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Assessment of the impact of climate change on residential energy demand for heating and cooling

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Assessment of the impact of climate change on residential energy demand for heating and cooling

Climate change in Europe leads to a decrease of residential heating needs and an increase of residential cooling needs. The impact on cooling needs is higher than on heating, in each of the climatic European regions. The overall residential heating and cooling needs are expected to decrease by a quarter by the end of the century, due to climate change. This order of magnitude remains when accounting for a higher insulation level of buildings.

Contents

Foreword

This work was carried out under the PESETA 3 project (Projection of Economic impacts of climate change in Sectors of the European Union based on bottom-up Analysis). The goal of the project was to study the impact on various sectors of climate change, in Europe and across the century. This report presents the results on energy (task 5).

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Executive summary

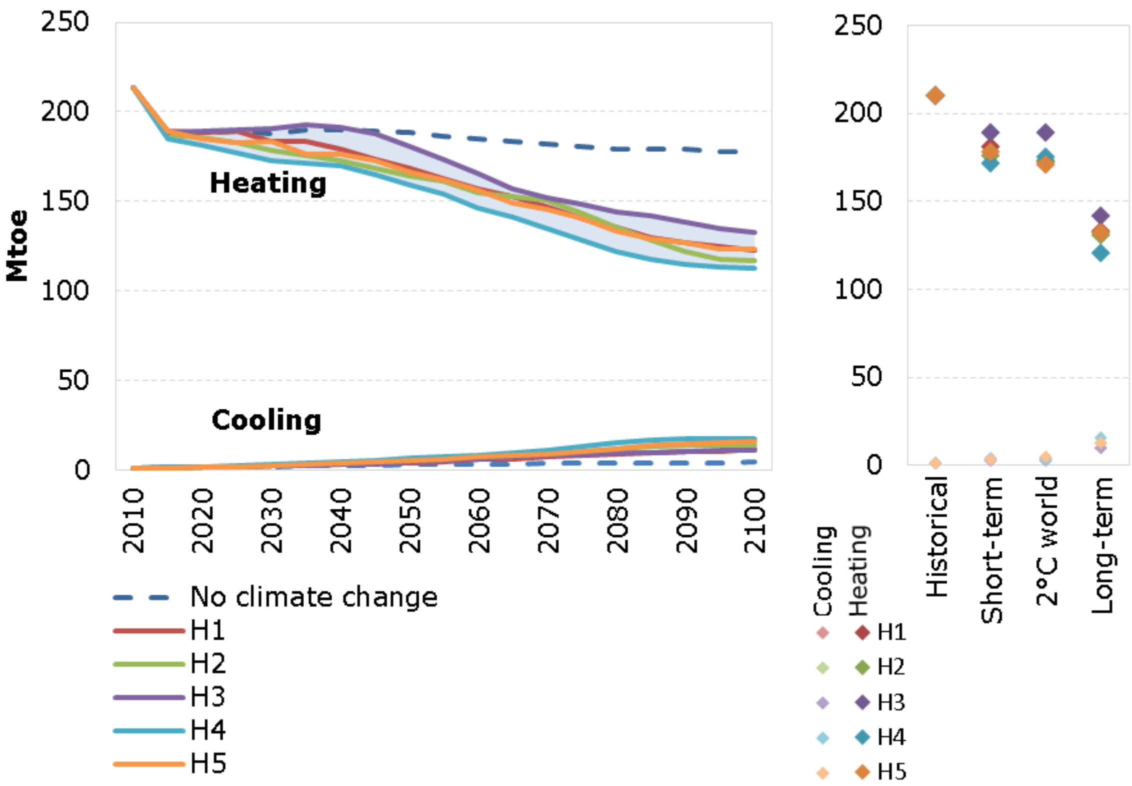
Policy context

This report studies the impacts of climate change on the energy system. The work is based on five global scenarios (H1 to H5) provided by climate modelling teams within the PESETA III project. The daily average temperatures are transformed into heating and cooling degree-days, used as inputs of an energy model. This model links the temperatures to the residential heating and cooling energy needs, although other drivers come into play: income, energy prices, insulation efforts and technology efficiency improvements. The time-step of such a model is annual, so short-term extreme events cannot be assessed.

Key conclusions

Results show that the increase in average temperatures in Europe scenario leads to a decrease of heating needs compared to a scenario without climate change, mainly in the long-term (-27% in the 2070-2100 period). The short-term effects are small (-5% in the 2020-2050 period). On the other hand, demand for air cooling is increased by 44% in the short-term due to the higher summer temperatures, and multiplied by a factor of 3 in the long-term, compared to a scenario without climate change. However, the dominant driver of the total energy needs in each of the climatic European regions remains the heating demand (see Figure 1 for the EU28 overview). Total residential final energy needs for heating and cooling decreases by 5% in the short-term and 22% in the long-term (-26% in 2100), compared to a scenario without climate change. If we compare to the situation in 2010, we also see that the residential heating and cooling energy needs are expected to decrease strongly in the long-term (-32% in the 2070-2100 period, -37% in 2100), but only moderately in the short-term (-14% in the 2020-2050 period, mostly between 2010 and 2015).

Figure 1. Heating and cooling final energy needs for Europe 28



Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

These impacts are twice those computed in PESETA II because the temperature data used as input increases more in the RCP8.5 scenarios of PESETA III than in the Reference scenario of PESETA II. In both cases cooling needs are dominated by heating needs.

A different set of scenarios was also computed to see the sensitivity of these results to a better insulation of buildings. Although the overall energy needs are smaller than in the baseline scenario, the impact of climate change still amounts to around a quarter of heating and cooling energy needs. Therefore the results are robust to various policies for insulation of buildings.

Main findings

The policy implications are that, in an integrated EU power market, overall needs for heating and cooling energy and for peaking power plants would both decrease in a RCP8.5 scenario. Nevertheless, better insulation and efficiency of cooling devices remain important since they can bring strong additional energy savings.

Related and future JRC work

A global analysis could also be carried out, in order to see what regions of the world are most impacted and evaluate the spill-over effects. For example, this is the objective of the HELIX project.

1 Introduction

The PESETA III project also brings together different types of models in order to analyse the impacts of climate change in different parts of Europe. It builds on PESETA2, with new, more transparent climate scenarios (the RCP8.5 scenario was used in this study).

We focus in this report on the impacts of climate change on the energy sector. These impacts range from changes in the availability of water, which can cause decreased thermal production efficiency or changes in hydro production, to risks for the infrastructure, for example implied by (infra-annual) extreme events, or changes of demand patterns. Studying these impacts is crucial for evaluating and designing the adequate mitigation and adaptation policies in order to minimize the negative impacts of climate change. Ciscar and Dowling (2012) looked at how impact assessment models represent these impacts and show that more work is needed in this area. The modelling tool available (POLES model, see Annex A) allows evaluating impacts on yearly energy demand. Indeed, it deals with the impacts of temperature changes on the energy demand for residential heating and cooling. Other impacts are not studied here since the available data and modelling capabilities are not adequate.

Several studies focused on the energy impacts of climate change. One of the few global studies is Isaac and van Vuuren (2009). They used Heating Degree Days (HDD) and Cooling Degree Days (CDD) indicators[1] to represent the impact of climate change on heating and cooling residential needs in the world.

Mima et al. (2011) and Mima and Criqui (2015) looked at the impacts at a European scale within the Climatecost FP7 project, country by country. They carried out an evaluation of the increase of cooling needs and decrease of heating needs. They also looked at the variations of water resource for hydropower and the decreased thermal production because of constrained water resource.

Dowling (2013) studied the impact of several climate change scenarios from different global climate models (GCM[2]), as part of the PESETA2 project, at the European scale. The interest was on residential and service energy needs for heating and cooling, as well as the efficiency of thermal power plants and the changes in renewable production (hydro, wind, solar). The main conclusion is that the heating needs will decrease as average temperatures increase, and this energy gains largely outbalance the increase in cooling needs.

The global climate models provide updated scenarios of average (bias-adjusted) daily temperatures for Europe, which are converted to HDD and CDD. This sector study then provides an assessment of the impact on the energy needs for future cooling and heating demand in the residential sector. Europe is divided in five regions for reporting so that small-scale effects are averaged-out[3].

[1] HDD and CDD are indicators based on the measured external temperature and a reference temperature. They reflect the energy needed to heat (HDD) or cool (CDD) a building.

[2] Global Climate Model, e.g.: HadGEM3 GC2 (see Williams et al. 2015)

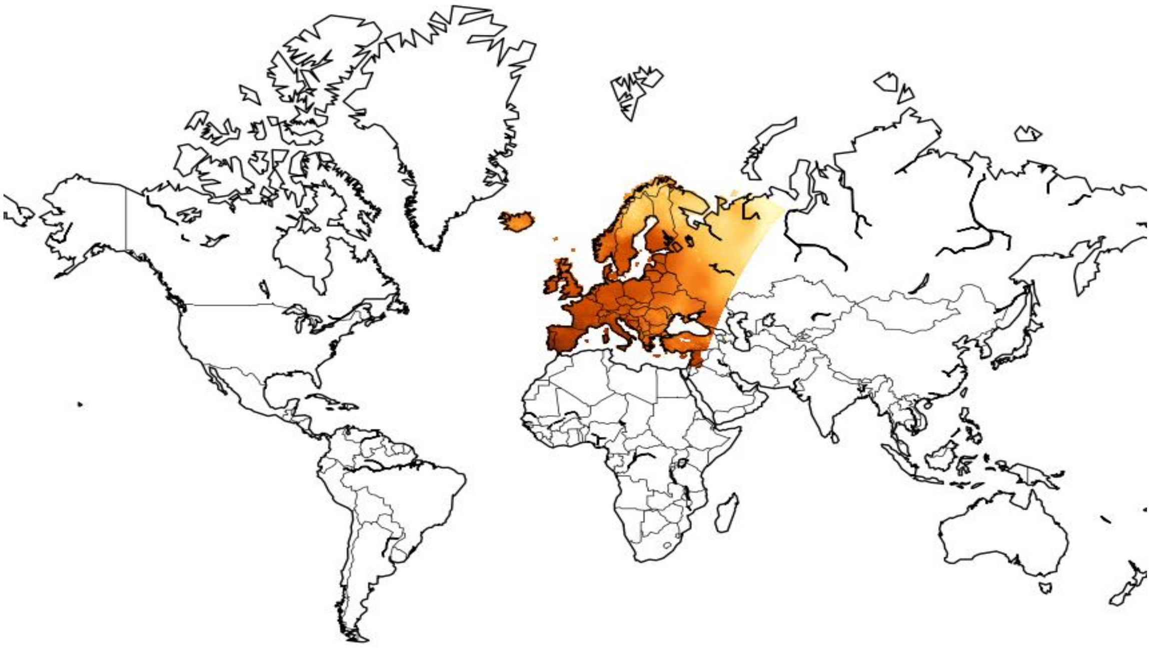
[3] Although POLES allows computing the country-by-country effects, the inputs from the climate models may be less relevant for small countries.

