



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 691287

EU Framework Program for Research and Innovation actions (H2020 LCE-21-2015)



MEDEAS

MODELING THE RENEWABLE ENERGY TRANSITION IN EUROPE

Project Nr: 691287

Guiding European Policy toward a low-carbon economy. Modelling sustainable Energy system Development under Environmental And Socioeconomic constraints

Annex 12: Task 2.2.e.6 Adaptation to climate change in terms of increase social energy requirements (in heating and cooling)

Version 3.0.0

Due date of deliverable: 31/12/2016

Actual submission date: 29/12/2016



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Document info sheet

Lead Beneficiary: MU – Masaryk University

WP: WP2 Data collection

Task: Annex 12: Task 2.2.e.6 Adaptation to climate change in terms of increase social energy requirements (in heating and cooling)

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Dissemination level : Public



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Scope of document

In this report we examine the energy requirements of adaptations to climate change in heating and cooling sector with a primary focus on energy demand impacts in buildings and industry. We identify drivers and wider trends that impact future heating and cooling, incl. adaptations required at the energy supply, as well as socio-economic, technological and policy adaptations. In the concluding section we provide suggestions for the MEDEAS model development.



List of abbreviations and acronyms

AR5 WGII – Fifth Assessment Report, Working Group II

EC – European Commission

EEA – European Environment Agency

EU – European Union

CC – Climate Change

CDD – Cooling Degree Days

CGE – Computable General Equilibrium

GDP – Gross Domestic Product

HDD – Heating Degree Days

IEA – International Energy Agency

IPCC – Intergovernmental Panel for Climate Change

Mtoe – Millions of tons of oil equivalent

TWh – Terawatt Hours

WP4 – Work Package 4



Executive summary

it is highly agreed that climate change impact will globally reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors. The industrial sector lacks attention in most of the studies, however the energy demand for heating and cooling in industry is significant. The balance of the energy demand for heating/cooling influenced by climate change depends on the geographic (regional), socio-economic, social and technological drivers of adaptation as well as on the policies taken to adapt on the climate change. Importantly, the total energy requirements in different regions and sectors are influenced by wider trends, such as population growth (*increase*), increasing income (*increase*), technological improvements (*decrease*), rising price of energy (*decrease*). This report provides an overview of the drivers (and trends) and the estimates of their impact on the energy demand, and it reflects on variables, which could be implemented in the MEDEAS model development.

Globally, IEA (2013) expects that by 2050 **energy demand for space heating will increase by 12% from the 2010 level, compared with 28% in the absence of climate change. In the same scenario, global space cooling demand is projected to rise by 220%, compared with 175%**. The solely climate change impact is projected to decrease the global energy demand in 2050 due to higher decrease of heating, than increase of cooling. However, a reverse pattern is expected in the second half of the century with a global energy increase from climate change impact (Isaac and van Vuuren, 2009). **For Europe, by considering both heating and cooling energy requirements from climate change, total energy demand during 2000-2100 is estimated to decrease** (Isaac and van Vuuren, 2009).

Under these conditions, energy requirements resulting from the adaptation to climate change need to consider:

- uncertain predictions of wider trends
- various climate change scenarios
- datasets availability for the presented indicators and variables

The suggestion to the MEDEAS consortium for the further development of the model would be to focus mainly on variables that enable model calculations of energy required for space heating and cooling in residential and commercial sector, such as Heat degree days, Cold degree days, among others. Potential strategy might be to adapt one of models covered in literature of the topic. Analysis of the industrial sector however may be limited due to uncertainties of industry



performance and its spatial distribution in the future. Therefore it is suggested to project the industrial sector in a shorter scale. In addition, analyses on energy effectiveness of the energy sector and effects of new technologies and policies as well as attitudes of consumers may be desirable. Finally, it is recommended to include mitigation practices of climate change to the analyses, since there are important synergies and trade-offs between adaptation and mitigation.



Introduction

The results of the WP4 conceptual overview of the MEDEAS model assume that additional energy investments will be required for adaptation to climate change (CC), reducing the Net energy supply availability. In this report we analyse the assumption in two of the key sectors that are directly influenced by climate change – heating and cooling. Based on projections overviewed by *IPCC* in the *Fifth assessment report WGII AR5* (IPCC, 2014), it is highly agreed that **CC will globally reduce energy demand for heating and increase energy demand for cooling in the residential and commercial sectors**. The balance of the two depends fundamentally on the annual air temperature, particularly in the winter and summer seasons, therefore the energy requirements will vary across **regions**, as well as intraregionally due to altitude variations. The balance will also vary with **time**; therefore the analysis is highly dependent on chosen CC scenario. **The solely CC impact is projected to actually decrease the global energy demand in 2050 due to higher decrease of heating, than increase of cooling. However, a reverse pattern is expected in the second half of the century with a global energy increase from CC impact. For the whole century (between 2000 and 2100) the total energy requirements will increase (Isaac and van Vuuren, 2009), and so we may clarify the assumption of the WP4. For Europe, however, by considering both heating and cooling, total energy demand in the residential sector during 2000-2100 is estimated to decrease (Isaac and van Vuuren, 2009).**

Several constraints have been identified and are suggested for consideration in further analysis and the MEDEAS model development.

