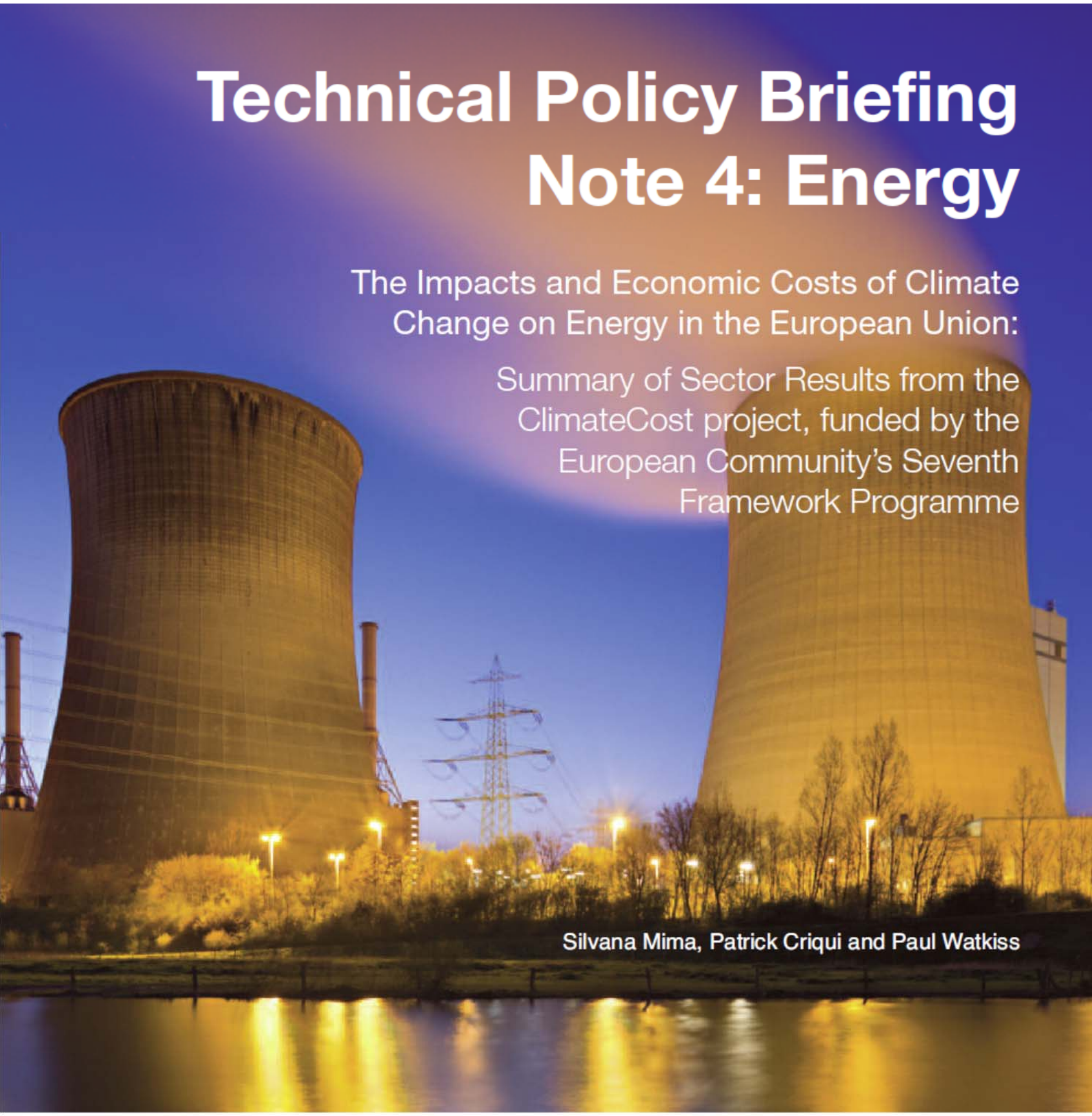
Technical Policy Briefing Note | 4



Technical Policy Briefing Note 4: Energy

The Impacts and Economic Costs of Climate Change on Energy in the European Union:

Summary of Sector Results from the ClimateCost project, funded by the European Community's Seventh Framework Programme

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ClimateCost

SEVENTH FRAMEWORK PROGRAMME

DRAFT FINAL VERSION

Key Messages

- Temperature is one of the major drivers of energy demand in Europe, affecting summer cooling and winter heating, for both the residential and service sectors. While cooling is predominantly powered by electricity, heating uses a wider mix of energy sources.

- Climate change will have negative and positive effects on future energy demand, increasing summer cooling but reducing winter heating. These responses are largely autonomous, and can therefore be considered as an impact or an adaptation. These future changes also need to be seen in the context of other socio-economic drivers and energy/mitigation policy.

- The ClimateCost study has assessed the potential impacts and economic costs of climate change on energy demand in Europe for two scenarios. A medium-high emission scenario (A1B) and a low emission mitigation scenario (E1), the latter consistent with the 2 degree stabilisation target. The study has considered uncertainty by considering a large range of climate model outputs for each of these scenarios. The study has used the POLES model, and considered future socio-economic change and future climate change together, as well as the change due to climate change alone. This takes account of growth and the effects of mitigation policy on overall energy demand and energy/generation mix.

- The study has first assessed the **increase in cooling demand** in the residential and service sectors. Future cooling demand is expected to increase in the future, even without climate change, with EU27 electricity use for cooling increasing (on average) by around 3% per year during the century (A1B scenario).

- Under **a medium-high emission baseline (A1B),** with no mitigation or adaptation, demand for cooling in the EU27 is expected to increase to a total of 145 Million tonne of oil equivalent (Mtoe) per year by 2050 and 269 Mtoe/year by 2100 from the combined effect of socio-economic and climate change together (ensemble mean). Of this, the estimated increase in cooling due to climate change alone (above the A1B baseline without climate change) is 16 Mtoe/year by 2050 and 53 Mtoe/year by 2100. There is a strong distributional pattern of changes across Europe, with a much higher increase in cooling demand in Southern Europe.

- There is a wide range around these central (mean) estimates, representing the range of results from different climate models. The study considered around ten alternative climate models and these reveal that the potential costs vary considerably: as an example, in the residential sector, cooling demand varies by +/-25% for the A1B scenario (2100).

- Under an **E1 stabilisation scenario, broadly equivalent to the EU 2 degrees target**, with no adaptation, cooling demand is lower at around 113 Mtoe/year by 2050 and 139 Mtoe/year by 2100 (EU27, ensemble mean, combined effect of socio-economic and climate change), with around 10 Mtoe/year of this being due to climate change (ensemble mean). There is therefore a significant benefit compared to the A1B scenario. However, consideration of the range of climate models show that the increase in cooling could still be significant under this mitigation scenario, with high increases projected from the warmer models.

- The additional costs of climate change alone – from the additional electricity consumption for more air conditioning due to higher temperatures - is estimated at around €22 billion/year in EU27 by 2050 rising to €89 billion/year under the A1B scenario (current values, undiscounted). However, this only reflects energy use, and the cost of investment costs of new air conditioners needs to be added to these values, estimated at an additional €8 billion by 2050 and € 20 billion/year by 2100, giving a total of € 30 billion/year and €109 billion/year in 2050 and 2100 respectively (current values, undiscounted). Under the E1 scenario, the total costs due to climate change (alone) are around € 20 billion/year across the period 2050 - 2100).

- The study has also assessed the **decrease in heating demand** in Europe (a benefit) from climate change. The reduction in heating demand from climate change alone – on top of the baseline change – is estimated at -28 Mtoe/year by 2050 rising to -65 Mtoe/year by 2100. This is approximately a 10% and 20% reduction respectively on the future heating demand baseline. Under the E1 scenario, the reduction in heating demand is lower, estimated at -11 Mtoe/year by 2050 and -13 Mtoe/year by 2100. Again, there are large variations across the suite of climate models considered also large differences across regions of Europe, with the largest reductions in Western Europe.

- While the physical energy reductions are higher than the increase in cooling demand, the relative costs are closer (as cooling is more expensive than heating). When considered in economic terms, the reduction in total heating demand (from climate change alone) is estimated at €34 billion/year in 2050 and €121 billion/year in 2100 for the EU27 under the A1B scenario (current prices, undiscounted) – about the same as the increase in cooling demand.

- The study has also looked at the potential for planned adaptation, and the costs and benefits of possible measures or strategies for energy demand. This can include specific measures for addressing cooling or heating, or options that address both, notably low- and very low-energy consumption buildings, which reduce energy requirements. While these have the potential to be no regret, the analysis finds the benefits vary strongly across the range of climate projections, and with the assumptions on capital costs versus operating savings.

- Climate change may also affect energy demand by changing water availability. Currently around 3.5% of electricity consumption in the EU is used for water supply and treatment. An initial analysis indicates that climate change could increase energy demand associated with water by 5% in 2050 and 12% in 2100 on average in the A1B scenario, with costs of €1.5 billion/year and €5 billion/year respectively (ensemble mean, undiscounted current prices). These increases are significantly reduced under the E1 scenario.

- Climate change will also have effects on **energy supply**, notably on hydro-electric generation, but also potentially on thermal power (nuclear and fossil) plants and on other renewables. The scale of these effects has been considered using POLES.

- Hydropower plants are affected by climate change by effects on precipitation and other factors. The impacts of climate change on hydro generation varies strongly according to the scenario and the climate models, and alternative models project very different levels of precipitation change, even in terms of the sign of change. Using an initial POLES analysis, the climate change associated with the A1B scenario (ensemble mean) is estimated to decrease European hydro generation by around -3% in 2050 and -8% in 2100, compared to the future baseline. The impacts are lower for E1 scenario at -2% and -3% respectively (ensemble mean). However, there is considerable uncertainty over these central estimates. There are also varying patterns across Europe, with the potential for decreasing discharge volumes for southern and east-central Europe, but potential rises for northern European, though this does not take annual variability into account.

- Finally, higher temperatures from climate change may potentially affect power plant cooling and potentially reduce efficiency for thermal power plants (nuclear and fossil). Indicative results estimate that thermal and nuclear power generation could be reduced by up to 2-3% (thermal) and 4-5% per year (nuclear) for current plant under the A1B scenario. While changes in plant design and anticipatory action could reduce these significantly, the potential size of these effects indicates that further investigation is needed.

1 Introduction

The objective of the ClimateCost project is to advance the knowledge on the economics of climate change, focusing in three key areas: the economic costs of climate change (the costs of inaction), the costs and benefits of adaptation and the costs and benefits of long-term targets and mitigation.

This summary provides an overview of a European wide assessment of the impacts and economic costs for the energy sector, and early work on the costs and benefits of adaptation, as part of the ClimateCost project.

1.1 Climate and Energy

Climate change has potential effects on energy demand, as outside temperature affects space heating and space cooling requirements. Energy demand increases with colder temperatures (heating) and with higher temperatures (cooling). Climate change will therefore lead to a decrease in the demand for winter heating in Europe, but an increase in summer cooling (which can be described as an impact or an adaptation). This will affect the energy use of buildings in the residential and service sectors, with potentially important benefits and costs. Climate change may also increase energy demand via other mechanisms as well, notably from energy associated with water supply.

Climate change also has the potential to affect energy and electricity supply. Changes in precipitation could affect the potential of hydropower, positively or negatively according to the region considered, and broader changes could affect thermal generation and renewable production, as well as exposing energy infrastructure to changes in extreme events.

2. Scenarios

2.1 Socio-economic and climate scenarios

In the assessment of the future damages of climate change, assumptions have to be made on future conditions and this implies the development of adequate scenarios. The most widely used are the emission scenarios of the IPCC Special Report on Emission Scenarios (the SRES scenarios, Nakicenovic *et al*. 2000). These define a set of future self-consistent and harmonised socio-economic conditions and emission futures, which in turn have been used to assess potential changes in climate through the use of global and regional climate models. There is a wide range of future drivers and emissions paths associated with the scenarios, and thus the degree of climate change varies significantly, which has a significant impact on the results. The ClimateCost study has focused on two scenarios.

The first is the SRES **A1B scenario**; this is based on the A1 storyline with a future world of rapid economic growth, new and more efficient technologies and economic convergence between regions. The A1B scenario adopts a balance across all sources (fossil and renewable) for the fuel-mix and technological changes in the energy system. This scenario has been extensively used in recent European regional climate modelling studies, notably in the ENSEMBLES study. For this reason, it has also been used in ClimateCost. It reflects a medium-high emission trajectory and leads to central estimates of global average surface temperatures of around 3.4°C relative to pre-industrial levels[1], though individual models show a wide range of results.