2 Methodology

2.1 Climate data management

Figure 2 shows a map of the bias-corrected near-surface air temperature (data points are in colour) transmitted by GCMs.

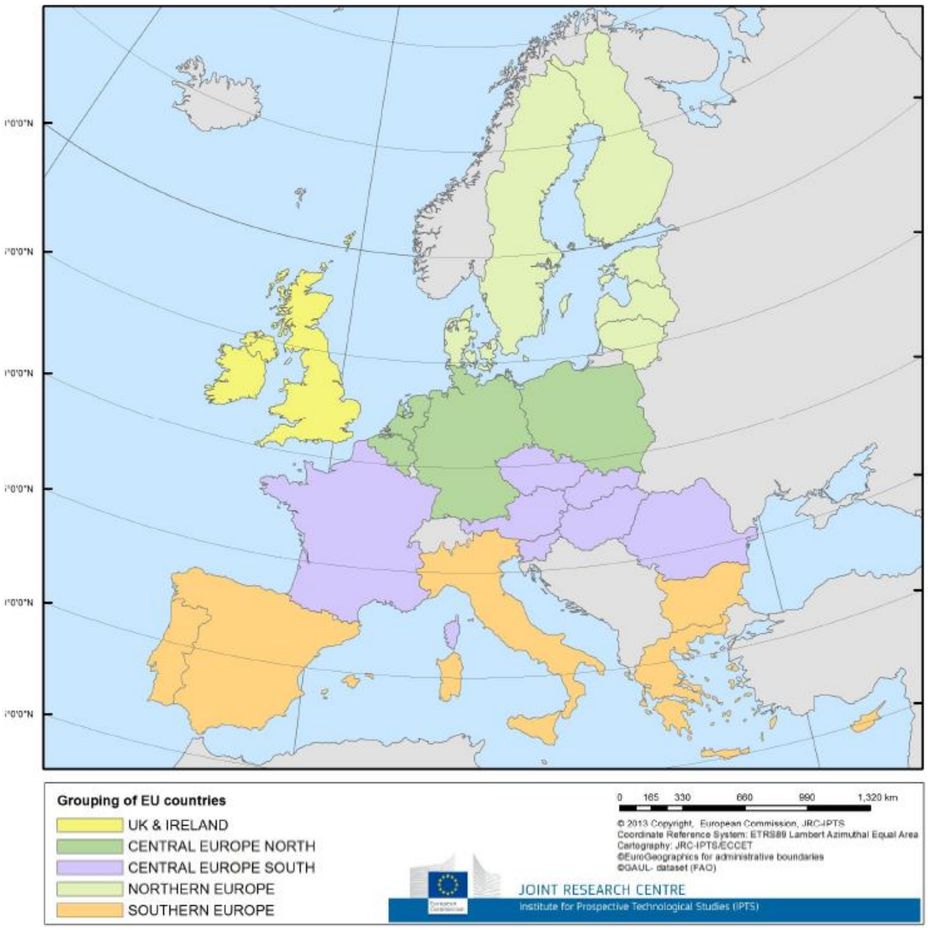
Figure 2. Coverage of data transmitted by Global Climate Models (in colour)



In accordance with the scope of the PESETA III project, all results are provided for EU28, with a focus on the following 5 selected European regions (see Figure 3):

- WE: UK & Ireland
- CN: Central Europe North: Belgium, Germany, Netherlands, Poland
- CS: Central Europe South: Austria, Czech Republic, France, Hungary, Slovakia, Romania
- NO: Northern Europe: Denmark, Estonia, Finland, Latvia, Lithuania, Sweden
- SO: Southern Europe: Bulgaria, Croatia, Cyprus, Greece, Italy, Malta, Portugal, Slovenia, Spain

Figure 3. Regional grouping of EU regions used for cooling and heating impact



2.2 Climate heating and cooling indicators

The effects of climate on energy needs for heating and cooling are captured through the use of respectively "heating degree days" (HDD) and "cooling degree days" (CDD). Degree-days are the summation of temperature differences from a human comfort level over time. They capture both extremity and duration of outdoor temperatures. HDD and CDD are measured in “degree-days” below (HDD) or above (CDD) a temperature set point (here: 18°C). The HDD and CDD are calculated for each geographical cell for which daily temperature is provided:

$$HDD_{year} = \sum_{days} \max(0, (18 - T_c))$$

$$CDD_{year} = \sum_{days} \max(0, (T_c - 18))$$

with Tc: the average daily temperature expressed in °C

After the data on average daily temperature by geographical cell has been transformed into HDD and CDD by cell, values at country or region level are then calculated through a weighting by population density. This allows capturing requirements for heating and cooling services at country / region level while coping with potentially heterogeneous distribution of population.

$$HDDi = \frac{\sum_j HDD_{i,j} P_{i,j}}{\sum_j P_{i,j}}$$

$$CDDi = \frac{\sum_j CDD_{i,j} P_{i,j}}{\sum_j P_{i,j}}$$

with:

i: country

j: geographical cell

Pi,j: population of cell j belonging to country i

HDDi,j / CDDi,j: HDD and CDD of cell j belonging to country i

The population migrations within a country are not accounted and can lead to an over- or underestimate of the future weighted HDD and CDD.

2.3 Energy demand in residential buildings

Residential buildings are represented by a building stock module that captures the need for new dwellings as a function of population, income, renewal of scrapped buildings and renovation of existing buildings. The time-step is annual (no infra-annual phenomenon, such as extreme events, are accounted for). The module also describes the evolution of surfaces per dwelling, as a function of income.

2.3.1 Space heating

The model simulates the evolution of heating demand derived from the building module. Key drivers are:

- development of insulation (which diffusion follows a logistic function dependent on the return on investment, compared to both heating and cooling expenses),
- energy prices,
- residential surfaces (which includes a wealth effect),
- and the evolution of HDD over time, captured through an elasticity coefficient.

2.3.2 Space cooling

The representation of energy needs for cooling purposes in the residential sector is derived from work by Mc Neil (2007), Isaac (2009), Mima (2009) and Daioglou (2012).

Energy demand for space cooling in the residential sector (AC_{RES}) in any country is currently described as a function of air conditioning (AC) unit electricity consumption (UEC) multiplied by the number of dwelling equipped with cooling systems (Dwl_{AC}):

$$AC_{RES} = UEC * Dwl_{AC}$$

The first factor is the unit electricity consumption; it depends on:

- per-capita revenues (adapted from Isaac 2009 and Daioglou 2012),
- CDD (adapted from Isaac 2009 and Daioglou 2012),
- the efficiency of the air conditioner,
- the insulation of the building.

The equation describing the unit electricity consumption is:

$$UEC = UECth * TechnicalImprovementFactor * InsulationFactor$$

Where UEC_{th}, the theoretical unit electricity consumption, is evaluated as (adapted from Isaac 2009 and Daioglou 2012):

$$UEC_{th} = 5.13 * \text{Income per capita} + 0.0621 * \text{CDD} * \text{Income per capita} - 1658$$

The technical improvement factor is based on an improving trend, modulated by the budgetary coefficient related to cooling, and a floor value derived from the historical best performance.

The insulation factor follows the return on investment of insulation (which combines heating and cooling expenses).

The second important factor determining the AC consumption is the number of dwellings equipped; it is the product of the number of dwellings (Dwl) by the share of dwellings equipped (ShDwlAC):

$$DwlAC = Dwl * ShDwlAC$$

The share of dwellings equipped depends on:

- a diffusion rate: DiffAC, that depends on income per capita
- a maximum penetration rate: DwlACMax (expressed in % of total dwellings), that depends on CDD so as to capture the climate characteristics of the country/ region:

$$ShDwlAC = DiffAC * DwlACMax$$

with DwlACMax being fitted on US data (McNeil 2007):

$$DwlACMax = 1 - 0.949 * \exp(-0.00187 * CDD)$$

and DiffAC fitted on international data (Isaac 2009):

$$\mathrm{DiffAC} = \frac{1}{1 + \exp(4.152 - 0.237 * \text{Income per capita})}$$

2.4 Caveats

The modelling of residential heating and cooling needs is based on a limited amount of data points, which makes it difficult to separate the impacts of HDD and CDD from the socio-economic drivers (population, size of households, income per capita and other drivers), particularly for cooling.

In this latter case the data availability is scarce, corresponds to a limited set of climate situations and usually covers only a short time frame (2000-2010).

Finally, the modelling does not capture explicitly the way the evolution of technical progress and lifestyle change may influence energy uses over such a long-term time frame.

3 Data input

Socio-economic data

The population and GDP (Gross Domestic Product) projections are taken from Task 2 of the PESETA III project.

Cooling and Heating historical demand

The ODYSEE database[4] gives a detail of energy consumed by energy service in the residential sector. Data used here go up to 2010, although they were prolonged to 2015 by maintaining the share of heating (respectively cooling) in total residential energy demand (which is available until 2015).