- 1) Heating and cooling in the **industrial sector** lacks attention in most of studies, although the share of demand of heating for industry in cold and temperate countries is almost as significant as in residential and commercial buildings sector and in warmer countries even higher (IEA, 2016). Therefore the industrial sector is also taken into account in this report. **Commercial sector** also needs to be reflected with its specificities, due to rapid new developments and higher average consumption on floor area.
- 2) The **supply side of the energy sector** will be affected by climate change too. In particular, the water-energy nexus of cooling in thermal and nuclear power plants may considerably decrease energy efficiency and increase vulnerabilities of the energy sector. It is projected, that CC will also affect efficiency of some renewable energy technologies.
- 3) The future use of new **technologies** in heating and cooling sector, building adaptations as well as the future energy will be highly dependent on implemented **technological adaptation policies**, whose impact and success may be less predictable in many countries.

- 4) Studies predict that CC will affect **socio-economic** performance, incl. labor productivity and economy output. There will be also considerable **social** impact, particularly on more vulnerable social groups. **Social adaptation** policies incl. **risk management** will require further energy demand and costs that needs to be taken into account.
- 5) There are important interactions between adaptation and **mitigation** practices with both potential synergies and trade-offs that may influence the energy requirements.
- 6) Finally, adaptation **attitudes of consumers** (households, services, industry) to CC impacts may considerably shift the estimated scenario. Survey on consumption attitudes may be desirable.

The heating and cooling sectors are considered to be the most influenced by CC temperature changes (Mideksa and Kallbekken, 2010). It was already presented, that temperature itself is not the only driver of climate change adaptations in the energy sector. Apart from **regional (climatic) driver**, we identified **technological, socioeconomic, social and political drivers**. However, it has to be understood, that the impact of CC on the heating and cooling sectors is relatively small in comparison to other drivers, such as **demographic changes, technology development, lifestyle, regulation and governance**. In this report, we understand these wider drivers as **trends**. Their relative importance will also differ regionally as well as over time. Globally, (IEA, 2013) expects that by 2050 **energy demand for space heating will increase by 12% from the 2010 level, compared with 28% in the absence of climate change. In the same scenario, global space cooling demand is projected to rise by 220%, compared with 175%.**

Methodology

In this report, for every identified driver we discuss projections to energy requirements (where possible) and indicators/variables that may be used for further analysis and for MEDEAS model development. We focus primarily at the World level and the time scope 2050. Where accessible we include European level findings or 2100 scope.

This report is primarily based on findings of the Fifth Assessment Report of the Intergovernmental Panel on Climate Change: Impacts, Adaptation and Vulnerability (IPCC, 2014) and on reports of International Energy Agency (IEA). The European data comes primarily from the EU Strategy on Heating and Cooling (EC, 2016).

Results

Sectors considered to climate change adaptations

The adaptations to CC in heating and cooling energy demand are dominated by space-heating and –cooling in buildings, which serve the residential function. Therefore many studies include only the residential sector in their analyses. However, the share of demand of heating for industry in cold and temperate countries is almost as significant as in residential and commercial buildings sector and in warmer countries even higher (IEA, 2016). The current demand for industrial cooling is similarly low as in residential sector with predictions for sharp rising in the future. In this report we understand the industrial sector as likewise important, although some of the estimates we provide cover only the residential sector. In addition the buildings that serve the public and commercial services shall not be neglected, due to the fact, that the service sector tend to have higher average energy consumption, 40% higher in the EU for example, (EC, 2016). Last but not least other facilities such as underground transport systems expect higher demand for ventilation and cooling in the hot days (IPCC, 2014), however they will not be included in this overview. In addition, studies identify that CC will affect not only the demand side, but also the energy supply and adaptations in the energy sector will be needed.

General results

The production of heat accounts for almost half of global final energy consumption, whereas cooling consumption is relatively low, but growing rapidly. Currently, about 75% of this energy demand is met by fossil fuels, accounting for one third of energy-related CO₂ emissions (IEA, 2016). In the EU, with 80% of final energy consumption in 2012, heating and cooling for space and industrial process is the biggest energy sector. From this energy, 45% is used in the residential sector, 37% in industry and 17% in services. Also in the EU 75 % of the energy demand for heating and cooling is covered by fossil fuels. (EC, 2016). See Figure 1 for primary energy sources in the EU; see Figure 2 for final energy consumption sources in the EU countries.