The second is the ENSEMBLES **E1 scenario** (van der Linden et al. 2009: Lowe et al., 2009), which leads to long-term stabilisation at 450ppm (450 ppm stabilisation in the 21st century after a peak of 535 ppm in 2045). This is a mitigation scenario that would limit the global warming to less than 2 degrees with a high probability (central estimates of around 1.8°C, though models also in that case show a wide range.

[1] The IPCC AR4 (IPCC, 2007) reports the best estimate of global surface temperature change from the A1B scenario is 2.8°C by 2090 – 2099, relative to 1980-1999, with a likely range of 1.7 to 4.4°C (noting that that temperatures have increased by about 0.74°C between 1906 and 2005).

2.2 Climate models and uncertainty

The standard approach to the development of climate scenarios is to run the above emissions scenarios in General Circulation Models (GCMs), and where needed to downscale these for a region such as Europe with the use of coupled Regional Climate Models (RCMs). The ClimateCost study has followed this approach, using the results of the ENSEMBLES project. For the energy analysis, the study has used a global energy model, hence this has required the use of the GCM data (rather than the coupled GCM-RCM outputs).

However, individual models lead to very different results, see the TPBN on climate models and uncertainty (Christensen et al, 2011). This makes a large difference to future climate change, and thus to the results. To capture this uncertainty, the ClimateCost project has run energy impact assessments for a large number of climate model outputs, for each of the scenarios considered. The variation in temperature – and especially precipitation – is very large across the models.

For the energy analysis, the data from the ENSEMBLES project were used, for two scenarios, each of which with around ten General Circulation Models (GCMs) outputs.

2.3 Future time periods

The assessments here consider the future projected impacts of climate change, set against a modelled baseline from 1961-1990. There is a range of potential future time periods that could be considered, reflecting different information needs. These vary from projections of short- and medium-term changes that can help inform early adaptation priorities, as well as longer-term more significant changes, that can help inform mitigation. In other sectors, the analysis in ClimateCost has worked with thirty year time slices (2011-2040, 2041-2070 and 2071-2100). For the analysis in the energy sector, the detailed energy projections has worked on a decadal level as this is needed for the energy model: the results are therefore presented below in this format. As the analysis has focused on long-term trends (rather than variability) this averaging period is acceptable.

2.4 Socio-economic scenarios and data

The socio-economic scenarios also set out a wide range of other determinants that are important in influencing future impacts. These include important primary drivers, including economic growth and demographic changes. Previous work has shown these future socio-economic drivers can be as important as future climate change in determining impacts and economic costs.

In the case of the energy sector analysis, future population and economic growth will make a very significant difference to future energy demand and these effects are taken into account in the model. While including these effects is challenging, and introduces additional uncertainty, these future changes need to be considered across the time frames of interest here, otherwise this implies that projected future climates will take place in a world similar to today.

One of the aims of the ClimateCost project has been to apply consistent climate and socio-economic scenarios, across sectors, in order to ensure comparability across the study. The energy analysis therefore includes projections of socio-economic drivers in the analysis below, primarily in relation to future population and per capita incomes in Europe that have to be consistent with the A1B and E1 emission scenarios.

For energy, the socio-economic analysis (including of existing policy) is particularly important, because the E1 mitigation scenario needs to be consistent with the achievement of GHG emission reduction targets for the energy sector. This leads to a very different energy use and technology mix between the two scenarios.

2.5 Attribution: separating climate and socio-economic signals

There is a need to consider socio-economic futures when assessing the risks of climate change. It is also important to split out this socio-economic component to identify the 'net' impacts attributable to climate change, rather than reporting the 'gross' impacts of climate and socio-economic change together - because the future impacts from socio-economic change would have occurred even in the absence of climate change.

For this reason, the analysis below first considers each scenario with a fixed climate as a baseline scenario, i.e. which shows the level of change in the energy sector that would occur in the absence of climate change but driven only by population and economic growth. Note that linked to the point above, for the energy sector this means two separate baselines for each of the A1B and E1 scenarios, in order to ensure that each is consistent with the associated global emissions path, and for E1, the adoption of mitigation measures to achieve stabilisation. It then considers the effects of climate change (in terms of temperature change, etc.) on the energy use in each of these scenarios. This then gives the marginal or net impact of climate change.

This is also included in the analysis of adaptation, and is important in allowing attribution of the specific effects due to climate change, whilst noting that adaptation policy will need to address the combined future effects of both climate and socio-economic change.

2.6. The reporting of economic values (including adjustments and discounting)

Consistent with all sector-based analysis in ClimateCost, the economic valuation results in this note are presented in terms of constant current prices for the time periods considered, without any adjustments or discounting. The results are presented in this way to facilitate direct comparison over time and between sectors.

However, the use of the values in subsequent policy analyses, for example in looking at the costs and benefits of adaptation options, would need to work with present values (i.e. values that are adjusted and discounted as with standard economic appraisal). This point is discussed in the later adaptation section.

A number of other technical issues are also highlighted. The analysis applies unit values for the impact categories covered, using energy price estimates from the PRIMES model. These involve different prices for the two scenarios, A1B and E1, because of the different energy mix and policy in each case.

However, the analysis does not include price effects (rebound effects from reduced winter heating, or demand reductions from higher energy costs of cooling) and the subsequent changes in demand.

The values reported represent direct costs only. They do not consider the wider economic costs associated with damage costs or with adaptation. The analysis of these wider economic effects is included in the Computable General Equilibrium analysis in ClimateCost.

3. Methodology

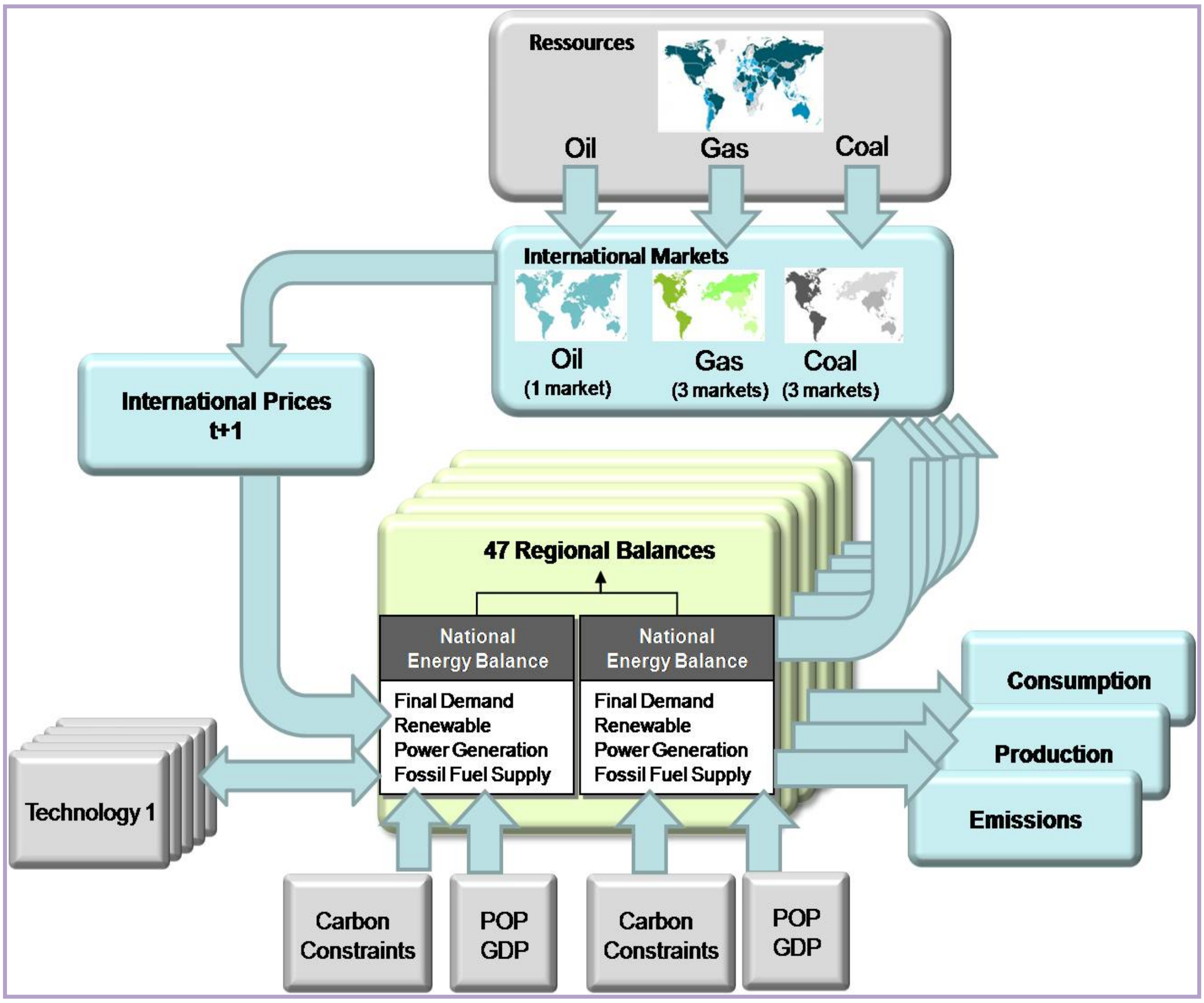
Climate models and projections provide indicators of changes in Heating Degree Days (HDD) and Cooling Degree Days (CDD). These represent an annual measure of the requirements for building heating and cooling respectively[2]. These can provide an immediate and direct energy indicator, i.e. the risk of ‘exposure’ to changes in temperature. However, they can be converted to physical impacts of energy usage (Mtoe or kWh) and economic costs. Note that in practice, energy demand is basically influenced by technical, socio-economic and economic factors.

The study has been performed using a widely recognised energy model, POLES, to assess the impacts of changes in HDD and CDD for Europe and globally, shown in the figure below. POLES is a partial equilibrium model of the world energy system, with a dynamic recursive simulation process[3].

[2] The definitions of these vary slightly, but Heating Degree Days (HDD) are estimated by the number of degrees Celsius that the daily mean temperature is below 18 ºC for every day of the year (ignoring negative numbers, that is, when the mean temperature is above 18 ºC) and this is summed for all days of the year. For example, if the temperature on every day in a year were at 16 deg C, then you would have 2 x 365 = 730 HDDs. Cooling Degree Days (CDD) is a similar measure, related to energy needed for cooling. To derive it, the number of degrees Celsius that the daily mean temperature is above 18 ºC is calculated for every day of the year and this is summed for all days of the year.
[3] Note the model does not take into account wider (indirect) economic effects, i.e. macro-economic effects, but these effects are being considered by other models in the ClimateCost project.

From the identification of the drivers and constraints in the energy system, the model describes pathways for energy development, fuel supply, greenhouse gas emissions, international and end-user energy prices, from today to 2050 or 2100. The approach combines a high degree of detail in the description of the key components of the energy systems and a strong economic consistency for the changes in this system. The main exogenous inputs relate to world population and economic growth – from the A1B and E1 scenarios - as main drivers of energy demand, oil and gas resources, while the future costs and performance of energy technologies may be endogenous to the model[4]. Climate change is then introduced as a variable in the model.