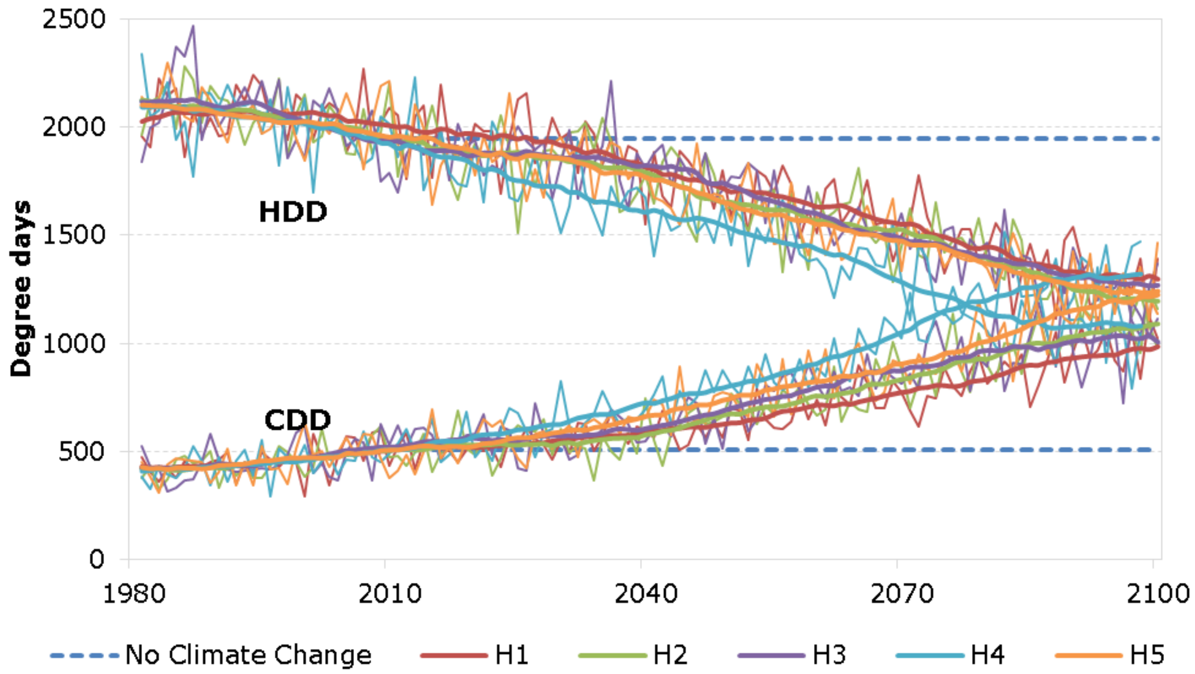
Heating degree days and cooling degree days

The analysis combines information on CDD and HDD at country level. The sources of information are bias-adjusted temperatures in RCP8.5 scenarios, provided by the following models (in bold the short version we use to designate them):

- **H1**: CNRM-CERFACS-CNRM-CM5_r1i1p1_CLMcom-CCLM4-8-17
- **H2**: ICHEC-EC-EARTH_r12i1p1_CLMcom-CCLM4-8-17
- **H3**: IPSL-IPSL-CM5A-MR_r1i1p1_IPSL-INERIS-WRF331F
- **H4**: MOHC-HadGEM2-ES_r1i1p1_SMHI-RCA4
- **H5**: MPI-M-MPI-ESM-LR_r1i1p1_SMHI-RCA4

The averaged data (moving average over 20 years) are then derived; Figure 4 below shows the example of Spain for this averaging.

Figure 4. HDD and CDD built from the five climate models and moving average (example of Spain)



Source: PESETA3 climate data

The increase in CDD and decrease in HDD across all five models show the warming of temperatures in Spain. The averaged data is the input of the energy model. The warming tendency causes the decrease of heating needs and increase of cooling needs, as shown in the following section.

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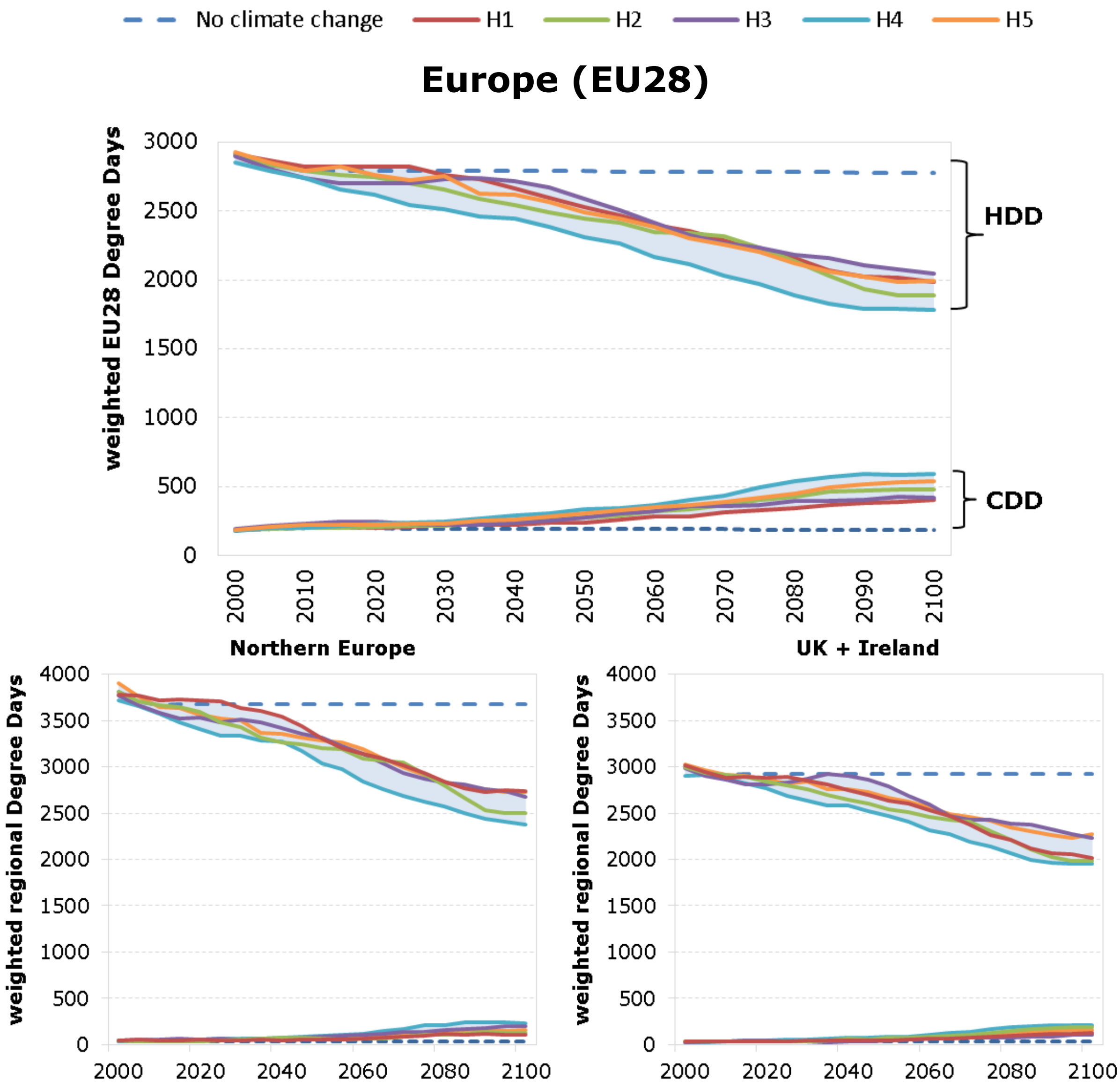
[4] http://www.indicators.odyssee-mure.eu/energy-efficiency-database.html

4 Definition of scenarios

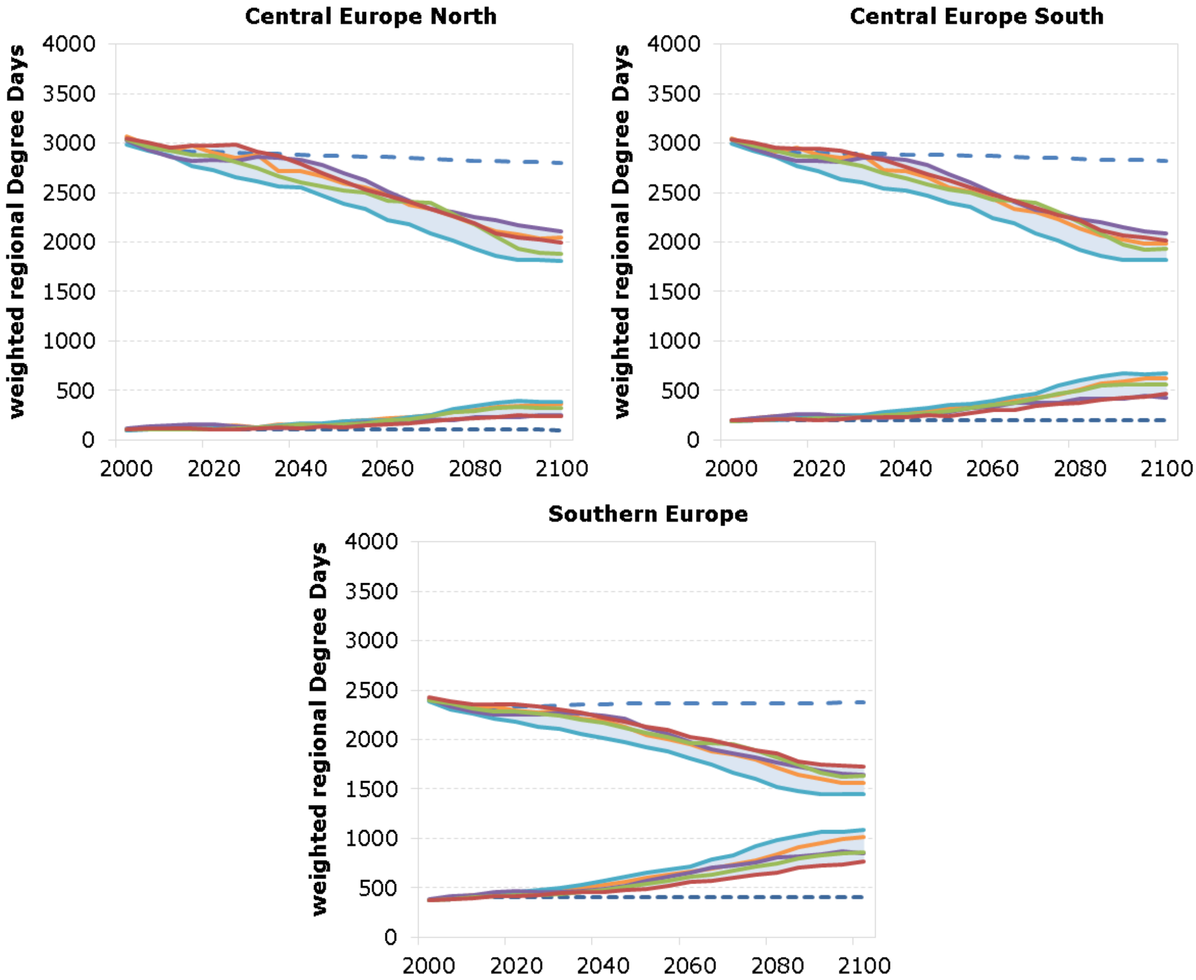
We analyse the scenario of a RCP8.5 climate evolution, with the POLES-JRC modelling developed for the FP7 ADVANCE project[5], which basic principles are described in Annex.