Under *New Policies Scenario* (2 °C increase by 2050, 3 °C increase by 2100), IEA (2013) projects a 12% increase of global energy demand for space heating by 2050 (from 2010 level), compared with 28% increase, in the absence of CC. Global space cooling demand is projected to rise by 220% compared with 175% in the absence of CC. We have to consider that the current demand for cooling is relatively low. Isaac and van Vuuren (2009), using the *TIMER/IMAGE model* and *reference scenario* (2,1 °C increase by 2050, 3,7 °C increase by 2100) estimate that space cooling demand will rise from current 300 TWh (2000) to about 4000 TWh in 2050 and more than 10000 TWh in 2100.

Variable : Millions of tons of oil equivalent (Mtoe) per resource type ; per sector

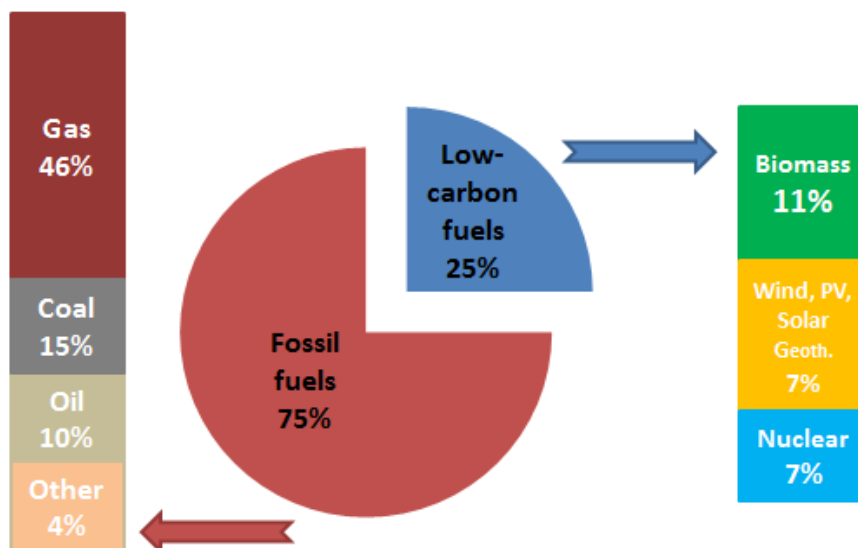


Figure 1 Primary energy for heating and cooling in the EU, 2012.

Source : (EC, 2016)

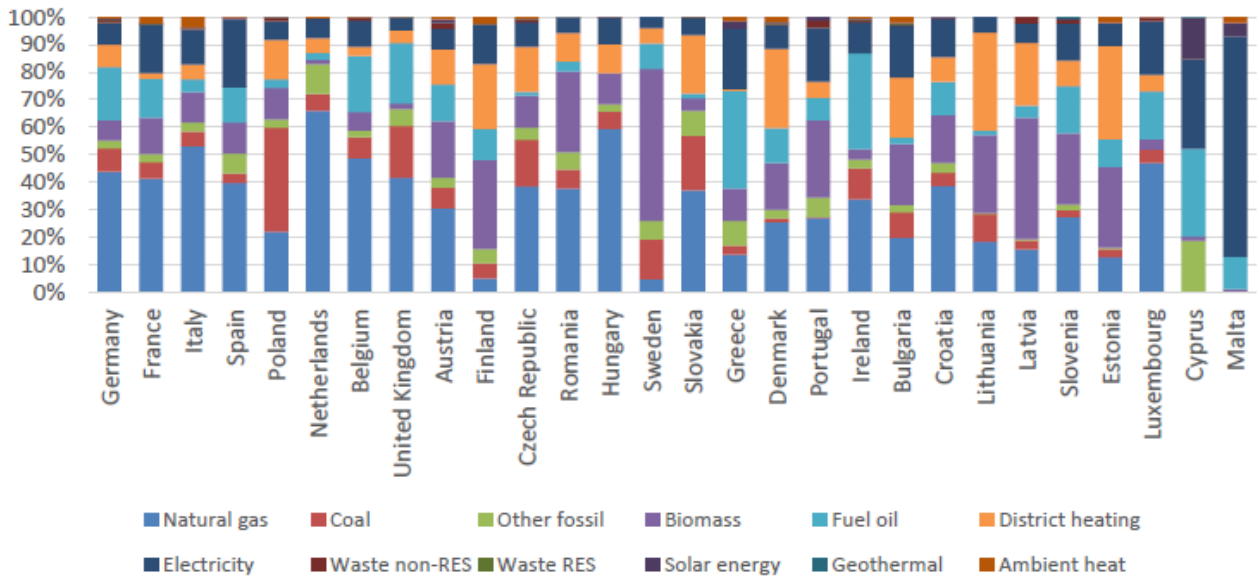


Figure 2 Final energy consumption for heating and cooling in the EU, 2012.

