime of appliances.

The lifetime for each appliance type was considered constant. The lifetimes are defined for each type of appliance in the constant section 6.1.2. As the lifetime of a product depends on the consumption behaviour, a factor for how much the lifetime is extended as a more sustainable behaviour is introduced in the lifestyle module: the product-substitution-rate. The lifetime is enhanced by multiplication with the product substitution rate to enable a change in consumer behaviour[15].

The ratio of appliances replaced each year was defined by dividing with the enhanced lifetime of each type of appliance, e.g. the replacement ratio of refrigerators is 1 / 15 = 0.067, resulting in the following replacement ratio for each appliance type:

- Refrigerator – 0.067
- Freezer – 0.067
- Dish-washer – 0.1
- Washing machine – 0.067
- Dryer – 0.1
- TV – 0.2
- PCs – Laptops – 0.33
- Mobile phones – smartphones – 0.33
- DH – pipes – 0.0125
- DH – utilities (heat pumps, boilers, etc.) – 0.04

[15] For more details on the product substitution rate please see the documentation of the lifestyle module.

Afterwards the number of each type of appliances was multiplied with the corresponding ratio to calculate the number of appliances that were replaced per Member State.

7.3.1.1 References

- Eurostat
- Odysee-Mure database

7.4 Description of levers and ambition levels

7.4.1 Lever list and description

Table 3 – List of levers for heating, district heating and appliances

	Lever	Brief description	Content
1.	**Appliances, cooking, lighting efficiency**	This lever controls the average rate of energy use for appliances, cooking and lighting.	A variety of different technologies are used in buildings for cooking, lighting and appliances. This lever allows you to use more electricity in cooking (rather than gas, oil or traditional biomass), and to introduce more efficient lighting options like LED bulbs.
2.	**Appliance use [in lifestyle]**	This lever controls the average number of appliances per household.	The appliances modelled for this lever are refrigerators, dishwashers, clothes washers, clothes dryers and TVs. Miscellaneous appliances like laptops and phoneplayers are modelled separately.

7.4.2 Appliance efficiency

7.4.2.1 Lever description

With this lever we want to quantify the impact of more efficient new appliances, aligning with the ambition of the European Commission expressed through the development of the energy labelling framework regulation[1]. According to present regulation, appliances that are currently rated as A+++, will be rated as B in 2021, encouraging the development of more energy efficiency appliances.[16] As the energy labelling regulation is already in place, it was considered as Level 1 of the lever. For Levels 2, 3 and 4 the appliances which are currently rated as A+++ in 2021 would be rated as C, D and E, respectively. The higher the lever level, the more efficient the appliances. The efficiency gain requires more effort from manufacturers in order to achieve appliances that are rated as A.

7.4.2.2 Rationale for lever and level choices

Definition of ambition levels and list of levers with that kind of ambition levels

Lever	Level 1	Level 2	Level 3	Level 4

[16] Energy efficient products. Available at: ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficient-products

Appliance efficiency [kWh/h]	Appliances currently rates as A+++ in 2021 will be rated as B	Appliances currently rates as A+++ in 2021 will be rated as C	Appliances currently rates as A+++ in 2021 will be rated as D	Appliances currently rates as A+++ in 2021 will be rated as E

As the lever moves to the right, e.g. from Level 2 to Level 3, the efficiency increases and appliances that are rated as C in Level 2, will be rated as D in Level 3. Therefore, an appliance rated as A in Level 3, will be more efficient that an appliance rated as A in Level 2. Table 4 shows as example the labeling of refrigerators for each Level step. The cells highlighted in bold show the value that a refrigerator has with the current labeling scheme. This will give the incentive to manufacturer to invest in R&D in order to develop appliances that are rated as A.

Table 4: example of refrigerator labeling

Label	Level 1	Level 2	Level 3	Level 4
A	*0.0133 kWh/h*	*0.0126 kWh/h*	*0.0112 kWh/h*	*0.0084 kWh/h*
B	***0.014 kWh/h***	*0.0133 kWh/h*	*0.0126 kWh/h*	*0.0112 kWh/h*
C		***0.014 kWh/h***	*0.0133 kWh/h*	*0.0126 kWh/h*
D			***0.014 kWh/h***	*0.0133 kWh/h*
E				***0.014 kWh/h***

It was assumed that the same appliances are sold in all Member State, therefore the same relative reduction was assumed in all Member States. The relative reduction was assumed to be 5%, 10%, 20% and 40% for Levels 1, 2, 3 and 4 respectively.