Figure 5 below shows the evolution of the degree-days in all 5 climate scenarios as used in POLES inputs, averaged at EU28 level and for each of the five European regions considered. The "no climate change" scenario is defined by temperatures fixed at the level of 2010 and is used as a point of comparison.

Figure 5. CDD and HDD in EU28 and in the five identified European regions



[5] http://www.fp7-advance.eu/



Source: PESETA3 climate data

In Figure 5 we see that all European regions are warming throughout the century. They all see a decrease of cold days, representing around 1000 HDDs along the century. Countries in the Southern and Central Europe South have significant CDD, especially in the second half of the century. On the other hand, Northern and Western Europe still have very few hot days.

In the following we study the short term impact (30-year average of 2021-2050), long-term impact (30-year average of 2071-2100), as well as the energy impacts at 2°C global warming, defined in **Table 1**.

Table 1: Years in which the global climate models reach 2°C degree of warming

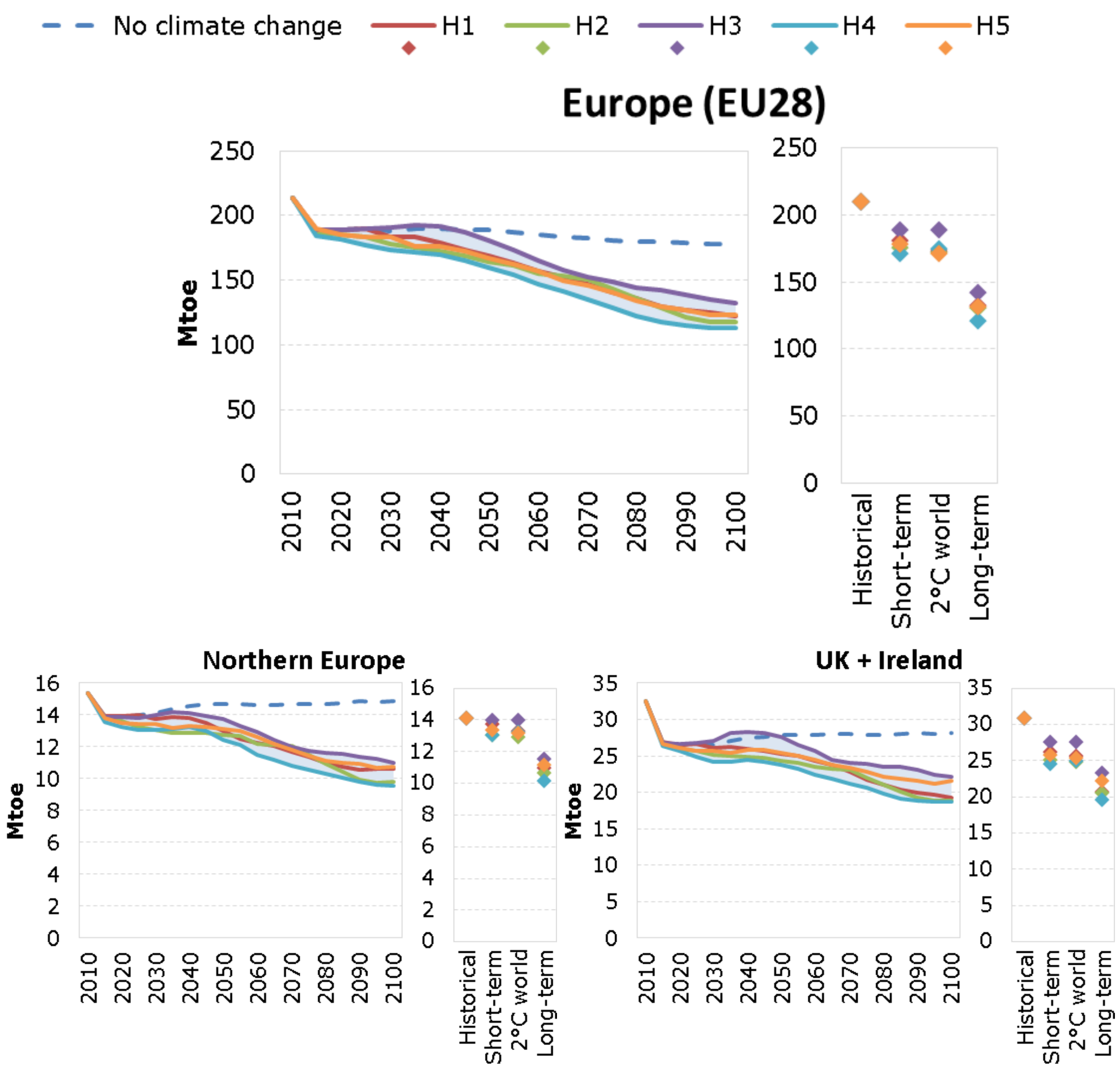
Scenario name	Central year of 2°C global warming	30-year period used for a 2°C global warming level
H1	2044	2030-2059
H2	2041	2027-2056
H3	2035	2021 2050
H4	2030	2016-2045
H5	2044	2030-2059

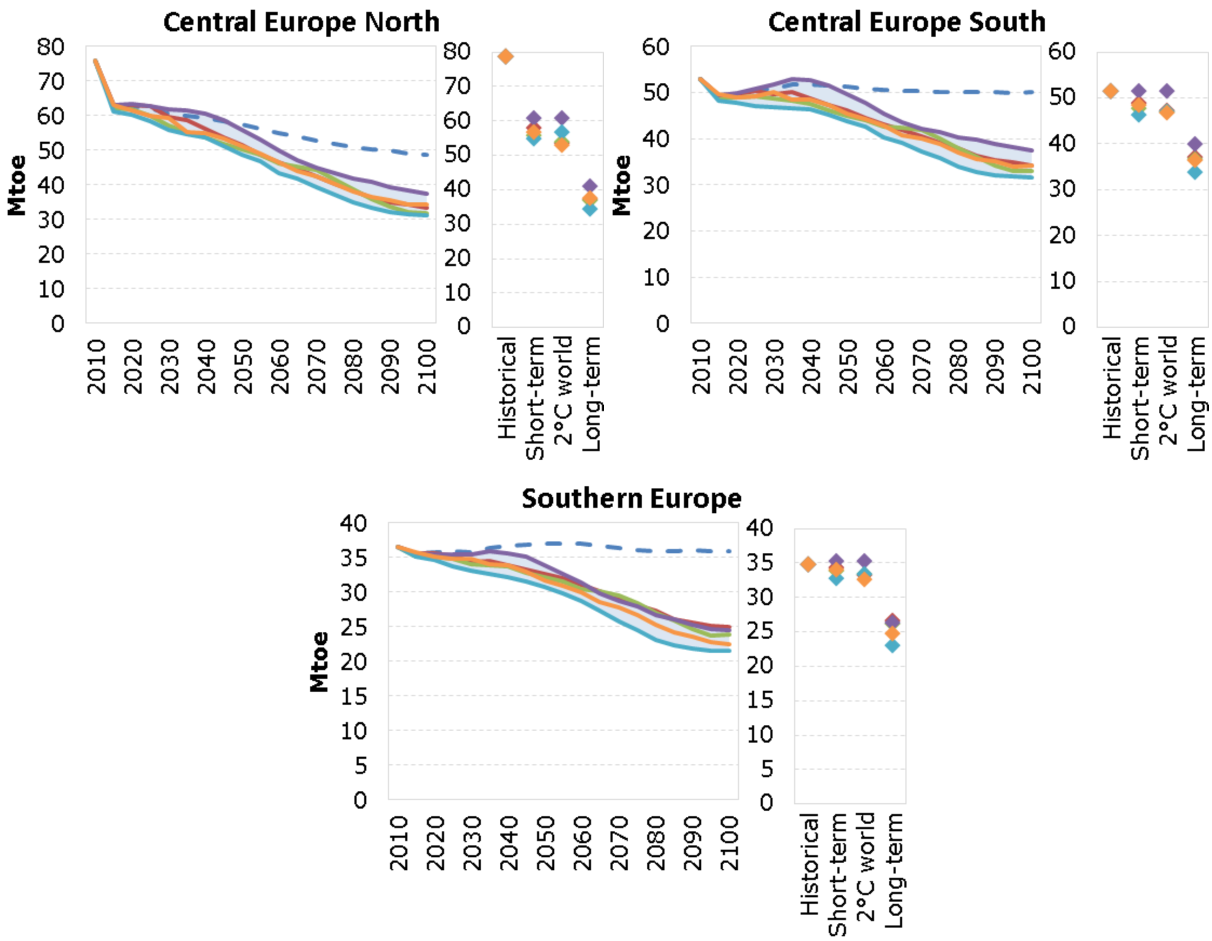
5 Results on energy demand

5.1 Baseline policies

The evolution of energy demand for heating and cooling reacts to the evolution of degree-days, corrected with the building insulation improvements and device efficiency improvements. Figure 6 shows the evolution of final demand for residential heating (aggregation of all final energy consumed) in Europe due to the decreasing HDD. The short- and long-term impacts and impacts in a 2°C world are also shown. The equivalent in primary energy is shown in Annex B; it is obtained by applying an efficiency factor to the electricity consumed in residential heating (see Figure 12), based on the electricity mix computed in POLES.