Figure 1. The POLES model framework

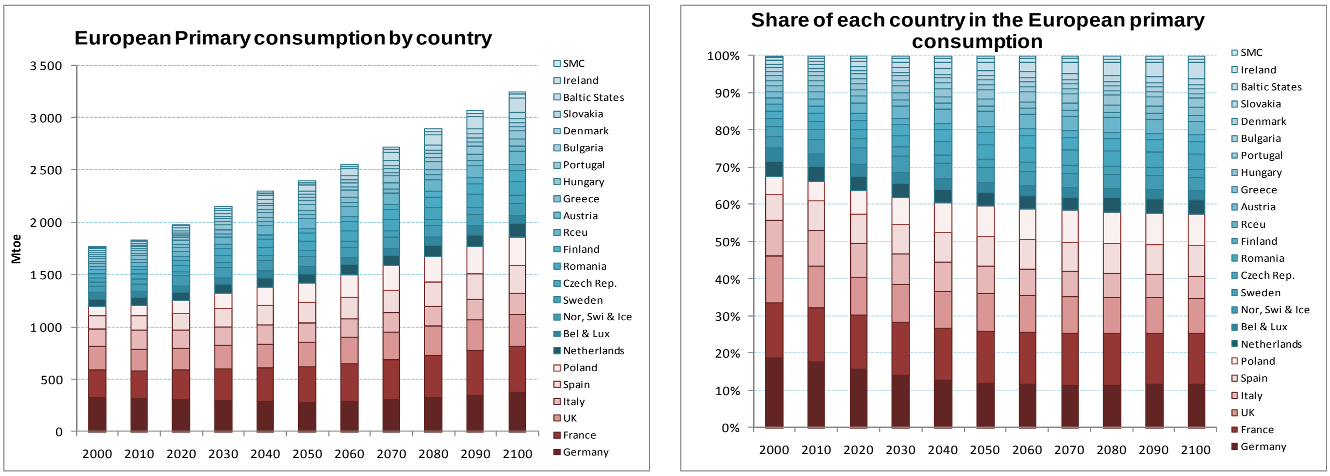


The study has used the SRES A1B scenario (using the consistent assumptions on population and economic growth) as the first baseline. The key outcome of the A1B case is a 1.6%/year increase in world energy consumption through 2100, which leads to a quadrupling of world energy consumption from 2010 to 2100, though with a levelling-off of world oil and gas production after 2050.

Globally, emissions nearly triple over the period considered. In the EU, primary energy consumption in EU27 increases more moderately over the whole period, from 1.7 Gtoe today, to 3 Gtoe in 2100.

[4] Note that in the analysis here, a standard discount rate of 8% is used, consistent with the use of the model in European policy analysis, while the ClimateCost project is considering the impacts of a wider range of social discount rates.

Figure 2. European primary energy consumption - by country and region (A1B scenario)



Source: POLES model, LEPII-EDDEN, Climate Cost project

Globally there is an increasing use of coal, particularly in the second half of the century. In the EU27, the contribution of fossil energy sources decreases from 79% at the beginning of the century to 62% by 2050 and represent 52 % by the end of the period. Renewables increase steadily over the period; however they represent only 24% of primary consumption by 2100. This leads to a high level of future CO_2 emissions, consistent with the IPCC SRES. It is stressed that this scenario is not consistent with current policy commitments in Europe.

The model has then been run with the E1 scenario. This is a mitigation scenario that implies global GHG emissions will be reduced by 50% in 2050 (relative to 2005) or by 75% compared to the baseline scenario emissions in 2050. Details of the emission reductions scenario are presented in the underlying energy modeling in ClimateCost.

3.1 What is included and excluded in the analysis?

When considering the results in this note, it is important to be explicit about what is included or excluded, and on the areas of uncertainty covered. In the graphs below, a range is often shown from the multi-model ensemble. This is for two scenarios only and it is stressed that there is a much wider range of possible future emission outcomes and scenarios. Furthermore, this range of values only reflects the climate model variability: there is a much wider range of uncertainty across the impacts and valuation assessment.

The analysis of energy for heating and cooling looks at trends: it does not consider the additional effects and issues associated with peak supply, or the effects of variability and extremes (including heat extremes). Impacts from flooding (coastal and river) on energy infrastructure are not considered, though there is some analysis within the river flood TPBN (Feyen et al, 2011).

The values reported represent direct costs only. It does not include price effects (rebound effects from reduced winter heating, or demand reductions from higher energy costs of cooling) and the subsequent changes in demand, and it does consider the wider economic costs associated with damage costs or with adaptation.

4. Results

The study has modelled the impacts of climate change. The analysis is based on the A1B and E1 scenarios, using temperature projections projected from the GCMs, to investigate the effects of temperature on energy demand. One key dimension of the approach has been to highlight the large variability between the different regional climate models simulations and models.

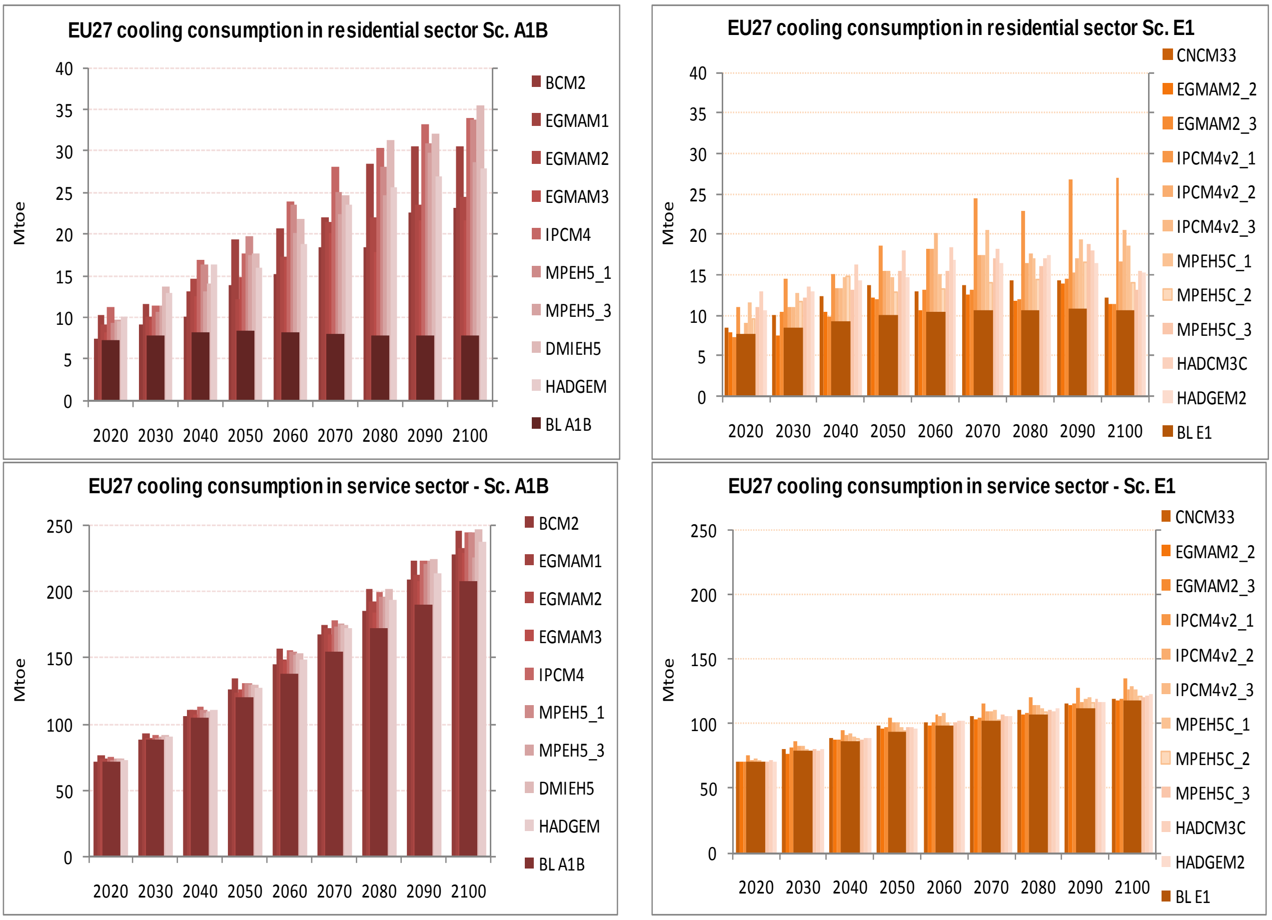
At European level, 37% of all final energy is consumed in buildings for the residential and service sector. This share will continue to increase in the future, to 57% in A1B scenario and to 48% in E1 scenario by the end of the period. More than half of this energy (57%) is used for heating. Although space cooling is currently a much less important energy use (around 5% of final consumption), it is foreseen to more than double by the end of the period.

Cooling

The study has first assessed cooling electricity demand. Currently, Europe has a low percentage of residential households equipped with air conditioning, at only around 5%, compared to some 65% in the USA and 85% in Japan. The percentage of commercial buildings with air conditioning in USA is 80%, even higher in Japan, but in Europe it is reported at only 27%. However, frequent warmer temperatures, increasing demand for comfort, increasing affordability and efficiency of cooling equipment are already leading to a strong increase in cooling demand in Europe. The diffusion of space-cooling is expected to be accelerated further by a warmer climate in Europe in the future.

The method has used the approach of McNeil and Letschert (2007). This first estimates air-conditioner ownership, which is strongly linked to income, using relationships from Isaac and Van Vuuren (2009). The change in cooling demand, as represented by cooling degree days, is then used to assess the future changes, using average unit energy consumption of typical equipment. As highlighted above, energy demand for air conditioning is projected to increase over the century, driven by income growth, even in the absence of climate change. The changes due to socio-economic growth alone, the baseline (BL-A1B, and BL-E1) with today's climate, are shown as the solid bars in the figures below. In the A1B scenario, EU27 electricity use for space cooling is estimated to increase by an average 3% per year during the century. The other columns show the combined impacts of economic development and of climate change together, considering different climate model outputs for the same scenario.

Figure 3. EU27 cooling consumption in residential and service sector in A1B (left) and E1 (right).



Source: POLES model, LEPII-EDDEN, Climate Cost project

Key: BL-A1B/ BL-E1 = Baseline with current climate for the two scenarios (A1B and E1). Other columns (BCM2 to HADGEM) include projections of energy with higher temperatures from alternative GCM projections.

With climate change, the analysis shows a very significant increase in energy use for air conditioning, though this varies with the climate model outputs. The greater relative increase in the residential sector (compared to the service sector) reflects the lower current penetration of air conditioning in Europe.

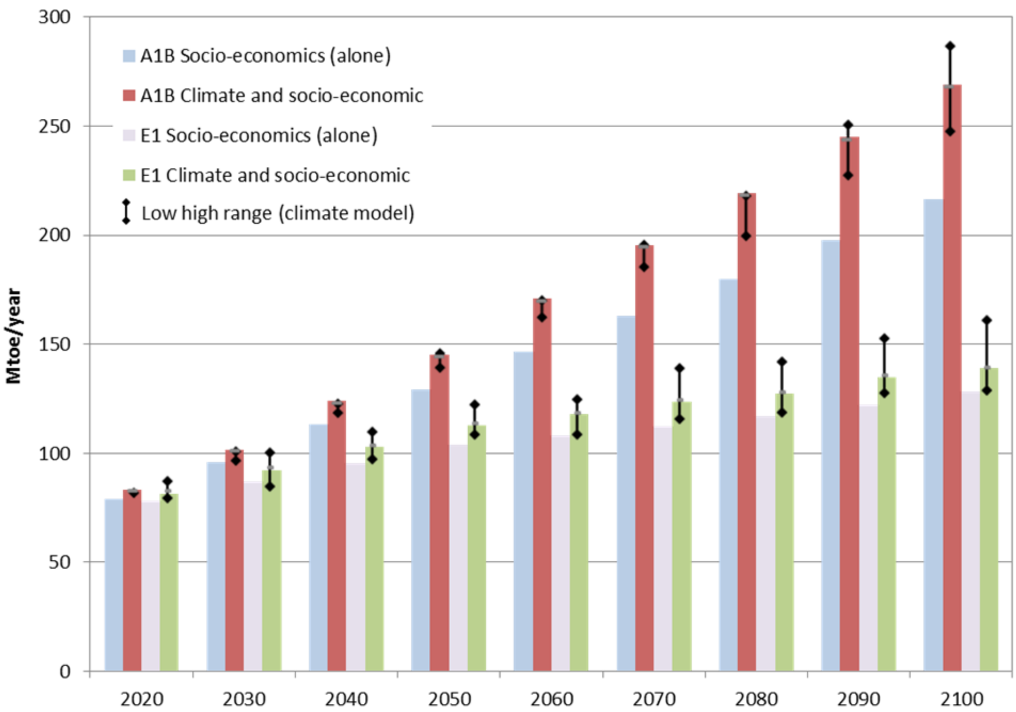
The figures also show the significant variation when different climate model projections are used, which can be seen very clearly in the analysis of residential cooling demand (top left). This has the effect that under warmer climate projections, even increases in the E1 scenario could still be significant (see top right).

The overall changes are shown below.