Source : (EC, 2016)



Trends

Considering low-carbon transition of the heating and cooling sectors, it is necessary to identify not only direct drivers of the adaptations to CC, but also wider trends.

Increasing income

Increasing income covers according to Isaac and van Vuuren (2009) 75% of the increasing demand for space cooling, whereas only 25% is covered by climate change. It will allow people to more widely use air conditioning in warm regions with low present income. In regions with high present income, the income increase will play a marginal role, and the energy demand changes will be driven primarily by increasing temperatures. The energy demand for heating will grow less rapidly, since in most regions with high need for heating, incomes are already high enough, and due to technological and CC effect the energy demand for heating in these regions will actually decrease. Notably, regional (country) analyses might provide some general findings, but they have to consider also intraregional differences in temperatures (particularly in large countries and countries with big altitude range) and disproportion of income among population. In the EU, where incomes are generally high, 11% of population currently cannot afford to keep their homes warm in winter (EC, 2016).

Variables: Income per capita, GDP, GINI index

Trends that increase energy demand

The following trends cover indicators which will globally shift the energy demand upward :

- *Increasing population*
- *Decreasing average household size*
- *Increasing average floor areas of dwellings*

Variables: Floor area per capita, Population growth rate

Trends that decrease energy demand

These trends are projected to lower the energy demand for heating/cooling:

- *Building regulations*
- *Energy efficiency*
- *Rising price of energy*

Variables: Average cost of energy (by source) for household consumers, Average cost of energy (by source) for industrial consumers, Energy productivity by source, Building regulations variables



Drivers

This section will cover drivers, which directly influence climate change adaptations.

Regional drivers

Heating and cooling demand and the CC effect are fundamentally influenced by climatic regions. In the microclimate scale, the most important regions are urban agglomerations. The variables are logically connected to temperature differences between outdoor and indoor space.

Climatic regions

Adaptation to CC in heating/cooling is directly influenced by rising temperatures, particularly in winter and summer periods. Whereas regions from colder climate may benefit from CC in terms of energy decrease in heating, regions with warmer climate will generally increase the energy demand for cooling. In bigger countries it is difficult to provide general estimates, due to big climatic differences. However, at Figure 3 we provide such macro-regional projections. We see that the net effect of climate change on increase of heating and cooling energy demand in the residential sector is driven by Asian and Latin-American countries. In Europe, a decrease of total annual energy demand is estimated between 2000 and 2100.

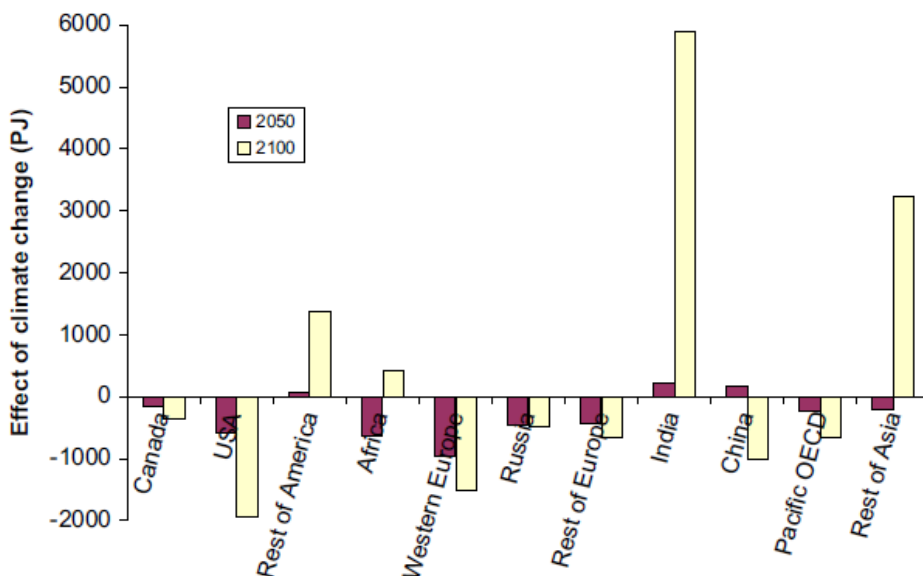


Figure 3 Regional net effect of climate change on energy demand for heating and air conditioning in the residential sector in the years 2050-2100 (reference scenario).

Source : (Isaac and van Vuuren, 2009)

We can also estimate the pattern of changes in time, depending on the climate change scenario we analyze. Isaac and van Vuuren (2009) present the time changes on the reference scenario and the scenario with a stabilization of the CO₂ concentration in the atmosphere at 450ppm (see Figure 4).