Figure 6. Impact of climate change on European residential heating final demand, for EU28 and for the five considered European regions





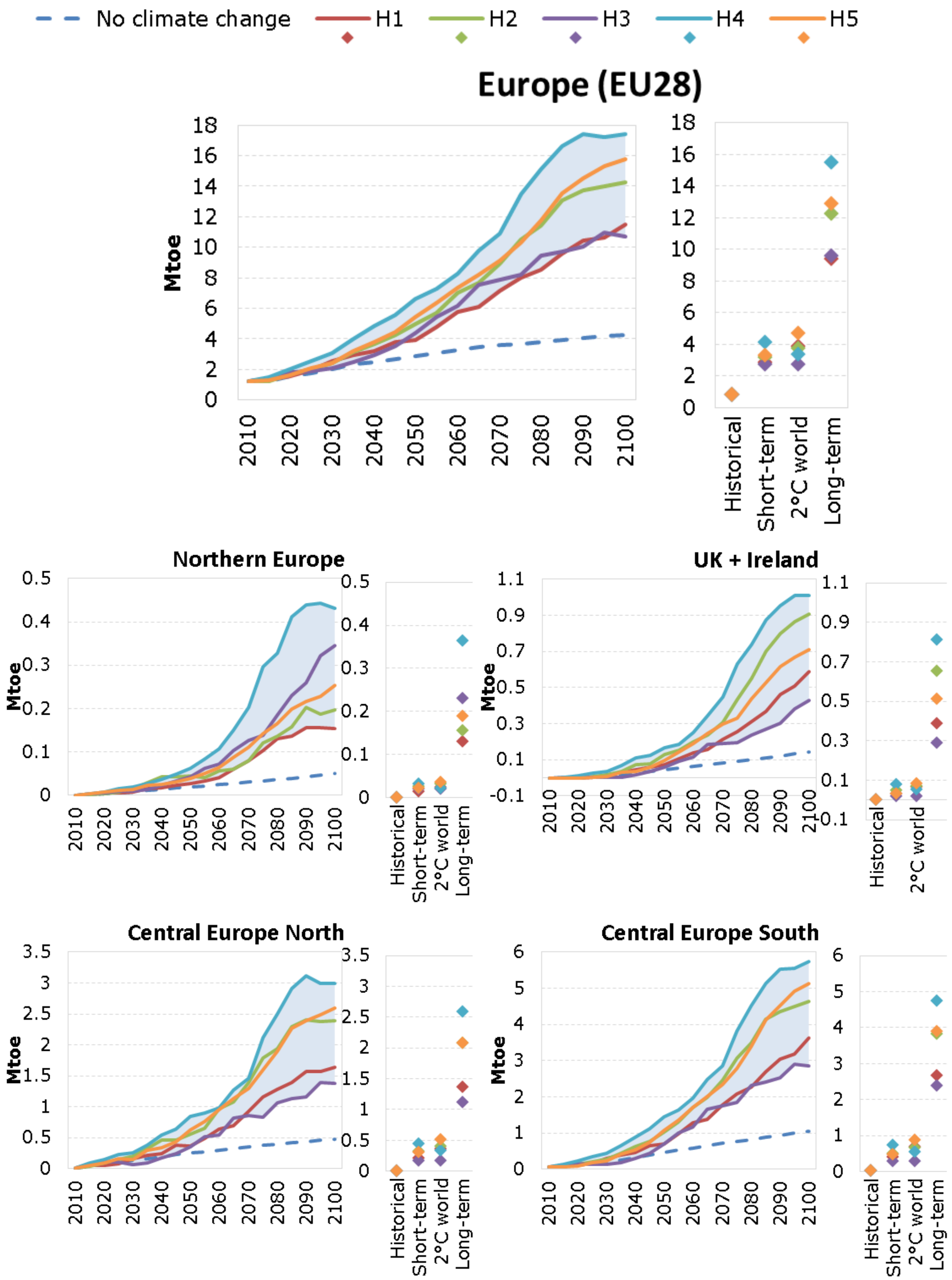
Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

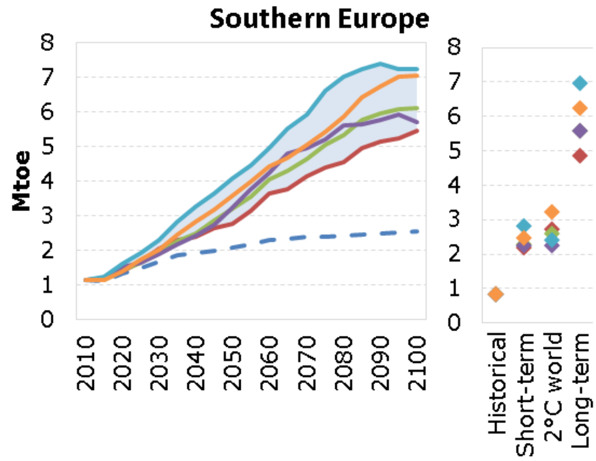
The results in Figure 6 confirm that the decrease of HDD in all European countries (see Figure 5) leads to a decrease in heating needs. The continent needs 15% less heating energy in the short-term (2021-2050) than in 2010, and 37% less in the long-term (2071-2100). Compared to the no climate change scenario, climate change has effects of 5% in the short-term and 27% in the long-term (32% in 2100).

The effect in each of the regions studied is also much more pronounced in the long-term, although Central Europe North already sees -27% in the short-term (and -53% in the long-term), mainly due to insulation improvements.

Figure 7 shows the increase of final demand for residential cooling, due to the increasing CDD (see Figure 13 for primary energy equivalents).

Figure 7. Impact of climate change on European residential cooling demand (final demand), for EU28 and for the five considered European regions





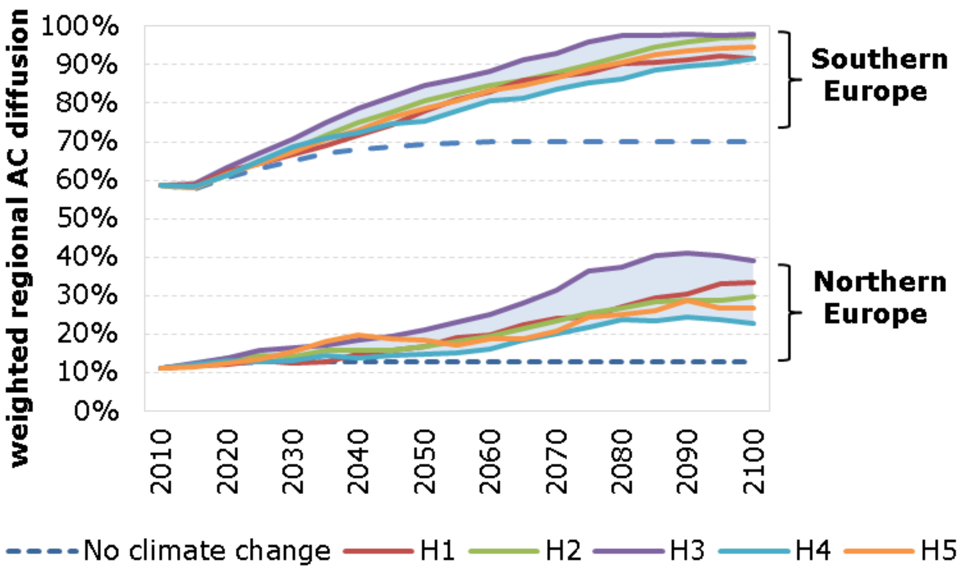
Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

The increase of CDD has a direct impact on the residential cooling needs, especially above a threshold of around 250.

Most of the European residential cooling demand today is concentrated and growing in Southern Europe. By the end of the century, it represents around 50% of all cooling demand, and Central-Southern countries rise to around 30% in the second half of the century. For the whole Europe, they increase by a factor of eleven to eighteen by the end of the century.

Even without climate change, all regions adopt more air conditioning to increase comfort. Still, in Europe the AC equipment is mainly driven by the warming climate. Revenue effects are negligible, contrary to Africa, for example. The diffusion of AC equipment in buildings also shows this (see Figure 8).

Figure 8. Diffusion share of AC equipment for 2 European regions



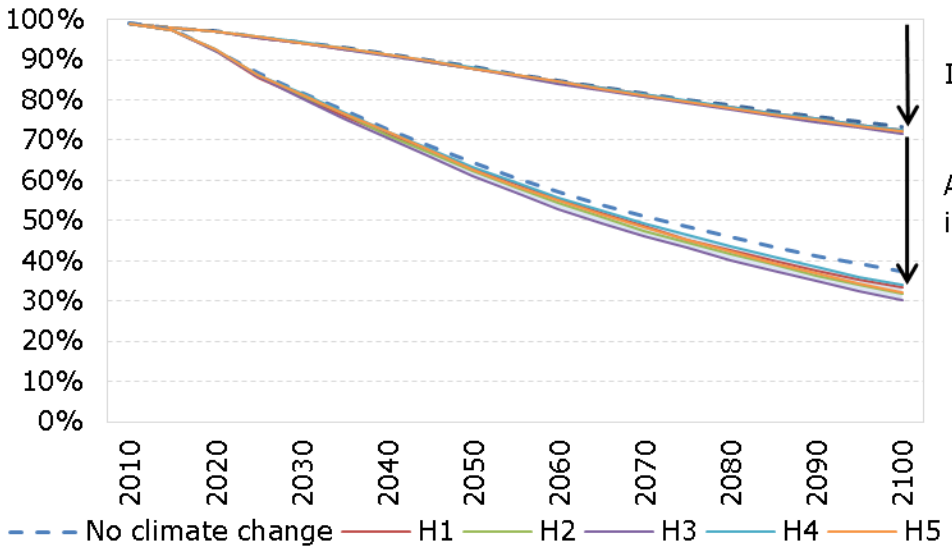
Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

The increasing temperatures trigger higher AC equipment rates of residential households (the EU28 average increases to around 60% by 2100, with climate change). Southern Europe reaches 95% at the end of the century. Other regions accelerate their equipment rate in the second half of the century. They reach two-thirds for Central Europe South by 2100, 45% for Central Europe North, 33% for UK and Ireland, and 30% for Northern Europe.

Even in a scenario with no climate change, the effect of increased revenues is a slight increase (until 2030) of AC equipment rate in Southern Europe, as well as an increasing unit energy consumption for all regions. This explains the slightly increasing cooling demand without climate change in Figure 7.