Under **a medium-high emission baseline (A1B),** with no mitigation or adaptation, the demand for cooling in the EU is expected to increase to a total of 145 Million tonne of oil equivalent (Mtoe) per year by 2050 and 269 Mtoe/year by 2100 (ensemble mean, combined effect of socio-economic and climate change together, residential and service sector). Of this, the estimated increase due climate change (above the future baseline) is 16 Mtoe/year by 2050 and 53 Mtoe/year by 2100. There is a particularly large relative increase in cooling demand from the residential sector.

Under an **E1 stabilisation scenario, broadly equivalent to the EU 2 degrees target,** with no adaptation, these increases fall to a total of around 113 Mtoe/year by 2050 and 139 Mtoe/year by 2100 (ensemble mean, combined effect of socio-economic and climate change together, residential and service sector), with the increase due to climate change alone being only 10Mtoe/year across the period (ensemble mean). There is therefore a significant benefit compared of the E1 over the A1B estimates.

Figure 4. Total EU27 cooling consumption with climate change for the A1B and E1 (Ensemble mean, and low high range from individual model projections sampled).

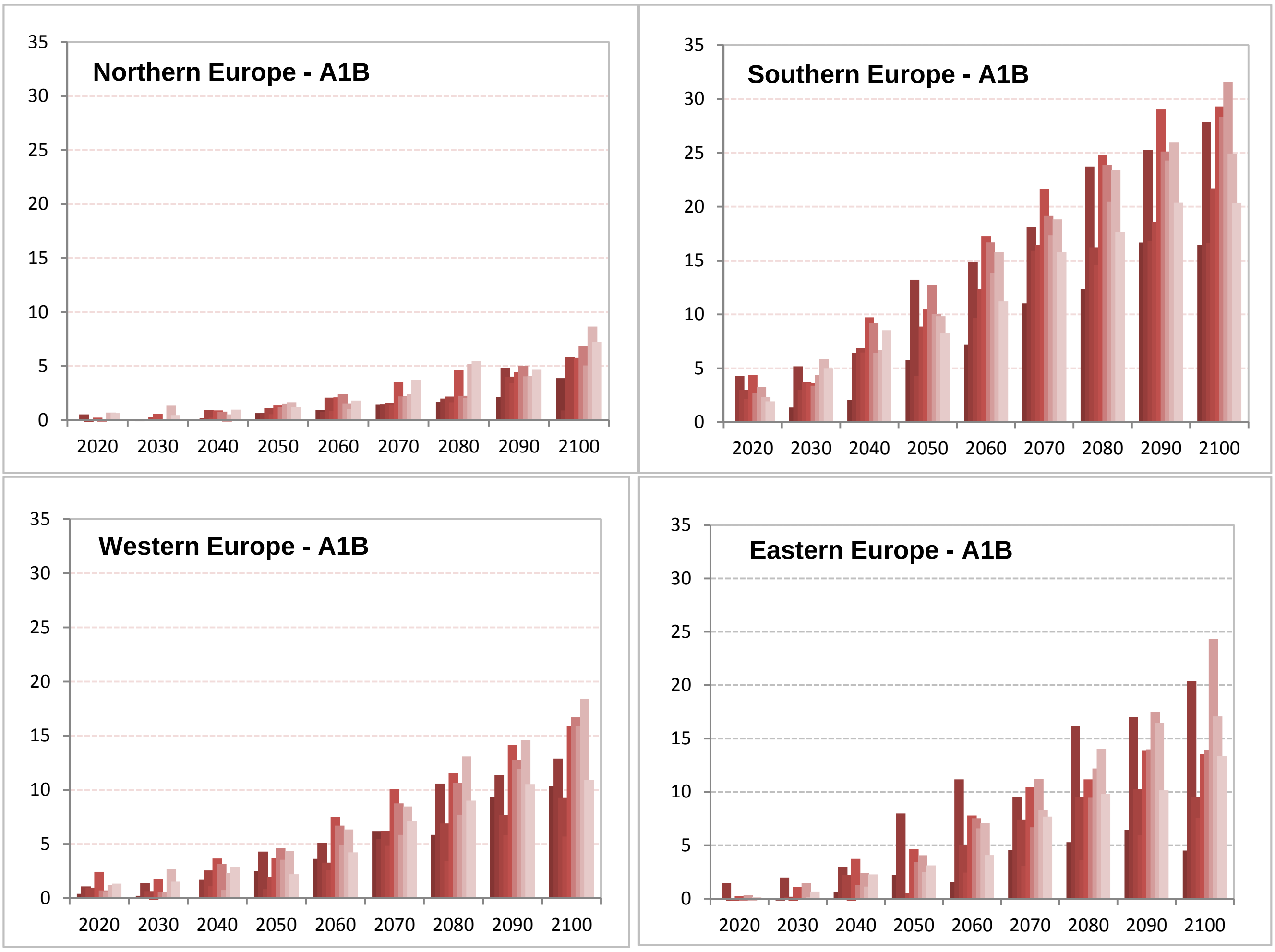


In the A1B scenario, EU27 electricity use for space cooling is estimated to increase by an average of 25% on the baseline due to climate change, though by potentially as much as 33% under the warmer models. Under the E1 scenario, the increase is only around 10% on the baseline, though even here, cooling increases could still be significant for Europe, with high increases projected from the warmer models.

Increases in cooling energy demand are also expected to translate to higher peak electrical demands in summer. This particularly important for those regions with summer peaks.

As can be expected, the impacts vary from region to region and from country to country. The figure below shows the addtional change in cooling demand from climate change by region for the A1B scenarios. Southern and Western Europe are most impacted in both scenarios. A similar but lower relative signal is seen under the E1 scenario.

Figure 5. Impact of climate change on EU27 energy consumption (Mtoe/year) for cooling space in residential and service sector by region under A1B (additional increase due to climate change alone, for a range of climate model projections).

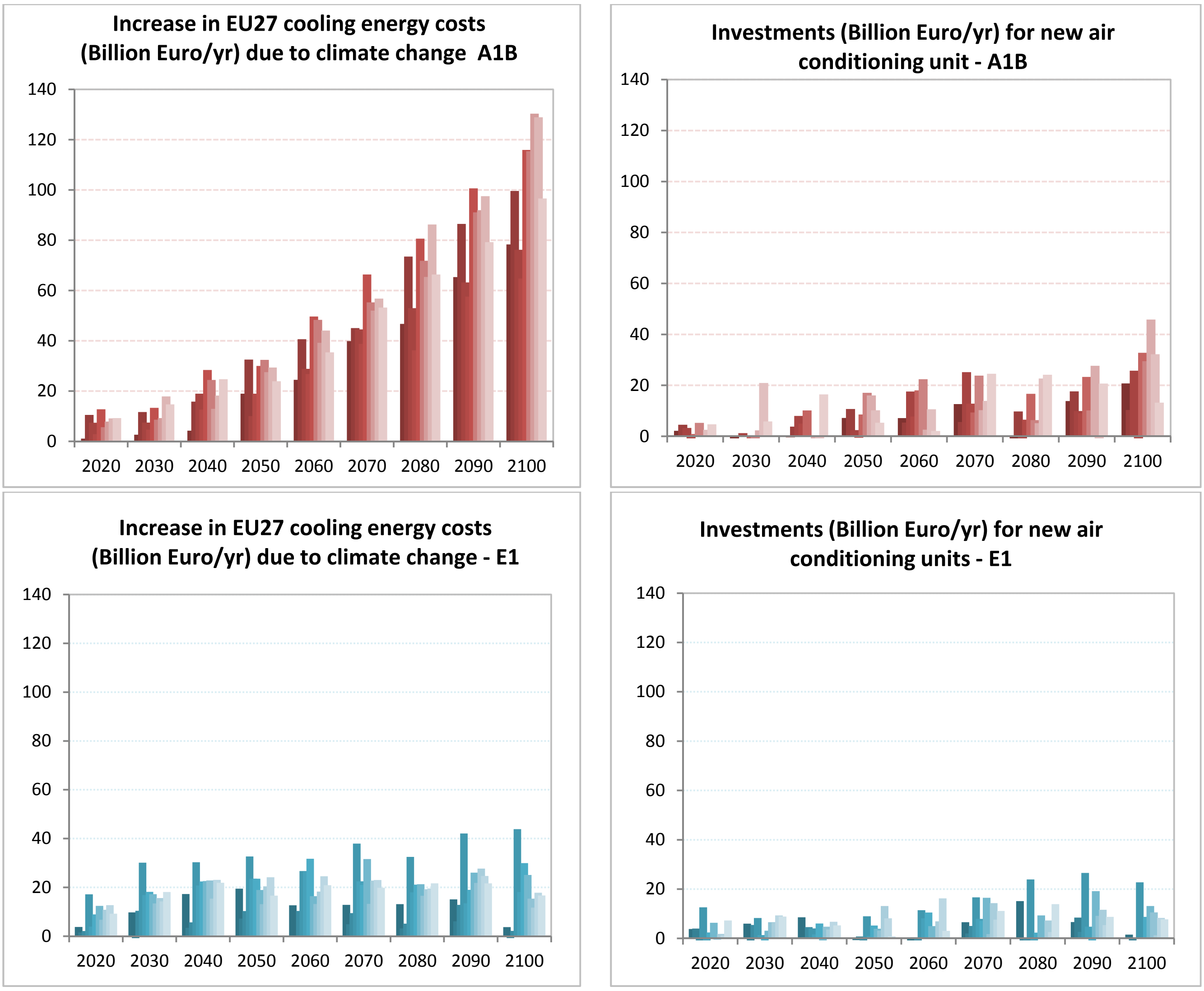


Source: POLES model, LEPII-EDDEN, Climate Cost project

The study has then assessed the costs of additional electricity consumption for air conditioning. The approach has been to multiply the absolute impacts with the average energy price for cooling in the residential and service sector (as it was not possible to estimate the marginal cost, though this would be the more appropriate value to use). Note that these results have also been input into a CGE model in other parts of the ClimateCost study.

The additional costs of climate change alone – from the additional electricity consumption for more air conditioning due to higher temperatures - is estimated at around €22 billion/year in EU27 by 2050 rising to €89 billion/year under the A1B scenario (current values, undiscounted). However, this only reflects energy use, and the cost of investment costs of new air conditioners needs to be added to these values, estimated at an additional €8 billion by 2050 and € 20 billion/year by 2100, giving a total of € 30 billion/year and €109 billion/year in 2050 and 2100 respectively (current values, undiscounted). Under the E1 scenario, the total costs due to climate change (alone) are around € 20 billion/year across the period 2050 - 2100).

Figure 6. Changes in energy costs (current 2010 prices, undiscounted) due to climate change (on top of baseline) for EU27 cooling energy demand and investments for new air conditioners in A1B and E1 scenarios (individual columns show alternative climate model projections).



Source: POLES model, LEPII-EDDEN, Climate Cost project

These values also do not take into account additional impacts from urban heat island effects in major cities which would further increase cooling demand. This is an important limitation, while heat islands could significantly increase the cooling demand in Europe. These changes are also important in relation to mitigation policies. Indeed, this is probably a very important area for adaptation-mitigation linkages, if more cooling (an adaptation measure) implies more emissions when the electricity used for cooling is highly carbon intensive. There are also important cross-sectoral linkages through the health impacts of climate change and heat events, and through varying comfort levels for different categories of population.