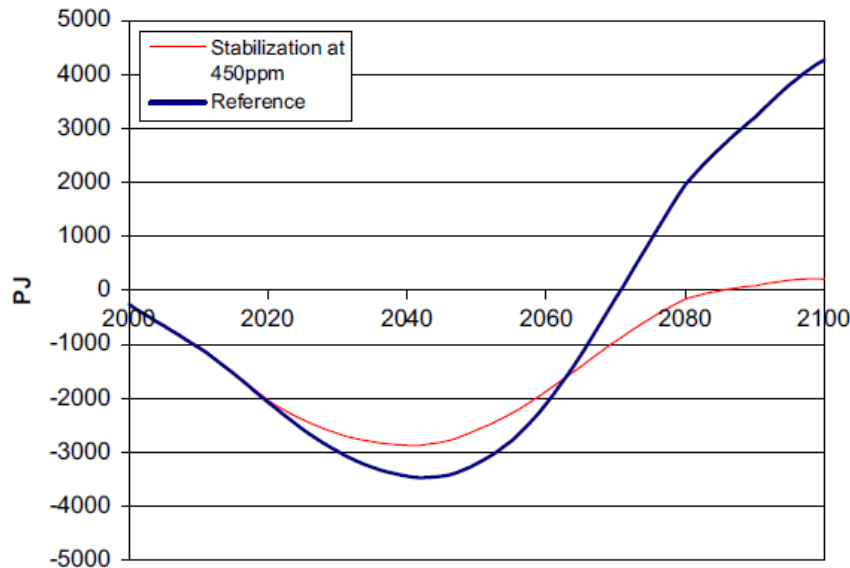


Figure 4 Global net effect of climate change on energy demand for heating and air conditioning in the residential sector for the reference scenario and scenario with stabilization at 450ppm.

Source : (Isaac and van Vuuren, 2009)

The most common climatic indicator of the demand for heating and cooling services is the degree day, which measures the departure of the average temperature from a base temperature. The base departure is in this sense an indoor temperature, which may differ between heating and cooling season. It often derives from computations of the least energy demanding indoor temperature at a certain location, and therefore varies substantially. According to Isaac and van Vuuren (2009), **heating degree days** (HDD) are expected to decrease, whereas **cooling degree days** (CDD) are expected to increase due to CC between 2000-2050. In Europe, heating degree days are expected to decrease by 11 to 20% between 2000 and 2050 due solely to climate change. In Figure 5, we see that this trend has been happening between 1981-2014 also. For cooling, very large percentage increases are estimated by the same authors for most of Europe until 2050, as the current penetration of cooling devices is low.

Variables: HDD, CDD, Air Temperature

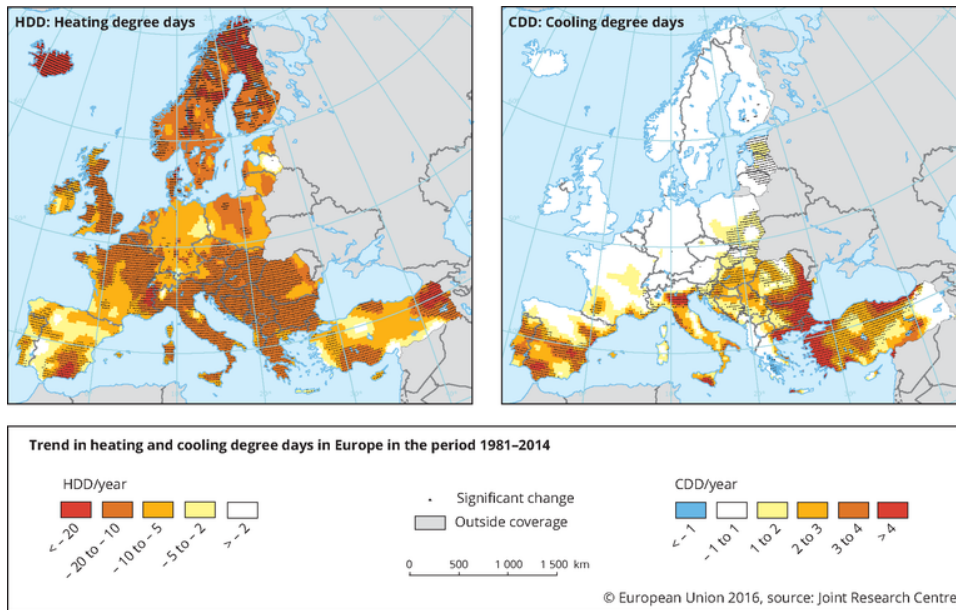


Figure 5 Trend in heating and cooling degree days in Europe in the period 1981-2014.

Source : EEA (online), <http://www.eea.europa.eu/data-and-maps/figures/trend-in-heating-and-cooling>

Urban regions

Increased frequency of hot days will exacerbate **urban heat island effects**, which will increase energy demand for cooling in warm season (Fischer et al., 2012). The summer heat waves can result in blackouts (Mideksa and Kallbekken, 2010). The blackouts can be exacerbated in the low rainfall events with a decline in the supply of water to cool power plants.