The building insulation and AC technical improvement drivers of cooling demand are the other drivers of cooling demand, shown in Figure 9.

Figure 9. Efficiency gains for air conditioning, decomposed between building insulation and AC technical improvement (EU28, relative evolution of energy per m2 and per CDD)



Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

Insulation and AC technical improvement each bring approximately a 30% reduction in cooling demand by 2100. While technical improvement is not impacted by climate change, the heating and cooling spending has an impact on the insulation effort.

In total, the increase in European residential cooling is dwarfed by the decrease of heating demand. Residential cooling reaches around a tenth of the heating demand for EU28 in 2100. The overall demand for residential heating and cooling is reduced by a quarter by the end of the century for the whole of Europe, compared to a scenario without climate change. All five regions considered see such a decline, from -23% for Southern Europe to -29% for Northern Europe.

The "no climate change" scenario also shows a reduced residential heating and cooling consumption of around 15%, due to efficiency improvements (particularly insulation). The combination of efficiency improvements and climate change thus lead to an overall decrease of residential heating and cooling energy needs of 37% between 2010 and 2100 (from -21% for Southern Europe to -53% for Central Europe North).

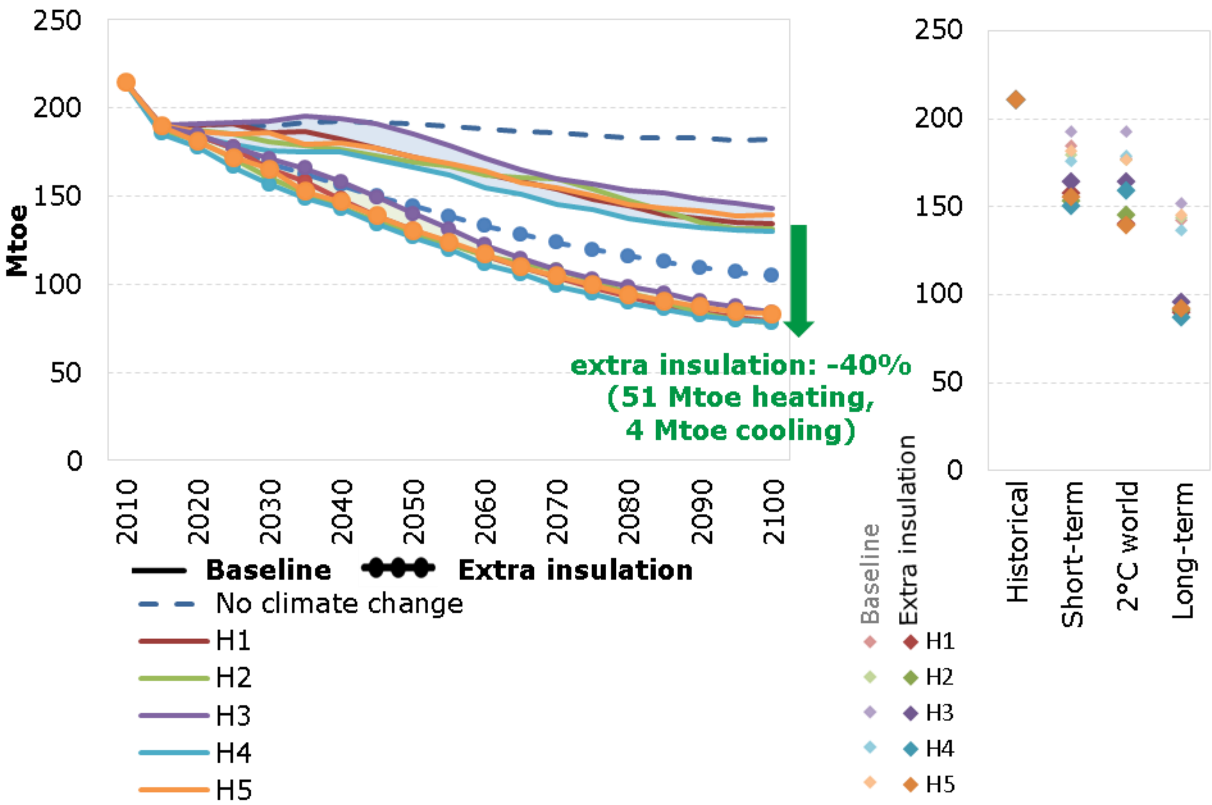
Compared to other residential energy consumptions, the share of heating and cooling goes from two-thirds in 2015 to around half by the end of the century. The total European residential energy needs decrease by 16% in 2100 thanks to climate change (despite non-temperature-related needs actually increasing).

The analysis with the POLES-ADVANCE model also shows that climate change decreases the peak power needed across Europe by 55 to 75 GW by the end of the century, thanks to lower heating needs in peak winter times.

5.2 Impact of improved insulation

Another scenario was carried out in order to test the sensitivity of the system to an increased building insulation. We introduce a high carbon value mimicking a strong action against climate change[6]. Figure 10 shows the impact on energy demand for residential heating and cooling, considering the RCP8.5 climate change scenario used in this report.

Figure 10. Impact of a better insulation on the sum of heating and cooling demand in EU28



Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

Additional insulation can bring up to 40% of additional energy savings in heating and cooling demand. However, the impact of climate change stays the same: a quarter of the residential heating and cooling needs are still avoided by the RCP8.5 climate. The relative impacts of climate change on the energy sector are robust to the level of insulation.

In this scenario with strong climate policies, the European residential heating and cooling needs decrease by 62% by the end of the century, climate change playing only a small role compared to the large efficiency improvements (roughly a ratio of one to four).

When insulation is promoted, climate change can be seen as less beneficial to the European energy needs in absolute terms, since the total consumption is also reduced. Insulation decreases the sensitivity to climate change.

[6] Although this scenario still considers a climate consistent with RCP8.5, a strong climate policy is added. For this sensitivity analysis, the retro-action on the level of climate change is not considered.

6 Conclusion

The conclusions of this study are the following.

First, the 32% decrease of heating needs in 2100 (compared to a scenario without climate change) is a positive effect of climate change. Less power plants will be needed, especially in the second half of the century (55 to 75 GW of avoided plants by 2100 for EU28).

Second, several actions can improve adaptation to the (negative) effects of climate change on increased cooling demand (a multiplication by three because of climate change). Air conditioning efficiency improvements are crucial to control the increase of cooling demand. Insulation should also be pursued, which would limit both heating and cooling demand.

Lastly, a comparison with a scenario without climate change shows that climate change reduces the combination of European residential heating and cooling demand by a quarter. This is because Europe is a fairly cold region, compared with the rest of the globe. The effect of climate change under a RCP8.5 scenario on total residential final energy demand is a reduction of 16%.

The main take-away results are the following:

- the diminution of heating needs is the dominant effect in each of the five European regions; needs for cooling strongly increase in South and Central Europe but still remain much lower than heating needs (a factor of 3.7 in final energy and 2.5 in primary energy in Southern Europe);
- most of the climate change impacts on energy demand takes place in the long-term (second half of the century);
- some important changes in demand are noticed in the short-term, although unrelated to climate change: more insulation in Central Europe North, more AC equipment in Southern Europe;
- additional insulation can reduce the sensitivity of heating and cooling demand to climate change;
- results of relative impacts of climate change remain robust to building insulation assumptions.

In addition, a comparison with PESETA II Reference scenario shows the impact of different input temperature data. PESETA II reported a 13% decrease of heating and cooling needs, i.e. half the impact seen in this report, because the temperature increase was more moderate, which means less (downwards) impact on heating needs (the dominating factor).

The PESETA III projections does not capture well all behavioural aspects, especially regarding the use of cooling devices that have developed fairly recently in most regions. Another limitation of this work is that other effects of climate change on the energy sector are not studied. Some adaptation efforts may be required to ensure the resilience of the power system infrastructure to climate change (DOE 2013).

Future work will have to use updated heating and cooling data, both for residential and service sectors. A better understanding of the effects of extreme climate events on the power system (cold or heat waves, water scarcity) is also important. The future PESETA IV will cover some of these additional items, in addition to expanding the analysis to the world.

The policy implications are that, in an integrated EU power market, overall needs for heating and cooling energy and for peaking power plants would both decrease in a RCP8.5 scenario. Nevertheless, better insulation and efficiency of cooling devices remain important since they can bring strong additional energy savings.

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List of abbreviations and definitions

AC	Air Conditioning
CDD	Cooling Degree Days
HDD	Heating Degree Days
RCP	Representative Concentration Pathway
UEC	Unit Energy Consumption

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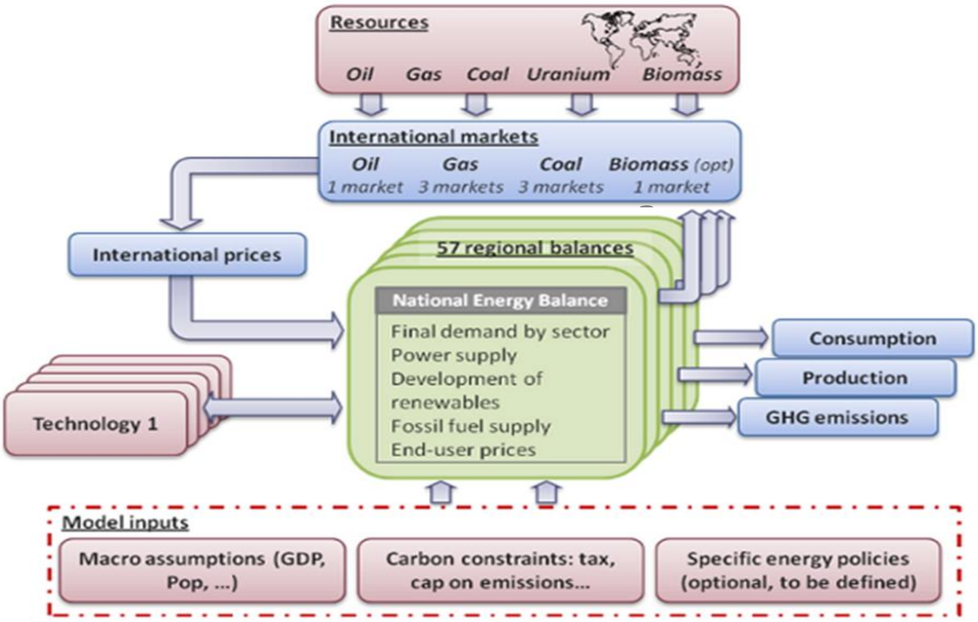
Annexes

Annex A. POLES-JRC description

POLES (Prospective Outlook on Long-term Energy Systems) is a global energy model covering the entire energy system, from primary supply (fossil fuels, renewables, ..) to transformation (power, biofuels, hydrogen) and final sectoral demand. International market and prices of energy fuels are simulated endogenously. Its high level of regional detail (57 countries / regions) and sectoral description allows assessing a wide range of energy and climate policies in all regions within a consistent global frame: access to energy resources, taxation policy, energy efficiency, technological preferences, etc. POLES usually operates on a yearly basis up to 2050 (2100 in this exercise) and is updated yearly with recent information (2012 data for most series).