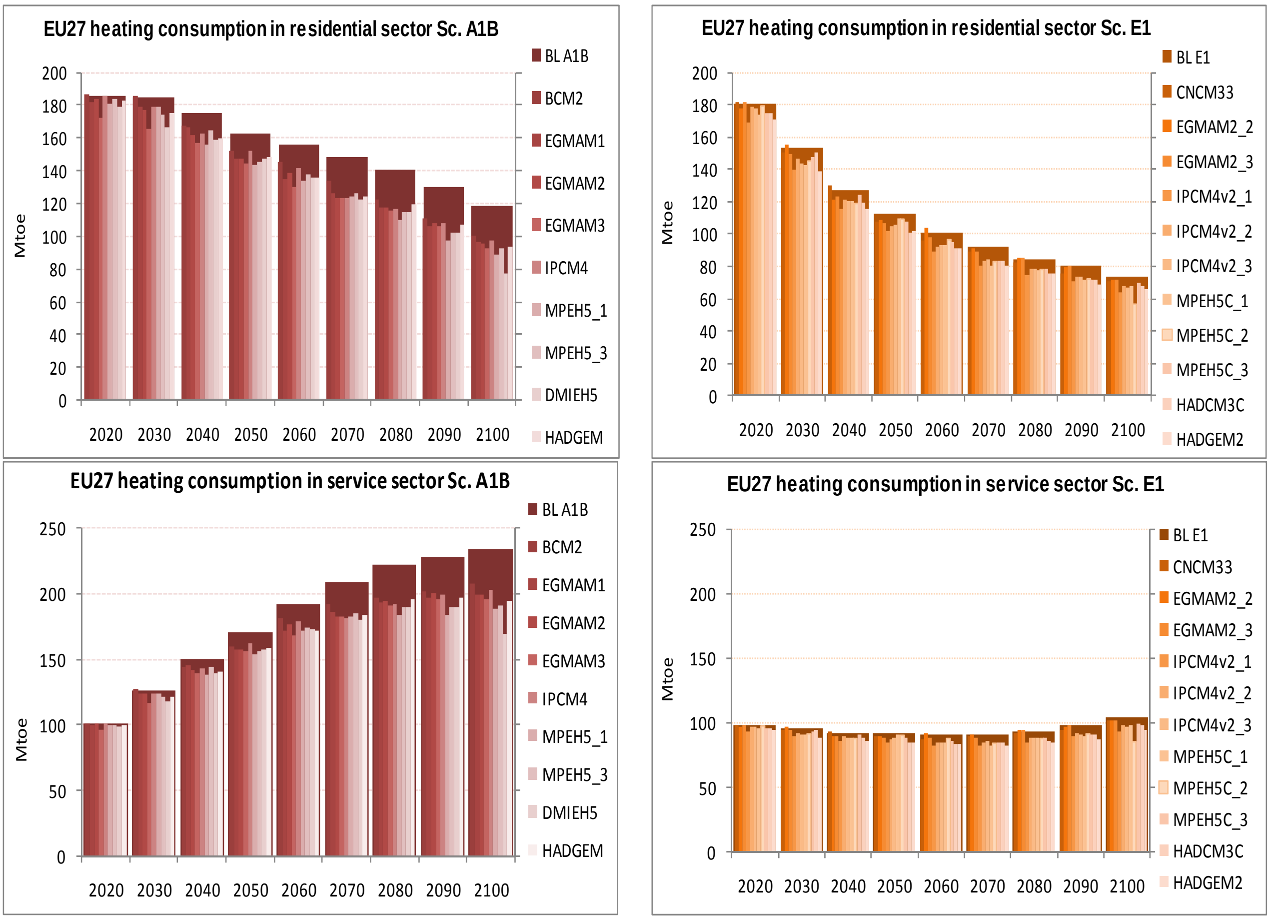
Furthermore, additional issues may arise for electricity in relation to the peak power needed across the network to meet demand, and the associated plant capacity and reserve margins. This might lead to additional problems (and costs) for satisfying peak summer demand, during heat waves, especially in Southern Europe.

Heating

The study has also assessed the decrease in heating demand in Europe (a benefit) with climate change, using the POLES model. The results are shown below. Again, the changes due to socio-economic growth alone, the baseline (BL-A1B, and BL-E1) with today's climate, are shown as the solid columns in the figures below. These baseline changes show an decrease for the residential sector (in the absence of climate change) but an increase in the service sector.

The individual columns below show the combined impacts of economic development and climate change acting together, considering different climate model outputs for the same scenario. Each figure therefore shows the level of reduction in winter heating with climate change, i.e. the level below the baseline. The difference between the two is the additional (or net) benefit of climate change.

Figure 7. EU27 heating consumption in residential (top) and service (bottom) sector for the A1B and E1 scenarios.



Source: POLES model, LEPII-EDDEN, Climate Cost project

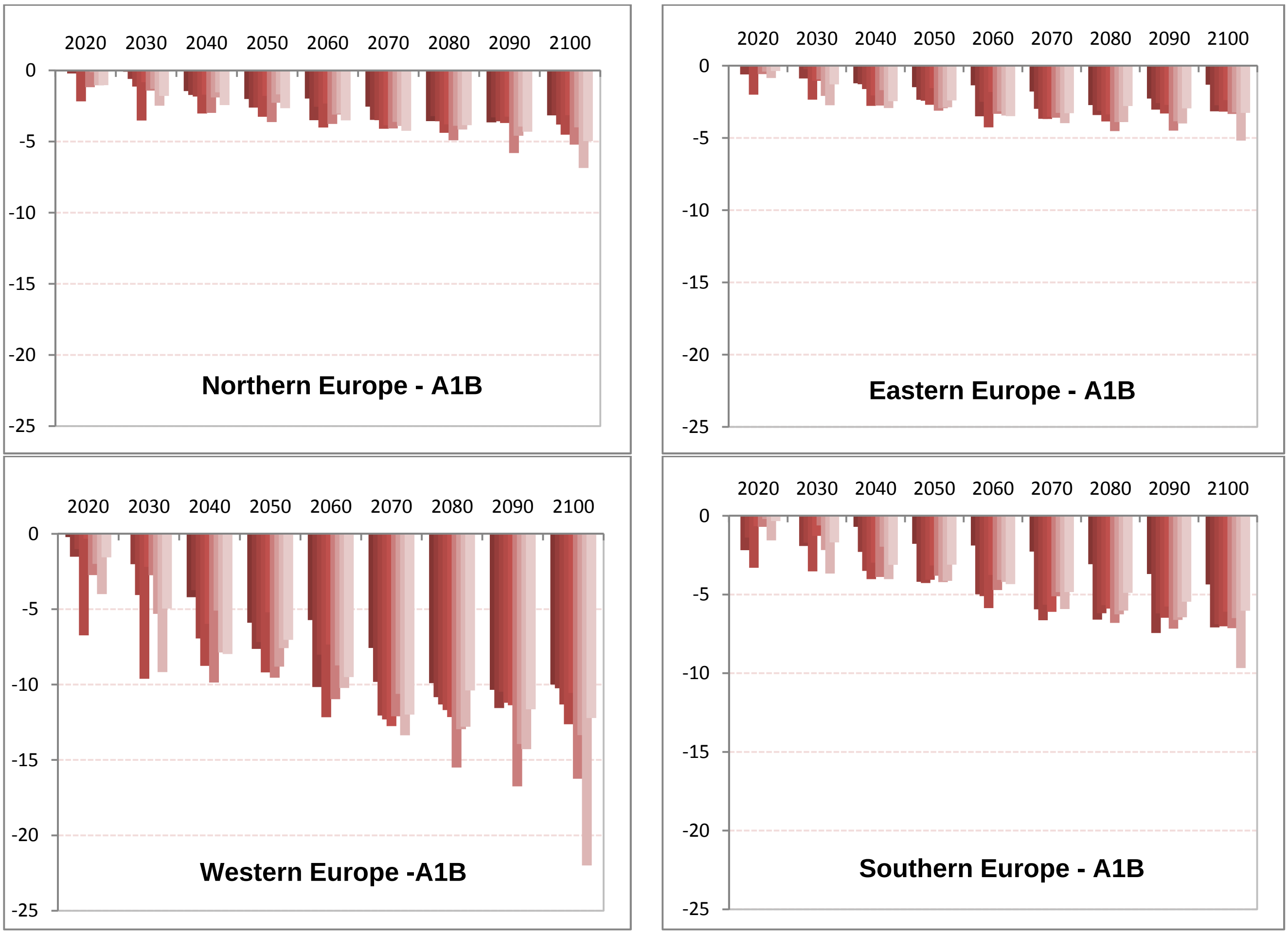
Key: BL-A1B/ BL-E1 = Baseline with current climate for the two scenarios (A1B and E1). Other columns (BLA1B to HADGEM) include projections of energy with lower winter temperatures from alternative GCM projections.

The reduction in heating demand from climate change alone (the benefit) for the combined residential and service sector for the A1B scenario – over the baseline– is estimated at -28 Mtoe/year by 2050 rising to -65 Mtoe/year by 2100. This is respectively an 8% and 18% reduction in heating demand from the future baseline. However, there is a considerable range around this, according to the climate model projection (above and below).

Under the E1 scenario, the reduction in heating demand is lower, estimated at a reduction (a benefit) of 11 Mtoe/year by 2050 and -13 Mtoe/year by 2100 (a 6% and 7% reduction respectively).

There are also large differences by region of Europe (and country), with the largest reductions in Western Europe.
The changes in heating demand vary from region to region. Western Europe has greater heating energy reductions than other European regions (Northern, Southern and Eastern). This effect is more pronounced in the A1B scenario, as shown in the figure below.

Figure 8. EU27 heating consumption (Mtoe/year) in (combined) sector for the A1B by region.



Source: POLES model, LEPII-EDDEN, Climate Cost project

Key: Columns show projections of energy with lower winter temperatures from alternative GCM projections.

The study has also assessed the costs of changes in heating energy consumption. The approach has been to multiply the absolute impacts with the average energy price for heating in the residential and service sector. Note that these results have also been input into a CGE model in other parts of the ClimateCost study.

The figures above translate through to a reduction of €34 billion/year in 2050, increasing to €121 billion/year in 2100 (current prices, undiscounted) for the A1B scenario, though there is a considerable range around these values. It can be seen that these are similar to the net cooling costs above. The benefits fall under the E1 scenario to €14 billion/year in 2050, increasing to €18 billion/year in 2100.

The impact of climate change on energy use for water in Europe

Energy is a key input to the pumping, treatment and management of water across Europe. Potential changes in water availability from climate change, whilst involving demand across many sectors and the overall supply-demand balance, could lead to an increase in energy use for the water sector. As an illustration, the requirements for desalination have already nearly doubled worldwide since 1995 and continue to grow steadily, including in some southern European countries such as Spain and Greece.

Furthermore, one of the key water abstractors in Europe is electricity generation. Water abstracted for cooling thermal power plants accounts for 37% of total freshwater abstracted across Europe[5], reflecting the fact that nuclear and conventional thermal power stations require large amounts of water for cooling. Current thermal power plants could therefore be potentially vulnerable to changes in water supply, though future plants could address this by changing technology.

The POLES model has been used to look at these issues. Currently energy needs for water supply from various sources (surface, groundwater abstraction, desalination and water treatment) amount to around 120 TWh/year representing 3.5% of total electricity consumption in the EU.

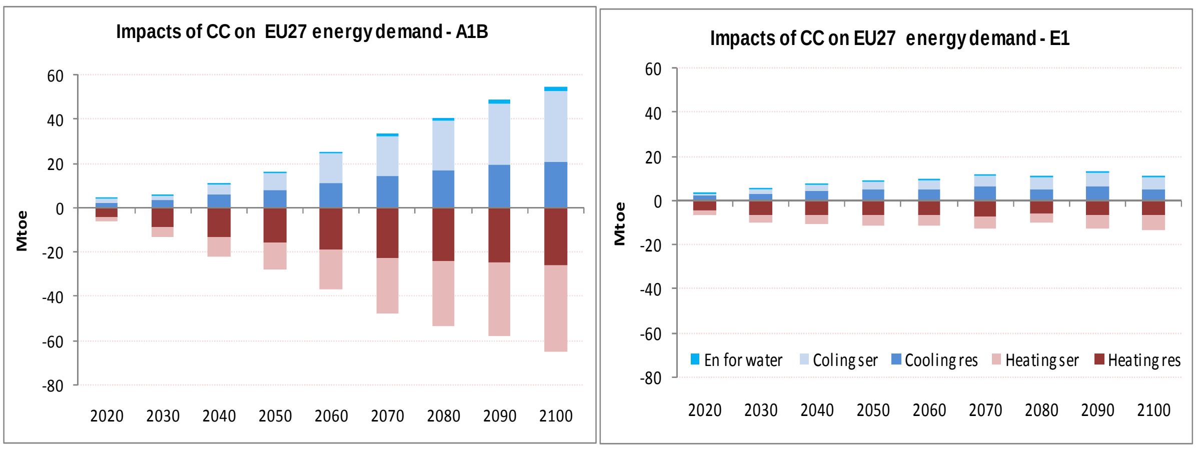
This analysis has used annual GCM outputs, and does not use detailed catchment level analysis of precipitation, surface run-off, river flow and water demand and supply, but it does provide an indicative analysis of the potential size of these effects from the perspective of the future European energy systems for the A1B and E1 scenarios.

The analysis finds that climate change could increase energy demand for water by 5% in 2050 and 12% in 2100 on average in the A1B scenario, though there is a large variation (even in sign) across the climate scenario, and important differences across Europe. The additional cost of increasing energy use for water supply is estimated to be around €1.5 billion/year by 2050, increasing to €5 billion/year by 2100 for A1B scenario (ensemble mean, undiscounted current prices). These increases are significantly reduced under the E1 scenario.