Less is known about the demand-side impacts in low- and lower middle- income nations, where hundreds of millions of urban dwellers still have no access to electricity and therefore also cooling devices. The impact of adaptation policies is also harder to estimate; see IPCC (2014) for a review).

Variables: Air Temperature, Days with reduced energy production

Energy-supply drivers

Climate change will affect not only energy demand, it impacts also directly the energy supply. Considering the scope of this report, we will look at the water-energy nexus and at potential of renewable energy sources in heating and cooling.



Water-energy nexus

Thermal and nuclear power plants require water for cooling. Apart from reduced water availability in some regions, rising water temperature reduces the overall plant efficiency, which in fact is also affected directly by decreasing efficiency of thermal conversion. During heat waves, this combined effect increases vulnerability of the energy sector. The number of **days with reduced useable capacity** of thermal power plants is projected to increase in Europe and the USA. In Europe, it is estimated that the usable capacity of power plants will decrease by 6-19% by 2031-2060 compared to 1971-2000. Impact on nuclear power plants is projected lower than on thermal plants, due to stricter safety regulations (IPCC, 2014).

Hydropower plants will be also affected by CC. In regions with high electricity demand for heating, the changes in annual hydrographs (earlier spring floods) may actually be of benefit for electricity production. In regions with high electricity demand for cooling though, the decrease in water supply in summer season might be detrimental (see e.g. Golombek et al., 2012).

Variables: Annual/Seasonal stream-flow changes and shifts, Air Temperature, Days with reduced useable capacity

Renewable potential

A potential of renewable energy sources (RES) in heating and cooling is highly important for assumptions of climatic, technological as well as policy scenarios that we deal with in other sections. RES are the fundamentals of the transition to the low-carbon economy. The variables to be considered shall reflect the RES potential under particular regional and sectoral context, considering price per unit, output and efficiency of the source.

Renewable heating and cooling include a set of technologies (see below) with different current state of deployment in the market. Figure 6 indicates this state of deployment. For example, solar heating and cooling technologies are expected to increase for up to 16 % of total heating energy supply and 17 % of cooling energy supply globally in 2050 (IEA, 2012).

Renewable cooling

- Cooling storage - seasonal storage of cold from winter; use of cold water from seas and deep lakes, use of snow or ice storage;
- Energy efficiency and conservation options in buildings and industry sector;
- Passive cooling building design and infrastructure, solar active cooling systems;



- Biomass cold producing systems;
- Active compression cooling powered by renewable electricity.

Renewable heating:

- Heat storage;
- Energy efficiency and conservation options in buildings and industry sector;
- Passive solar heating, active solar thermal or geothermal heating;
- Geothermal heat pumps;
- Biomass for cogeneration of electricity and heat (combined heat and power, CHP); biomass combustion for heat.

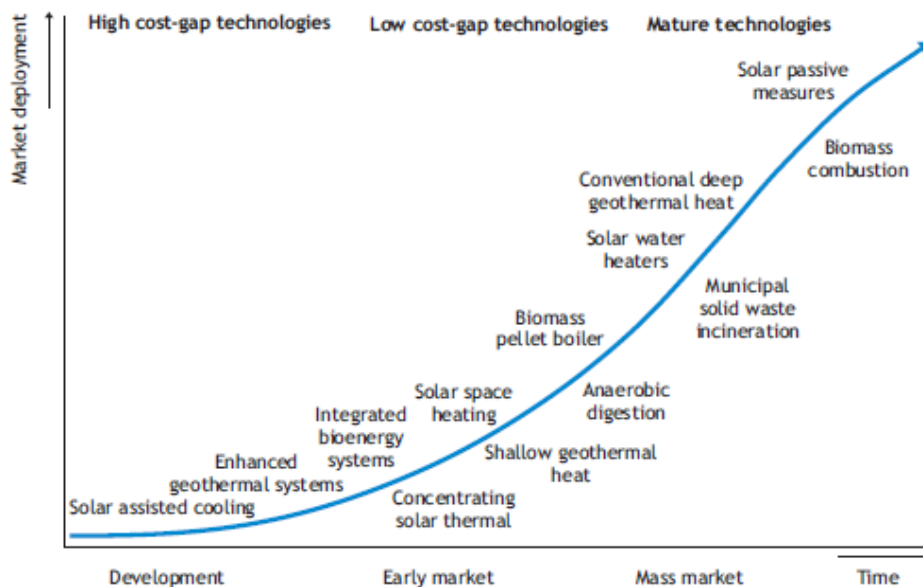


Figure 6 Indication of the current state of deployment of RES technologies from development to application in the mass market.

Source : (IEA, 2007)

Adaptation of renewables to climate change

Notably, also effectiveness of renewable energy sources will be affected by CC and will need to consider adaptations, which will increase energy consumption (IPCC, 2014).