The JRC POLES-ADVANCE version[7] (as developed in 2015) has been used for this exercise, it includes a module on climate impact on energy demand in residential buildings. Differences with other exercises done with the POLES model by JRC in other projects, or by other entities (namely the University of Grenoble and Enerdata) can come from different i/ model version, ii/ historical data sets, iii/ parameterisation, iv/ policies considered.

Figure 11. POLES model general scheme



Source: Enerdata

Final demand

The final demand evolves with activity drivers, energy prices and technological progress. The following sectors are represented:

- industry: chemistry (energy uses and non-energy uses are differentiated), non-metallic minerals, steel, other industry;

- buildings: residential, services (specific electricity uses are differentiated, different types of buildings are considered);

- transport (goods and passengers are differentiated): road (motorcycles, cars, light and heavy trucks – different engine types are considered), rail, inland water, international maritime, air domestic and international;

[7] See http://themasites.pbl.nl/models/advance/index.php/ADVANCE_wiki

- agriculture.

Complementary information on the impact of climate on residential buildings is given in the section "Methodology" above.

Power system

The power system describes capacity planning of new plants and operation of existing plants for 40 technologies.

The planning considers the existing structure of the power mix (vintage per technology type), the expected evolution of the load demand, the production cost of new technologies, and resource potential for renewables.

The operation matches electricity demand considering the installed capacities, the variable production costs per technology type, the resource availability for renewables.

The electricity demand curve is built from the sectoral distribution over 2 typical days: one for summer and one for winter, each decomposed into twelve 2h blocks.

Electricity price by sector depend on the evolution of the power mix, of the load curve and of the energy taxes (by default kept constant).

Other sectors

The model also describes other energy transformations sectors: liquid biofuel (BTL), coal-to-liquid (CTL), gas-to-liquid (GTL), hydrogen (H2).

Oil supply

Oil discoveries, reserves and production are simulated in 80 individual countries and for 6 types of fuel: conventional crude & NGLs (inland and shallow water), tar sands, extra heavy oil, oil shale (kerogen), deepwater and arctic oil.

The market is structured along the market power of the different countries:

- non-OPEC production produces depending on remaining reserves, oil price and production cost;

- OPEC production adjusts to the evolution of demand and non-OPEC production;

- Gulf production can develop a spare capacity to adjust for short term variations, it adjusts to the evolution of demand and non-Gulf production.

International oil price depend on the evolution of spare capacity in the Gulf (short term: 1 year), global Reserve / Production ratio (long-term) and marginal production cost of non-conventional oil. Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Gas supply

Gas discoveries, reserves and production are simulated in 80 individual countries or regions for 4 types of gas: conventional gas (inland and shallow water), shale gas, deepwater and arctic gas. They supply 15 regional markets, made up of the national gas demand of the 57 countries and regions. 37 of the producers are considered as key producers with a capacity to export on international markets through trading routes. Gas transport is done through inland pipeline, offshore pipelines or LNG.

Gas price is simulated for 3 regional markets: Europe, America, Asia. It depends on the transport cost, the regional R/P ratio (long-term trend), the evolution of oil price and the development of LNG (integration of the different regional markets). Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Coal supply

Coal production is simulated in 74 individual countries or regions. Some countries (USA, Australia, China, India) have two or more production regions to better represent transportation costs which can represent a significant share of the coal delivery cost. They supply 15 regional markets, made up of the national coal demand of the 57 countries and regions. 26 of the producers are considered as key producers with a capacity to export on international markets through trading routes.

Coal delivery price for each route depends on the transport cost (international and inland), the mining cost, and other operation costs. An average delivery price is calculated for each of the 15 consuming markets. The model also calculates an average international price for 3 "continental" markets: Europe, Asia, America. Price to consumer considers the evolution of taxation, including the impact of a carbon value.

Biomass supply

The model differentiates 3 types of primary biomass: energy crops, short rotation crop (cellulosic) and wood (cellulosic). They are described for each of the 57 country through a potential and a production cost curve – in the case of SRC and wood this is derived from look-up tables provided by the specialist model GLOBIOM-G4M (Global Biosphere Management *Model)*.

Biomass can be traded, either in solid form or as transformed liquid biofuel.

Wind, solar and other renewables

These renewables are associated to potentials per country, which can be more detailed (in the case of wind and solar, where supply curves are used) or less (hydro, geothermal, ocean where only a potential figure is used).

GHG emissions

CO_2 emissions from fossil fuel combustion are derived directly from the energy balance, that is influenced by mitigation policies (carbon value, support policies to technologies, energy efficiency targets).

Other GHGs from energy and industry are simulated using activity drivers identified in the model (sectoral value added, mobility per type of vehicles, fuel production,..) and abatement cost curves.

GHG from agriculture and LULUCF are derived from GLOBIOM-G4M lookup tables.

Regional coverage

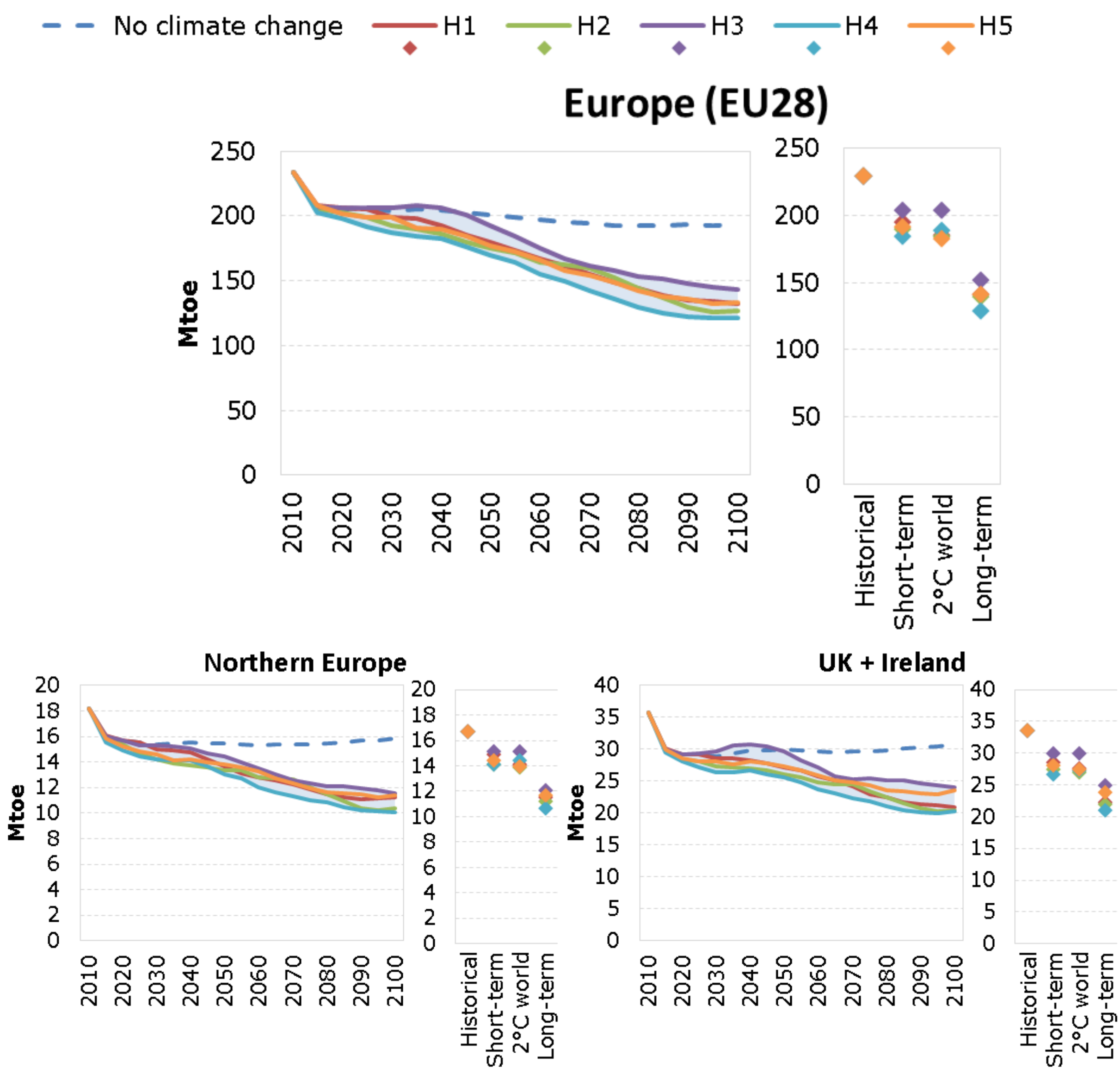
Table 2: POLES-JRC regional coverage (57 countries and regions, incl. 28 EU Member States)