Overall Demand

The total effects on demand are summarised below. The scale of change is dramatically higher in the A1B scenario, but much less important in the E1 scenario, as this mitigation case has high efficiency in everyday use of energy.

Figure 9. Effect of climate change (change from the baseline) on EU27 energy demand in A1B and E1 scenarios.



Source: POLES model, LEPII-EDDEN, Climate Cost project

[5] Note that water abstraction is different from water consumption, as most cooling water is reintroduced, warmer, in the water flow.

At the regional and country level there are strong differences, particularly as regards the impacts of climate change in the A1B scenario, with Southern Europe showing large net increases in demand (due to cooling) and Western and Northern Europe showing net decrease (due to heating reductions).

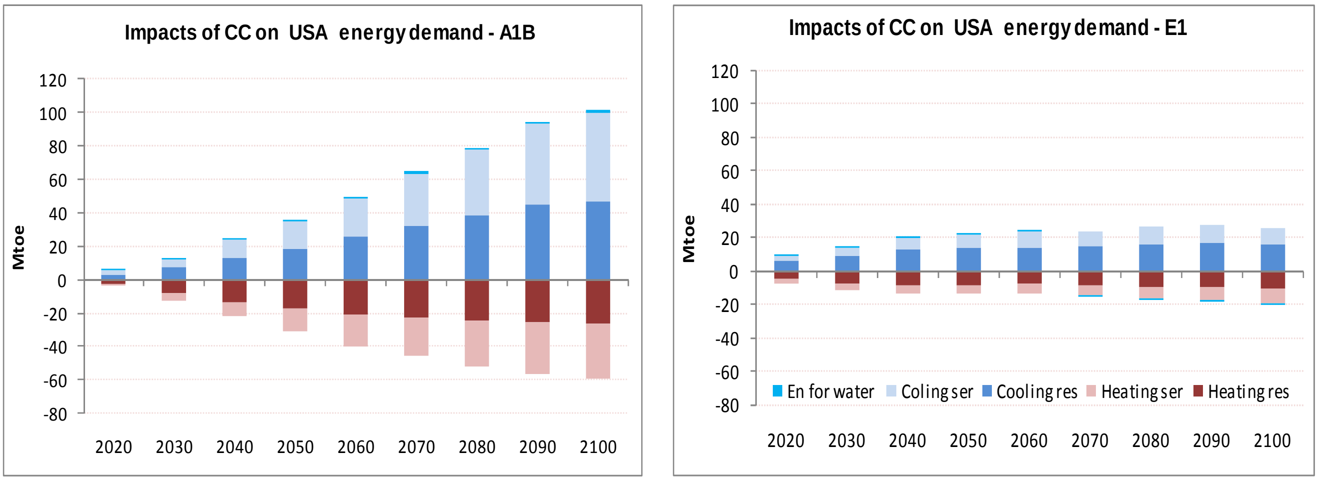
When compared in terms of economic costs, the analysis suggests very little net difference at the European level. The additional costs of climate change from the additional electricity consumption for more air conditioning, extra AC units, and increases in water, total around € 39 billion/year in EU27 by 2050 rising to € 137 billion/year by 2100 under the A1B scenario (current values, undiscounted). The reduction in winter heating is estimated at reduction of €34 billion/year in 2050, increasing to €121 billion/year in 2100 (current prices, undiscounted) for the A1B scenario. Under the E1 scenario there are also small net costs from the overall demand balance.

Heating and cooling in other world regions

The analysis has also considered other world regions, again using the POLES model, as part of an integrated global assessment. For each region, the reduction in energy demand for heating can be compared to the increase in electricity consumption for cooling, taking into account the different primary energy requirements respectively of heating fuels and electricity and the energy and electricity supply mix in each region.

For the USA, the increase in energy demand for cooling - over the baseline - more than compensates for the reduction of the energy requirements for heating. These effects are amplified when the changes in energy costs are considered. The figures are shown below, showing the additional change from climate change over and above future baseline levels.

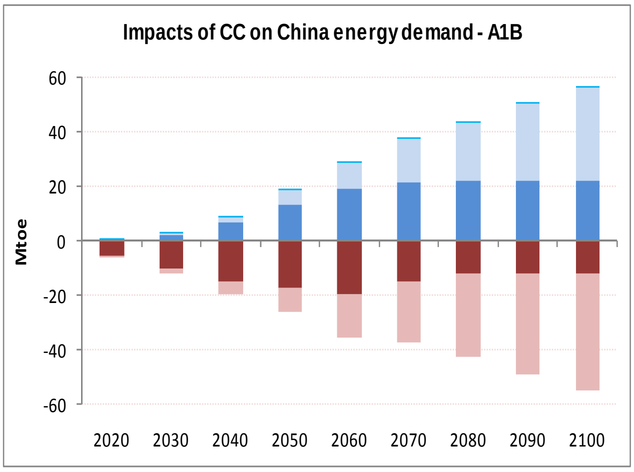
Figure 10. Changes in energy demand due to climate change (above baseline) for the USA in the A1B and E1 scenarios.

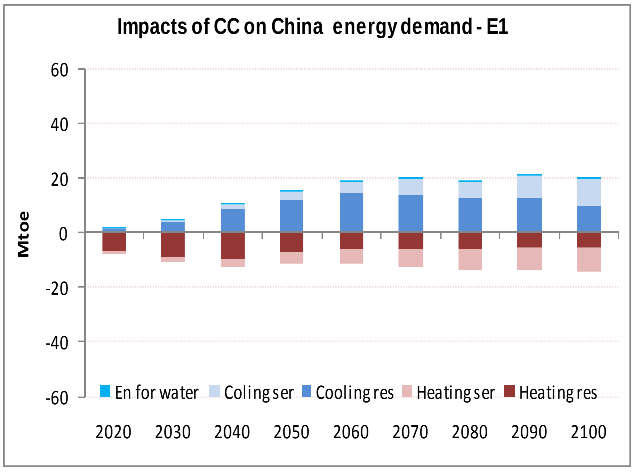


Source: POLES model, LEPII-EDDEN, Climate Cost project

For China, the increased cooling demand is broadly balanced by a reduced heating demand, largely due to the regional balance (and relative heating and cooling demand) between the Northern and Southern parts of China, though again, the change in economic costs will be dominated by the higher costs of electricity, leading to net economic costs from climate change.

Figure 11. Changes in energy demand due to climate change (above baseline) for China demand in the A1B and E1 scenarios.

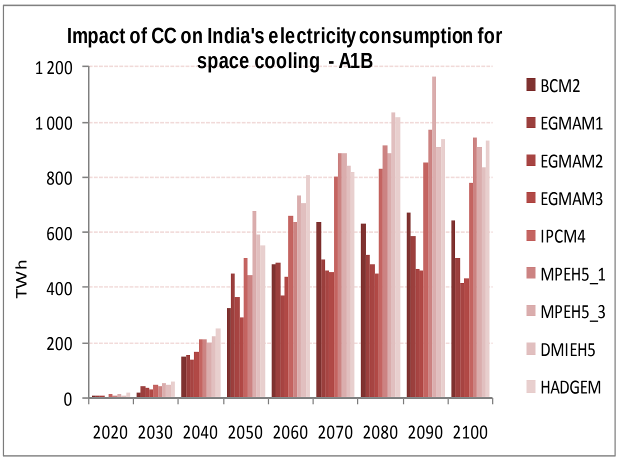


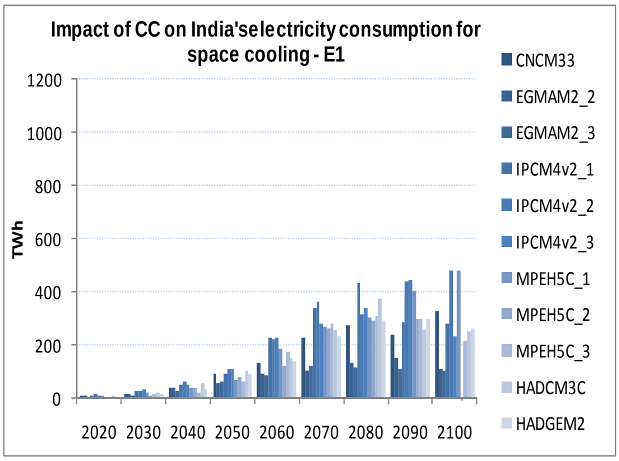


Source: POLES model, LEPII-EDDEN, Climate Cost project

Finally, for India, there is an extremely large anticipated increase in cooling demand in both the residential and commercial electricity consumption.

Figure 12. Increase in the energy demand for cooling due to climate change (above baseline) for India in the A1B and E1 scenarios.





Source: POLES model, LEPII-EDDEN, Climate Cost project

These global results are important, as they show globally that large net increases in energy demand will occur with climate change. These results have been used the CGM and IAM analysis reported in other parts of the ClimateCost study.

Impacts on Energy Supply in Europe

Climate change will also have effects on energy supply, notably on hydro-electric generation, but also potentially on thermal power (nuclear and fossil) plants and on other renewables. These effects have been considered in the POLES model.

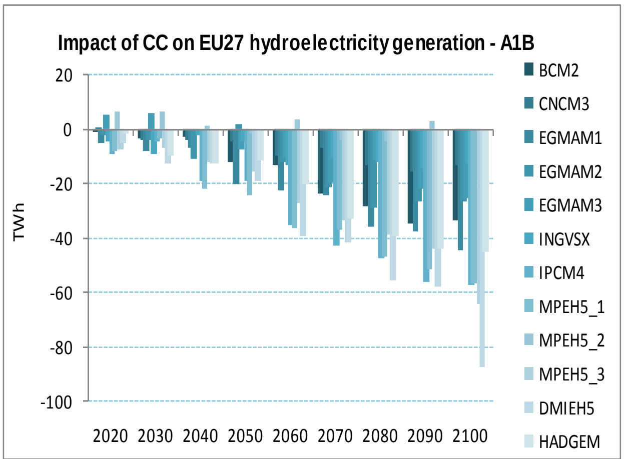
Hydropower plants are the most obviously vulnerable generation source to climate change. Factors such as the timing and geographical pattern of precipitation, temperature (evaporation) or snow-melt all affect stream flows and reservoir levels. While precipitation changes may increase as well as decrease across European regions (see Christensen et al, 2011), and there are large differences with season, evaporation is expected to rise in most cases, due to higher temperatures.

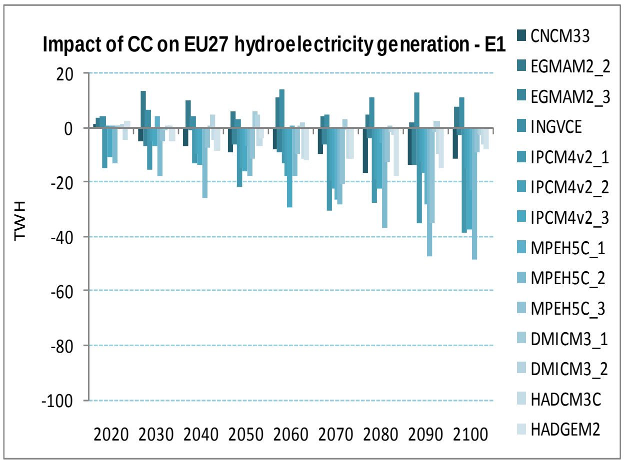
The POLES model was used to take account of potential changes in precipitation, linking to the climate model outputs, in order to calculate the potential impacts in terms of hydro generation and changes of the hydropower technical potentials on the construction of the new capacities. This analysis has used annual GCM level outputs, and does not use detailed catchment level analysis of precipitation, surface run-off, river flow and water abstraction, differentiated by season. or including variability, but it does provide an indicative analysis of the potential size of these effects from the perspective of the future European energy and electricity system, looking at the changes with future hydropower capacity for the A1B and E1 scenarios.

Hydropower is a major and increasing source of low-carbon electricity in Europe. In 2010 hydropower provided about 10% of the total electricity generation in Europe and, in spite of a relatively high rate of equipment of the potentials. Under the A1B scenario, generation is projected to increase in future years, rising from 352 TWh in 2010 to about 400 TWh by 2050 and 465 TWh by 2100. This is driven by expanded capacity particularly in Southern and Eastern Europe, in order to provide electricity in order to sustain a strong electricitiy demand growth.