Most notable impacts of CC include:

- Increasing efficiency of solar heating in colder regions
- Decreasing efficiency of photovoltaic efficiency due to overheating

Variables: Days with reduced useable capacity, RES energy production by technology, Investment in RES capacity, Renewable energy consumption by source and sector

Socio-economic drivers

Variables connected with the drivers of socio-economic adaptation effects will have to consider macroeconomic indicators and their use under different climatic, regional or sector scenarios.

Costs of adaptation

The total **costs of adaptation** of the energy sector have not been yet calculated (IPCC, 2014) We can expect high infrastructural costs of the public sector, however, the dominating actions will arrive from the private sector, due to people adjusting their buildings and changes in their heating/cooling preferences. Public sector may however support the private actions by various policies (see below).

GDP impact

Studies predict **effects of CC on GDP** using a Computable General Equilibrium (CGE) model. Studies focusing on EU predict -1% to -0,25% change in EU cooler regions, and -3% to -0,5% in EU warmer regions in 2100. Adaptation policies might however mitigate costs of CC impacts fundamentally (up to 85%). The real effects on GDP will therefore be influenced by effectiveness of the mix of adaptation policies, impacts of extreme weather events and other less predictable variables (IPCC, 2014).

Price impact

Prices of electricity have been calculated to increase by 1% in Western Europe in 2030 due to rising temperatures and consequent effects on demand as well as thermal efficiency of supply (Golombek et al., 2012). Bigger price fluctuations are estimated in a short-term scenario of water shortage and disaster events.

Impact on labor productivity

Productivity of workers is estimated to decrease with the current working practices due to heat stress up to 20% globally in 2100; with the highest impact in tropical climate and in outdoor manual labor. Adaptation to buildings or work practices will be needed to maintain labor productivity (Kjellstrom et al., 2009).

Variables: GDP, Energy price per unit, Labor productivity

Social adaptation drivers

Age, health and also geographic variations among population change perception of thermal comfort, which influence behavior to adjust to the thermal environment and therefore heating and cooling demand. The attitudes may also reflect environmental awareness among population.

Variables: Qualitative and quantitative survey on energy consumption attitudes by sector

Studies show social vulnerability to events such as heat waves among different social groups – elderly, sick, obese, diabetic, poor, marginalized and socially excluded, but also outdoor working persons. These groups are particularly vulnerable to **heat-related mortality**, but conversely the reduction of the very cold days will potentially reduce the **cold-related mortality** (IPCC, 2014). Hospitalizations resulting from heat waves will increase costs of medical services.

Variables: Heat (Cold) related mortality; Demographic indicators; Biophysical indicators

Technological adaptation drivers

Variables of the technological adaptation drivers will cover the technical performance and energy efficiency of different building materials and designs, efficiency of different heating/cooling technologies, but also indicators of economic circularity, such as amount of reused/recycled materials, and also energy savings.

Substitution to renewable energy sources

Industrial heat and sanitary hot water installations may be more easily substituted with renewable technologies than space heating, due to relatively constant demand over the year. Particularly in the case of solar energy, this becomes difficult in space heating due to the seasonal mismatch between demand and maximum source availability (IEA, 2016).

Energy savings

- **Industrial waste heat and cold** can be used in near building sector (EC, 2016);
- **Higher insulation levels and passive housing** incl. passive cooling from solar and also thermal mass will help to move toward zero-energy buildings. This technology may have higher fixed costs, but lower variable costs and could be used in new as well as retrofitted houses. The retrofitting is highly important, considering that in the EU, two thirds of buildings were built when energy efficiency requirements were limited or non-existent and most of these buildings will be standing still in 2050. Low/zero-carbon and energy-efficient heating and cooling technologies for buildings are projected to cover 63% of the energy savings projected in the BLUE Map scenario (IEA, 2011);
- **Green and white roofs** help reduce cooling demand. The green roofs have higher potential in suburban less shadowed areas, in older buildings and in hot-humid climate (IPCC, 2014);
- **Thermal power plants cooling adaptations** have more options for the new builds, however most adaptations will be required for existing and oldest power plants, where reusing and dry-cooling are currently the most promising options (IPCC, 2014).

Adaptation policies and risk management

Variables of the policy adaptations should include costs of concrete policies (investment costs, operation costs, but also CBA and SWOT analyses.

Adaptation policies

Only 40 countries have implemented **renewable heat support mechanisms**. Only few countries have comprehensive heat decarbonisation strategies. European Commission have published a heating and cooling strategy recently (EC, 2016). Contrary to most of the strategies, which focus on space heating/cooling, EC addresses also industrial sector. The EU budget for 2014-2020 allocates EUR 19 billion for energy efficiency.