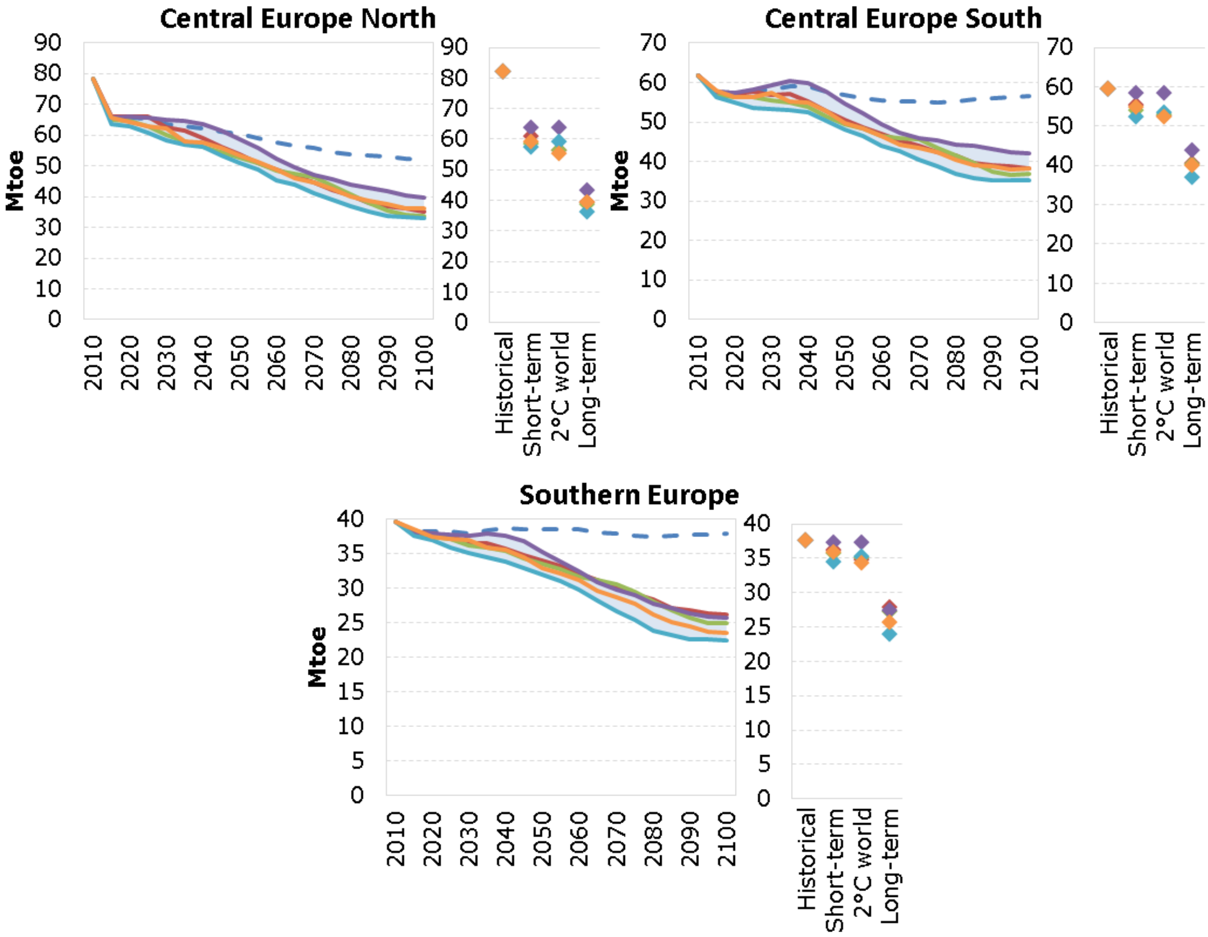
Europe	CIS	North America	Latin America	Africa	Middle East	Asia
Detailed EU28	Russia	USA	Mexico	Egypt	Gulf	Japan
Switzerland	Ukraine	Canada	Rest Central America	Morocco & Tunisia	Mediterranean Middle East	Korea, Rep.
Norway	Other CIS		Brazil	Algeria & Libya		China
Iceland			Rest South America	South Africa		Indonesia
Former Yugoslavia (excl. Croatia)				Rest Sub-Saharan Africa		India
Turkey						Oceania (inc. Australia & New-Zealand)
						Rest South-East Asia
						Rest South-Asia

Annex B. Results of residential energy consumption in primary energy

The analysis of Figure 12 and Figure 13 is similar to Figure 6 and Figure 7.

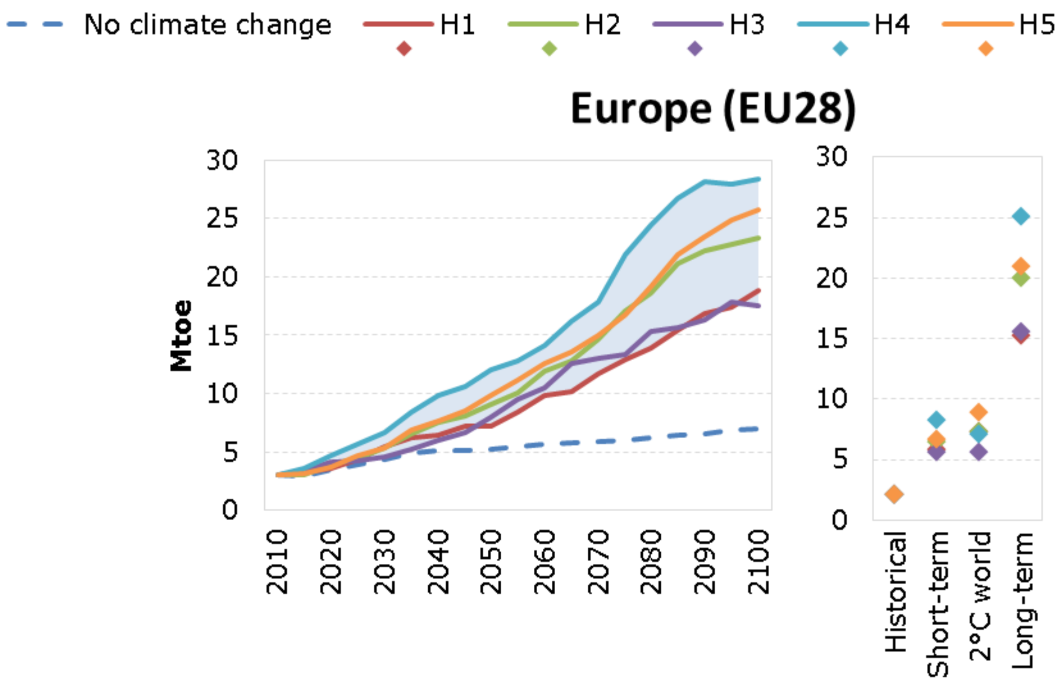
Figure 12. Impact of climate change on European residential heating demand (primary energy)

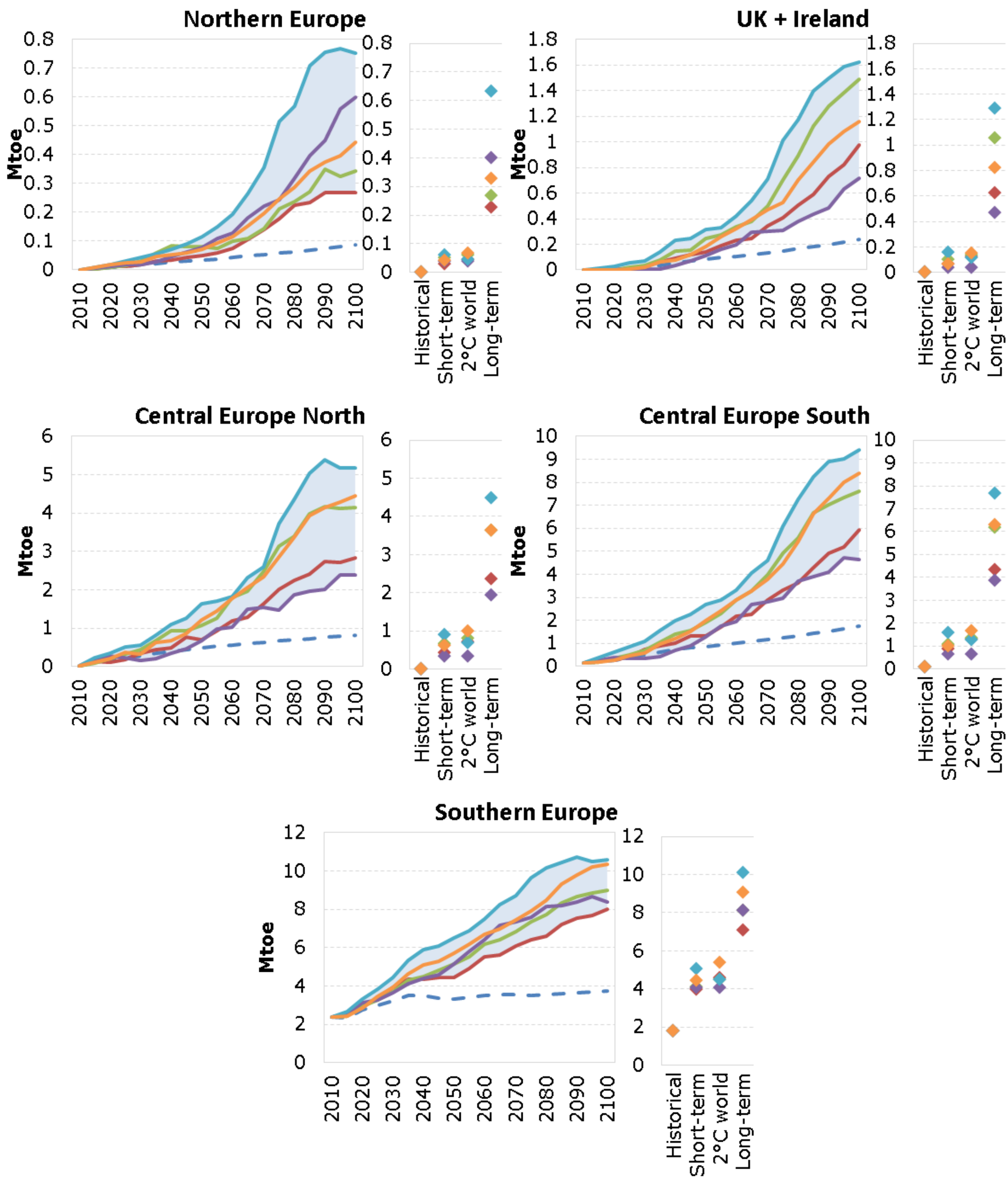




Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

Figure 13. Impact of climate change on European residential cooling demand (primary energy)





Source: POLES-JRC model (ADVANCE project version (ADVANCE wiki 2017))

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