The impacts of climate change on hydro generation vary strongly with the climate models, as individual models project very different levels – and even differences in sign - for the change in precipitation, even for the same scenario. The A1B scenario ensemble mean results show an estimated decrease in European hydro generation due to climate change of around -3% in 2050 (12 TWh/year) and -8% in 2100 (39 TWh/year), compared to the case with the baseline A1B projects (with the current climate, but future hydro generation increaes). The impacts are lower for E1 scenario at respectively -2 and -3% (-7 and -12 TWh/year respectively). These are shown below, as the change from the future baseline due to climate change alone.

Figure 13. Effects of climate change (on top of future baseline) on EU27 hydroelectricity generation (TWh/year).



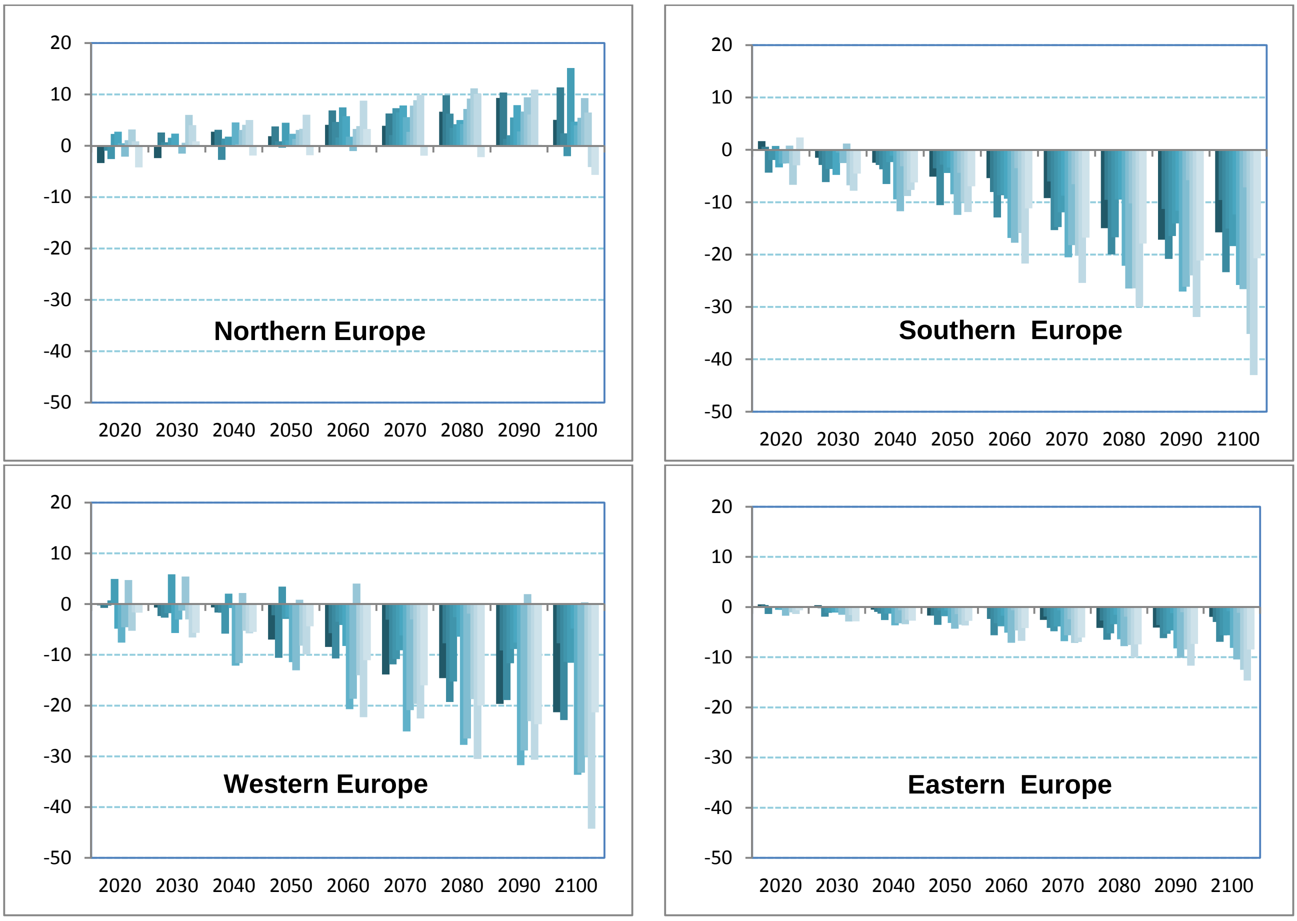


Source: POLES model, LEPII-EDDEN, Climate Cost project

Key: The columns (BCM2 to HADGEM) show projections of the change in hydro generation from climate change from alternative GCM projections.

The values vary across Europe. Results indicate decreasing discharge volumes for Southern and East-central Europe, by more than 20% in some countries, whilst the projected rises in discharge volumes for Northern Europe may at times exceed 20%. It has to be noted that this analysis does not take the annual variability into account. The changes for the A1B scenario are shown below.

Figure 14. Effects of climate change (on top of future baseline) on regional hydroelectricity generation (TWh/year) in A1B.



Source: POLES model, LEPII-EDDEN, Climate Cost project

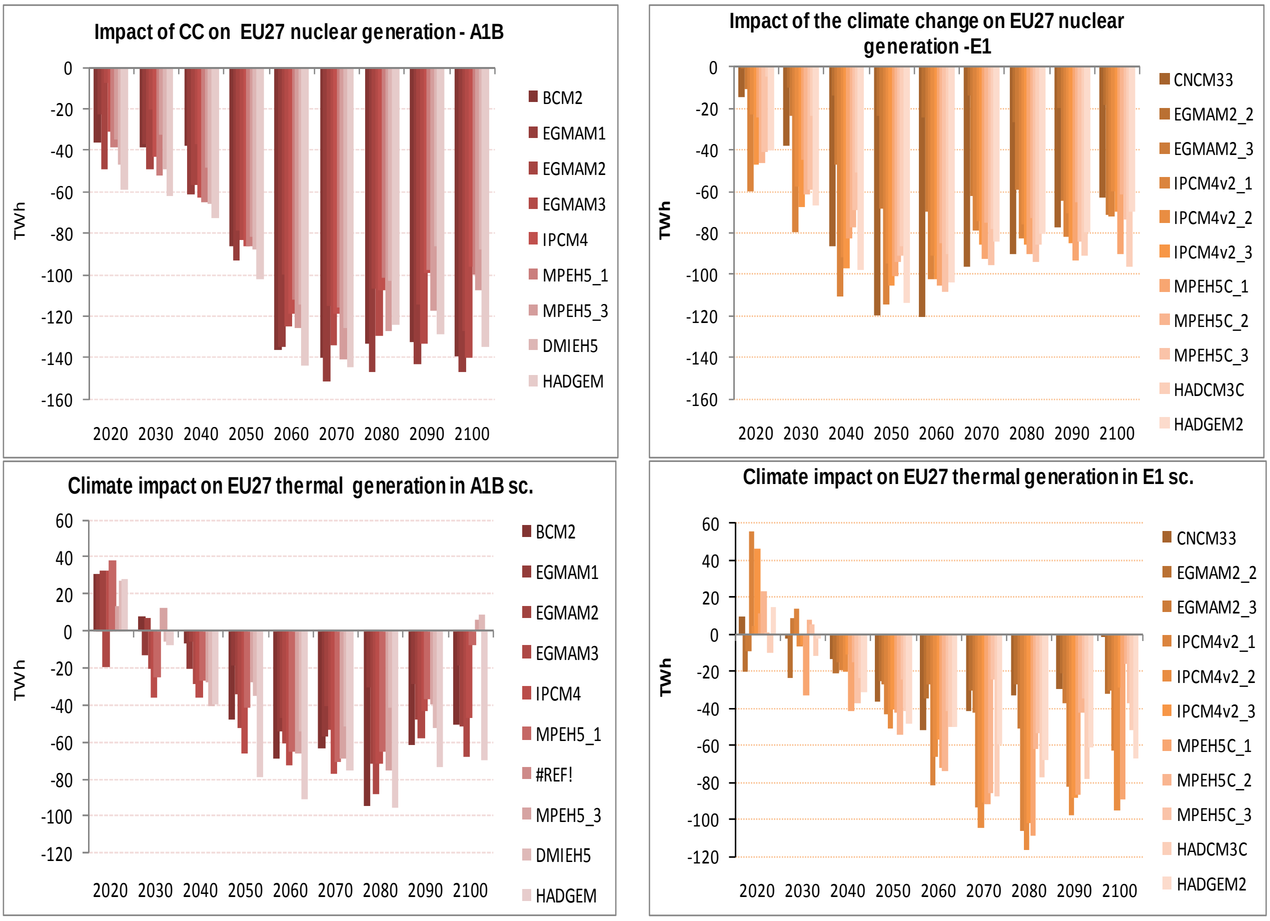
Key: The columns show projections of the change in hydro generation from climate change from alternative GCM projections.

Higher temperatures also affect power plant cooling and could potentially influence the generation efficiency (a higher heat differential leads to a higher efficiency, thus efficiency is affected by the temperature differential between the plant and the external environment, and thus higher air and water temperature from climate change can affect the power generated from a given amount of fuel).

This effect has been considered with the POLES model in the ClimateCost study. The efficiency decrease was derived and implemented for all types of thermal power plants (nuclear and fossil) using the assumptions from Durmayaz et al. (2006). This links changes in cooling water temperature to the thermal efficiency of power plans.

The results show that thermal and nuclear power generation could be reduced by 2-3% per year in 2050 and 4-5% per year by 2100 respectively, under the A1B scenario. This would - in theory - mean a reduction of 150 TWh per year. One way to consider the impact of this loss is to consider the additional marginal plant needed on the system to address the supply reduction. This would be equivalent to approximately an additional twenty additional 1 GWe plants. The results are shown below, showing the potential reduction in annual generation from climate change above the baseline.

Figure 15. Potential (indicative) effect of climate change – above the future baseline - on EU27 energy supply in A1B and E1 scenarios.



Source: POLES model, LEPII-EDDEN, Climate Cost project

Key: The columns (BCM2 to HADGEM) show projections of the change in hydro generation from climate change from alternative GCM projections.

However, some caveats are needed in interpreting these results. The analysis is based on a limited underlying literature, and some caution is needed due to the transferability of the relationships across Europe, due to site specific conditions, technology, etc.

It also assumes future plants have similar technology and efficiency losses, when in practice, changes in plant design (e.g. in terms of cooling technology) can address these issues, and future plants will have different efficiency characteristics.

Nonetheless, while this analysis is indicative, it does highlight that this effect could be potentially large. Importantly, it also suggests that including supply side effects could significantly shift the picture of how climate change affects energy in Europe, leading to high net economic costs. This therefore warrants further attention.

5. Adaptation

Planned adaptation for cooling

The key adaptation area considered in ClimateCost is for cooling demand. There are potentially a wide range of options that could reduce future cooling demand in Europe. These include both soft (non-technical, building design or behaviour) and hard (technical) measures, policies to influence demand, or improve the efficiency or uptake of technology. However, many of these overlap with issue of heating demand, which makes the analysis of adaptation costs and benefits more complex. Some examples of common approaches for adaptation cited in the literature are included in the table below.

Table 1. Selection of alternative options to reduce cooling demand**.**

Approach	Options
Cooling technology	Improved efficiency of air conditioning units, for example through technology efficiency standards, voluntary agreements, market signals or incentives
Demand reduction – non-technical	Awareness raising and education (costs of cooling) Behavioural change (changing activities) Market signals
Demand reduction – buildings (new and retrofit)	Range of options including low carbon cooling systems, low energy houses, heat exchangers, heat pumps, passive or natural ventilation, insulation, shading, shutters and visors, green roofs, intelligent buildings, etc. Note a variety of policies can be used to introduce these including building codes or regulations, planning permission, design guidelines, market mechanisms, etc/
Demand reduction - spatial	Spatial planning and city design to reduce urban heat island effects (building spacing, green spaces, zoning, wider planning and zoning policy)

The study has reviewed the literature on the costs (and benefits) of these options. This reveals a relatively low evidence base.