In order to catalyze the market dissemination of more **energy-efficient technologies**, public policies are needed. For example, in energy consumption of buildings, EU have two legislations – Energy Efficiency Directive (EU, 2012) and Energy Performance of Buildings Directive (EU, 2010); the latter mentioned is currently (November 30, 2016) being considered for updates regarding smart technologies.

Policies that promote **public green areas**, which may not only mitigate the urban heat islands, but also provide cooler space for the citizens, need to consider opportunity costs of other potential uses of the land.

Policies that support the renewable energy in heating should reflect an effect of potentially rising prices of electricity, which might keep heating sector based on fossil fuels.

Adaptations in the EU building sector

Low or zero carbon technologies in buildings will play a crucial role in the energy transition. The technology is available in high-tech - smart buildings (EC, 2016) as well as in a low-tech edge of the market - Low Impact Developments (Pickerill and Maxey, 2012). The adaptation policies have to focus on retrofitting of the current stock, as well as on new developments.

Privately owned residential buildings

In the EU, most of the population (around 70 %) lives in privately owned residential buildings. Policy makers have to consider lack of awareness of CC adaptations among owners, their financing constraints and the 'split incentives', which means that owners have less incentive to invest in adaptation to CC if tenants pay the energy bill (EC, 2016).

Publicly owned buildings

Publicly owned buildings such as schools, universities, hospitals or social housing are often energy intensive buildings with high adaptation needs. EC (2016) suggests developing new funding mechanisms, such as Energy Performance Contracting, which would enable to pay the investment by future cost savings.

Commercial buildings

Commercial or service buildings, such as banks, shops and offices make up a quarter of the stock. Their energy consumption is on average 40% higher than in residential buildings. It consumes most of EU space cooling. EC (2016) suggests developing training systems for professionals in the building sector to raise awareness about adaptation technologies as well as needs to incorporate them.

Adaptations in the EU industry sector

Industry accounts a quarter of EU energy consumption. Heating and cooling covers 72 % of it. A lot of energy savings has been done since year 2000. A potential of improvements remains particularly in SMEs. Waste heat and cold could be reused in residential and commercial sector (EC, 2016).

Risk management

Additional energy (and economic costs) will have to be given to risk management and adaptation services. Related to this report, adaptations to heat waves – and consequent drought waves will be crucial, particularly in urban regions. The infrastructure will have to consider new public water facilities, shed and public green and increase of cooling demand in public facilities such as offices, schools and hospitals (Pramova et al., 2012). It will have to consider revising the large-scale reliance on air-conditioning in places with higher vulnerability of the energy sector. In Europe the key vulnerability related to CC lies in limited water supply for cooling in thermal and nuclear power plants during heat waves (IPCC, 2014).

Adaptation – Mitigation synergies and trade-offs

This report focuses on adaptation to climate change in heating and cooling. However, mitigation practices, which aim to reduce the climate change impacts are highly connected with the low-carbon economy implementation and therefore with the main aim of the MEDEAS project. Adaptation and mitigation practices may create synergies, but also trade-offs. For the MEDEAS it therefore may be relevant to include the mitigation practices in the development of the model.

For example, in some cases, adaptation may increase greenhouse gas emissions (e.g. increased fossil-based air conditioning in response to higher temperatures) and in some cases mitigation may impede adaptation (e.g. reduced energy availability in countries with growing populations). Mitigation might increase water demand (irrigation of biofuel crops), which may effect adaptation practices (cooling) due to vulnerabilities in the energy sector (IPCC, 2014).

Conclusions

Energy requirements resulting from the adaptation to CC are generally difficult to project due to several reasons:

- Uncertain predictions of wider trends (GDP, population, technological progress, industrial performance, etc.)
- More CC scenarios, which relevance is fundamentally connected to economy-energy nexus, in other words to any economic activity resulting in CO2 emissions.
- Complexity of drivers - need for various datasets availability – climatic indicators, demographic indicators, technological indicators, macroeconomic indicators, biophysical indicators and behavioral surveys

Under these conditions, the suggestion to the MEDEAS consortium for further analysis would be to focus majorly on variables that enable model calculations of energy required for residential and commercial heating and cooling, such as Heat degree days, Cold degree days, among others. Potential strategy might be to adapt one of the models and climatic scenarios covered in literature of the topic. The analysis would have to consider, whether to include the industrial sector, which lacks reference projections. The projection is among other constraints with data availability limited due to constraints of industry performance in the future at a global as well as regional level (and therefore in different climatic regions). One suggestion would be to project the industrial sector in a shorter scale, second would be to focus only at space-heating of industrial buildings. Analyses focusing on energy effectiveness of the energy sector and of new technologies and buildings should be also considered. In addition analysis of the energy supply adaptations, and particularly energy requirements and influence of the policy implementations, as well as attitudes of consumers in heating and cooling should be considered to be included in the MEDEAS model development.

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