7.4.2.3 Ambition levels & disaggregation method

EU-Levels

Name / Unit	1	2	3	4
Refrigerator efficiency [kWh/h]	0.0133	0.0126	0.0112	0.0084
Freezer efficiency [kWh/h]	0.0171	0.0162	0.0144	0.0108
Dishwasher efficiency [kWh/h]	0.0171	0.0162	0.0144	0.0108
Washing machine efficiency [kWh/h]	0.0314	0.0297	0.0264	0.0198
Dryer efficiency [kWh/h]	0.0627	0.0594	0.0528	0.0396
TV efficiency [kWh/h]	0.0038	0.0036	0.0032	0.0024
Computer/laptop efficiency [kWh/h]	0.9500	0.9000	0.8000	0.6000
Mobile phone/smartphone efficiency [kWh/h]	0.0285	0.0270	0.0240	0.0180
Air-conditioning [kWh/h]	2.3750	2.2500	2.0000	1.5000

A text describing why the Lever levels are the same across Europe will be added.

As the energy efficiency is regulated across Europe by the Directive the assumptions are used for all Countries.

7.4.2.4 Source references

[1] European Commission (2017): Regulation (EU) 2017/1369 of the European Parliament and of the Council of 4 July 2017 setting a framework for energy labelling and repealing Directive 2010/30/EU, retrieved from eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017R1369&from=EN, cited on 22.05.2019.
[2] *www.stromverbrauchinfo.de*
[3] Öko-Institut e.V. (2018): Reparieren oder neu kaufen? Fragen, Antworten und Tipps für ein langes Leben von Elektrogeräten im Haushalt, retrieved from *https://www.oeko.de/fileadmin/oekodoc/FAQ-Langlebigkeit-elektronische-Produkte.pdf*, cited in February 2019
[3] German Environment Agency (2018), Öko-Vergleichsrechner für Arbeitsplatzcomputer, retrieved from www.umweltbundesamt.de/dokument/oeko-vergleichsrechner-fuer-arbeitsplatzcomputer, cited in February 2019

8 Description of constant or static parameters

8.1 Constants list

8.1.1 Emission factors

	CO2	SO2	CH4	N2O
• emission-factor heat-district: g/kWh [6]	262	0	0	0
• emission-factor electricity: g/kWh [6]	565	0	0	0
• emission-factor gas-ff-natural: g/kWh [5]	250	0	0	0
• emission-factor liquid-ff-heating oil: g/kWh [5]	319	0	0	0
• emission-factor solid-ff-coal: g/kWh [6]	450	0	0	0
• emission-factor solid-bio-pellets:	0	0	0	0
• emission-factor solid-bio-wood log:	0	0	0	0
• emission-factor solid-ff-coal	0	0	0	0

8.1.2 Lifetime of appliances

The lifetime for each appliance type was considered constant as described in the corresponding chapter earlier.

The following lifetimes were defined for each type of appliance:

- Refrigerator – 15 years
- Freezer – 15 years
- Dish-washer – 10 years
- Washing machine – 15 years
- Dryer – 10 years
- TV – 5 years
- VCR – DVD – Videogame consoles – 3 years
- PCs – Laptops – 3 years
- Mobile phones – smartphones – 3 years
- Air-conditioning – 15 years
- District heating network (DH) – pipes – 80 years [1]
- DH – utilities (heat pumps, boilers, etc.) – 25 years [2]

8.1.3 Capital expenses

For the district heating network, capital expenses of all utilities (unless otherwise stated) were taken from Reference [2].

- DH – combined heat and power (CHP) – 90 €/kW
- DH – Waste – 90 €/kW
- DH – Geothermal - 1,515 €/kW
- DH - Solar thermal - 720 €/kW
- DH - Centralised heat pump - 340 €/kW
- DH - Gas Boilers - 60 €/kW
- DH - Biomass Boilers - 115 €/kW
- DH - Oil Boilers – 55 €/kW
- DH - Coal Boilers - 115 €/kW
- DH – piping system - 20 €/m [3], length requirement: 118.3 m/MWh [4]

8.1.4 Efficiencies

For the district heating network, efficiencies of utilities were taken from Reference [2]. The efficiency is defined as the ratio of output energy over the input energy for a given technology. For the renewable solar thermal technology, the energy input comes directly from the solar radiation and it is not necessary to calculate how much solar resource is needed, therefore, it is assumed that the efficiency of solar thermal is 100%. The same assumptions are taken for geothermal: instead of considering their efficiencies, the capacity factors defined in section 4.2 in the module documentation D2.6 quantify the performance of solar thermal and geothermal. In addition, the centralized heat pump transfers heat from low temperature source to the high temperature sink by consuming electricity to do work, resulting in an efficiency over 100% which is linked to the coefficient of performance of a heat pump (COP≈4).