Table 2. Examples of costs and benefits of alternative options for reducing cooling demand**.**

Option	Cost and benefit information
Passive ventilation	Van Ierland et al 2006 (Netherlands) reports that *Isolation of existing houses* Estimated costs per household and number of house (*23349 MEuro over 6 809 581 houses in 2004, based on Ecofys, 2005.).* Hacker et al, 2005 (UK) assessed the performance and potential benefits of different types of buildings under climate scenarios, assessing energy savings. Arup (2008) [South-East England] estimates the costs of retrofitting passive measures to control overheating in summer considering the relative costs of around twelve options, and then providing costs for awning, night purging, ceiling fans, painting exterior walls, of approximately £16,000 per household (but half this if winter warmth measures had been installed.
Green roofs	Van Ierland et al 2006 (Netherlands) reports costs and benefits of green roofs in Toronoto (benefits as initial cost saving related to capital costs and annually recurring costs – from stormwater flow and sewer overflow reduction, reduced building energy consumption and reduced urban heat island). A very approximate analysis of the costs and benefits for Amsterdam and Rotterdam was derived, based on incremental unit costs ($75 to 90 /m2 of roof from city of Waterloo) for marginal cost. LCCP 2009 (London) reports that a scheme for four inner city areas with a green roof area of 226,750m2 would cost around £4 million and provide environmental benefits (stormwater management, combined sewer overflow, air quality, urban heat island, greenhouse gases and food production but excluding health benefits) worth £4 million. A wider scheme covering the City of London, part of the London Borough of Hackney, part of the London Borough of Tower Hamlets and part of the West End with a green roof area of 3.2 million m2 would cost around £55.5 million and provide environmental benefits worth £55.5 million.

However, a key factor in adaptation is the uncertainty involved in the level of future temperature projections, and the need to consider the linkages between cooling and heating demand, noting that while these may sometime be synergistic, they can also sometimes be in conflict.

There are a number of issues here that make this analysis challenging. First, the retrofitting of buildings with passive cooling options is expensive, and it is generally cheaper to install passive options during design and construction. Second, buildings (residential and service) have long life-times and will be affected by climate change in the future, but the level of future change is uncertain (see the climate model envelopes above), which affects the benefits of these measures. Third, the main benefits of passive measures arise from operational benefits (reduced energy costs) in the future, but they generally involve up front capital costs during construction. This means the discount rate is particularly important, i.e. the degree to which future benefits are discounted to the present to compare against capital costs[6]. Finally, for many measures, it is the combined effects on heating and cooling that is important: even though heating demand is projected to fall within warmer temperatures in Europe, there are still potentially high economic benefits from further reducing winter heating losses (e.g. through insulation, low energy building design, etc.). A measure that provides economic benefits in reducing winter heating, as well as reducing energy costs associated with summer cooling, may therefore be much more attractive than one focused on cooling alone.

If the uncertainties on future climate projections were low, and changes were immediate, then it would be possible to design buildings to match the climate, i.e. to optimise design. However as the projections above reveal, there are large dynamic changes in the climate over time, and for any future time period, there are a very large range of results between the scenarios (A1B vs E1) and across the range of climate model outputs for any given scenario. As highlighted by Halegatte et al (2007), it is easy to design buildings for future climates that are well defined, but much more difficult to do this to cover the range of possible climates from the current projections, and the change in the climate over time.

This has therefore led to a greater focus on decision making under uncertainty, looking at robust decisions (that perform well across the range of possible future outcomes), and/or looking at options that provide benefits now, whilst also providing enhanced resilience for the future, particularly no regret options (such as building insulation). There is also a need to build-in a more flexible and iterative approach to adaptation, providing the opportunities to learn and then act, but also keep future options open, often captured under the broad term of adaptive management. The study has undertaken additional case studies to provide examples of such approaches.

Finally, there are also important cross-sectoral linkages with the health impacts of climate change and heat events, which need to be considered when assessing the benefits of adaptation, as these provide additional ancillary co-benefits in addition to energy demand.

Modelling Adaptation in POLES

For the POLES modelling analysis, the study has looked at the potential effects of improving the energy efficiency of cooling equipment and building envelopes. This represents a form of planned adaptation, though there would also be some autonomous (market) uptake of these buildings. The study has not considered the policies that would lead to these changes, but they could, for example, be introduced through improved efficiency requirements, building regulations, voluntary codes or market mechanisms.

In the model, the uptake of these measures is taken into account through diffusion of new low energy (LE) or very low energy buildings (VLE). These consume only one half or one quarter respectively of the average rate in existing buildings in each region. The VLE building concept reflects current efforts performed in many countries to even develop positive energy buildings, i.e. with integrated solar PV panels.

While energy price increases allow for more energy efficiency in buildings, these may not be sufficient to overcome the building stock inertia and to trigger a full replacement of conventional buildings by low and very low energy buildings. This appears to be the case, as shown by the POLES modelling analysis in ClimateCost.

In the A1B case in 2100, very low energy buildings represent 15% in the residential sector and 41% in the service sector in Europe. In E1 case, very low consumption buildings represent 23 % of the residential building stock and 53 % in the service sector.

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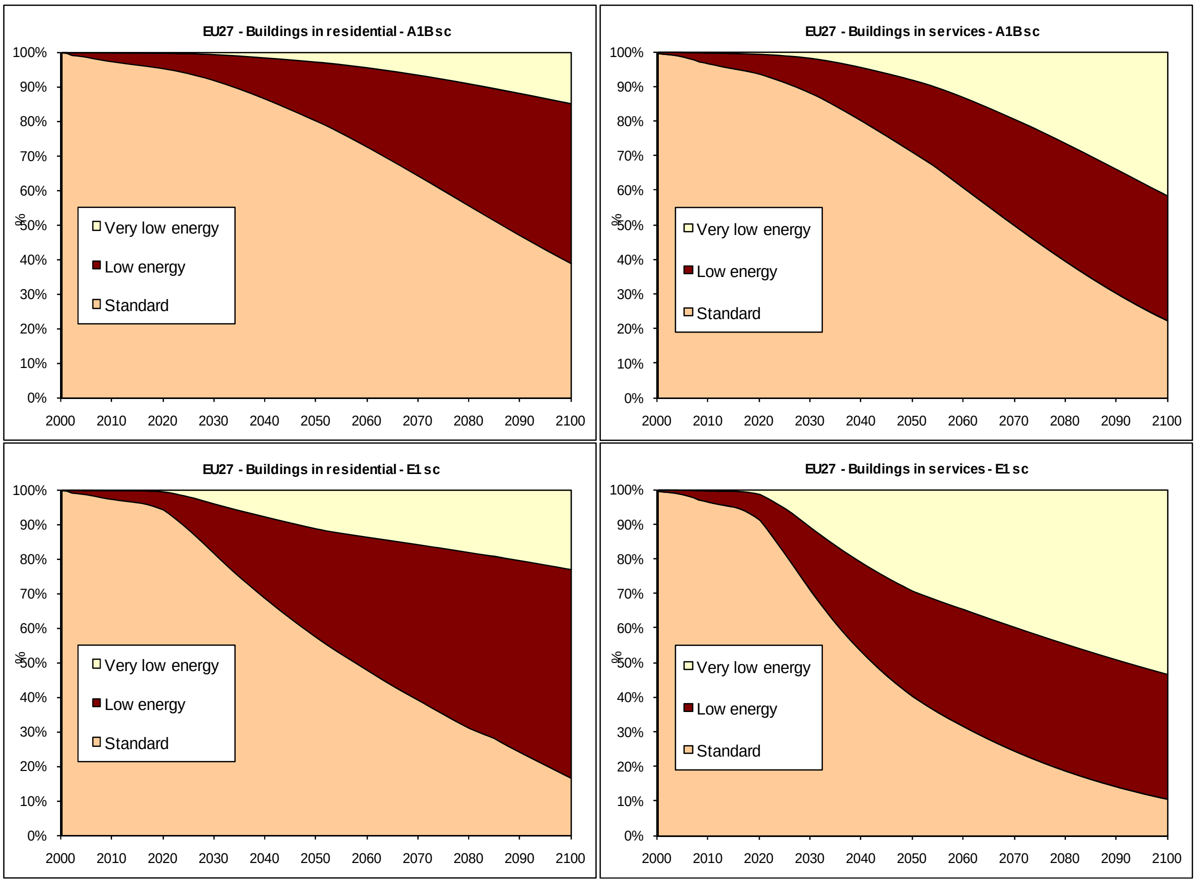
[6] In economics, a technique called discounting is used to directly compare economic costs and benefits at different times. This expresses all economic costs occurring at any future time in a common base year. The choice of discount rate has been one of the primary points of debate around the reporting of aggregated economic results for climate change, notably following the Stern review (2006). Discounting is especially influential for climate change because of the long time periods involved and because of the profile of damages over time (increasing damage costs in the far future).

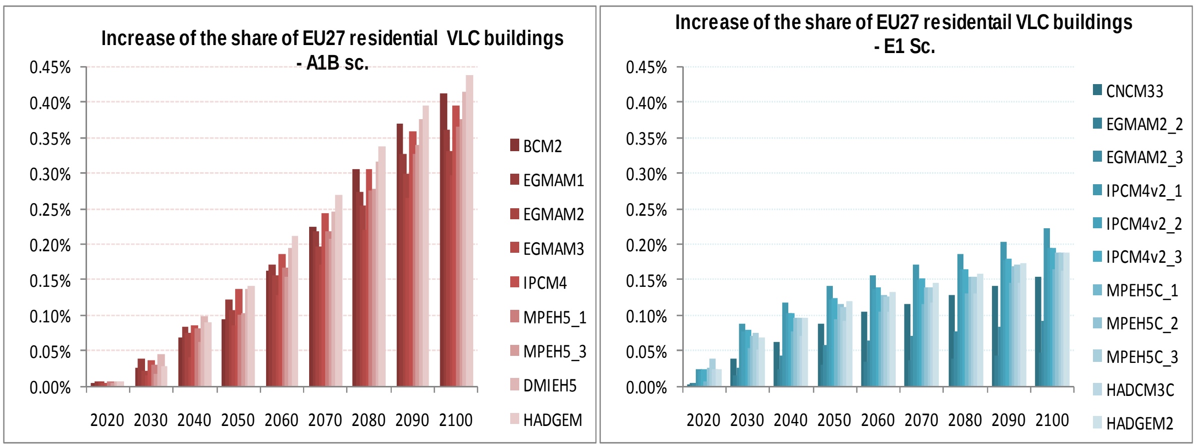
Figure 20. Role of low and very low energy consumption buildings.



Source: POLES model, LEPII-EDDEN, Climate Cost project

Changes in air conditioning and heating demand do not significantly affect the competition among the different types of buildings without additional policy action. The share of very low energy consumption buildings is affected in a limited way, with a market share increase of 0.23 and 0.05% in EU27 residential buildings respectively in A1B and E1 scenarios by 2100, and 0.55 and 0.08% in EU27 tertiary buildings.

Figure 21. Increase in the role of the very low energy consumption buildings in EU27 residential and tertiary sector in A1B and E1 scenarios.



Source: POLES model, LEPII-EDDEN, Climate Cost project

The adoption of new advanced cooling technologies will require more investment. However, some of this investment will be justified on the basis of other benefits, such as comfort, lower health damages from heat waves, or avoided air pollution externalities.

A final point is also highlighted. The benefits of planned adaptation to reduce cooling requirements will vary strongly with location (as well as with the projections). Therefore options that are attractive for some locations, which will have higher existing temperatures, or higher temperature signals from climate change, will have different cost/benefit ratios. This is a key issue: policies and measures that are cost-effective for Mediterranean countries will not necessary be the case for Northern Europe. This highlights the need for local considerations in adaptation policy.

Conclusions

The ClimateCost study has undertaken a preliminary model-based assessment of the effects of climate change on the energy sector, with a particular focus on Europe. While there are uncertainties associated with the climate models simulations, the study does provide robust results and conclusions. It shows that in the absence of adaptation, there will be significant reductions in heating demand and significant increases in cooling demand, which will have a strong distributional pattern across Europe. It also highlights a number of possible risks to energy supply, in relation to hydro, themal and nuclear power plants. Some early work on adaptation has highlighted the complexity of addressing the combination of uncertainty, and both heating and cooling demand changes, within an economic framework. None of these effects are far from negligible, and the estimates show potentially high economic costs, demonstrating that this area is a priority for future research on impacts and adaptation.

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To find out more about the ClimateCost project, please visit:
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