- DH – combined heat and power (CHP) – see WP5
- DH – Waste – see WP3
- DH – Geothermal - 100%

- DH - Solar thermal - 100%
- DH - Centralised heat pump - 400%
- DH - Gas Boilers - 92.7%
- DH - Biomass Boilers - 86.4%
- DH - Oil Boilers – 87.3%
- DH - Coal Boilers - 82%

8.2 References

[1] Webpage, https://santhoffplumbingco.com/the-lifespan-of-residential-plumbing-pipes/, accessed 01.04.2019

[2] Moret S, Codina Gironès V, Bierlaire M, Maréchal F. Characterization of input uncertainties in strategic energy planning models. Appl Energy. 2017 Sep 15;202(Supplement C):597–617.

[3] Webpage, http://www.fernwaermeleitungen.com/, accessed 01.05.2019

[4] Girardin L. A GIS-based Methodology for the Evaluation of Integrated Energy Systems in Urban Area. 2012 [cited 2018 Jan 24]; Available from: https://infoscience.epfl.ch/record/170535?ln=en

[5] Karlsruhe energy agency, http://www.kea-bw.de/service/emissionsfaktoren/

[6] German Environment Agency. 2016. "CO2 Emission Factors for Fossil Fuels." : 48. https://www.umweltbundesamt.de/sites/default/files/medien/1968/publikationen/co2_emission_factors_for_fossil_fuels_correction.pdf.

9 Historical database

Describes each historical dataset that is needed for the model, its sources, quality and the hypotheses needed to fill the data gaps

9.1 Database for energy demand for household and services in buildings

Table 5 – Database for buildings

Dataset	Description	Main sources	Data quality check	Hypotheses
Appliance efficiency [kWh/h]	The appliance efficiency expresses the energy (kWh) that is required by the appliance for one hour of use for each appliance type (Refrigerator, Freezer, Dish-washer, Washing machine, Dryer, TV, VCR/DVD/Videogame consoles, PCs/Laptops, Mobile phones /smartphones, Air-conditioning	www.stromverbrauchinfo.de	Description of main gaps in dataset No gaps were identified Assessment of data source reliability and data ratings The data source was considered reliable and the amount of provided data extensive. Nevertheless, the search for data is ongoing Are there outliers? Yes, but the sample was very close to normally distribution Was the dataset crosschecked (with other sources or expert opinion?) No, but the research for comparable sources is ongoing	• A medium size refrigerator (213 L) and freezer (94 L) were considered • A full load at 60°C was considered for washing machines
Current: Low T heating demand & district heating shares	The low temperature heating demand (TWh/y) and current district heating shares in all European countries (%) are data data stored in district heating modules	• Pardo N, Vatopoulos K, Krook Riekkola A, Moya JA, Perez A. Heat and cooling demand and market perspective.	Description of main gaps in dataset No gaps were identified Assessment of data source reliability and data ratings The data source was considered reliable	• Some countries' data was not provided in the reference; for those, different data sources were used (see Table 2, D2.6)

		Petten, The Netherlands: European Commission. Joint Research Centre Institute for Energy and Transport; 2012.	and the amount of provided data extensive Are there outliers? No Was the dataset crosschecked (with other sources or expert opinion?) No	
Capacity factors for DH technologies	e capacity factor of an energy technology is the ratio between the energy supplied during a certain time interval over the energy that would have supplied if the technology runs at full capacity during the entire time intervall	1.) Honoré A. Decarbonisation of heat in Europe: implications for the natural gas demand. Oxford, UK: The Oxford Institute for Energy Studies; 2018 May. • 2.) Energy statistics - cooling and heating degree days (nrg_chdd) [Internet]. [cited 2018 Sep 14]. Available from: link	Description of main gaps in dataset No gaps were identified Assessment of data source reliability and data ratings 19 data points with acceptable reliability. See hypotheses. Are there outliers? No Was the dataset crosschecked (with other sources or expert opinion?)	• The capacity factors for low T DH in some member countries are known from 1.) • The heating degree days (HDD) are known from 2.). The reference calculates the HDD of all countries based on a 15°C threshold. • The capacity factors of unavailable countries are linearly fitted among the 19 available data points.

Database references

[EC, 2017] Statistical Pocketbook 2017, European Commission, Luxembourg: Publications Office of the European Union, ISBN 978-92-79-62311-0, 2017