PUBLISHABLE FINAL REPORT

A) Project Data

Kurztitel:	PRESENCE
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B) Project Overview

1 Kurzfassung (German language)

Das derzeitige Energiesystem trägt wesentlich zum Klimawandel bei. Gleichzeitig ist das Energiesystem selber durch den Klimawandel betroffen. Mit dem Klimawandel ändern sich sowohl das Energieangebot, z.B. die Charakteristik der Verfügbarkeit von Wasserkraft, als auch die Energienachfrage für Heizen und Kühlen. Klimaschutz erfordert den Übergang zu nachhaltigen, weitestgehend klimaneutralen Technologien und Gesamtlösungen.

Das Ziel des Projekts PRESENCE ist es, am Beispiel Österreichs Maßnahmen und Pfade aufzuzeigen, wie die Resilienz des Energiesystems angesichts von Klimawandel, möglichen Trends und Energiekrisen als auch der Transformation des Energiesystems erhöht werden kann.

Die folgenden Schritte wurden dazu ausgeführt:

- Ausarbeitung und Klärung des Begriffs „Resilienz von Energiesystemen" angesichts von Klimawandel, sozialen und technologischen Veränderungen sowie möglicher Krisen
- Entwicklung und Diskussion von Methoden zur Bewertung von Extremereignissen
- Bereitstellung meteorologischer Basisdaten auf Basis von Klima-Szenario-Ensembles. Bias-Korrektur für Temperatur und Niederschlag für drei regionale Klimamodelle (REMO-UBA, RegCM3 und Aladin-Arpege) sowie Regionalisierung auf 1x1 km Raster für Österreich.
- Analyse der Auswirkung von Klimawandel und Extremereignissen auf die Wasserkraft
- Entwicklung eines Sets von drei energiepolitischen Rahmenbedingungen und Analyse des resultierenden Energiebedarfs sowie des Angebots unter verschiedenen Klimaszenarien. Dies wurde für Raumwärme, Klimatisierung sowie das Stromsystem durchgeführt.
- Analyse der Auswirkung des Klimawandels auf Kühlwasserverfügbarkeit in ausgewählten Industriestandorten
- Erarbeitung von Anpassungsmaßnahmen für eine erhöhte Resilienz des Energiesystems, Analyse deren Wirkungen und Ableitung von Schlussfolgerungen und Empfehlungen

Die Ergebnisse des Projekts PRESENCE zeigen, dass Klimawandel eine deutlich Auswirkung auf das zukünftige Energiesystem hat, insbesondere auf Wasserkraft und deren saisonaler und räumlicher Erzeugungsstrukturen als auch auf den Heiz- und Kühlenergiebedarf und resultierender Kühllastspitzen. Allerdings ist der für den Klimaschutz erforderliche Wandel deutlich relevanter und führt zu deutlich stärkeren Änderungen im Energiebedarf und im Technologie-Mix als der Einfluss des Klimawandels. Das heißt., dass die Kosten des Klimawandels im Energiesystem moderat sind, vorausgesetzt dass entsprechende Maßnahmen rechtzeitig getätigt werden. Allerdings sind dabei die Trägheiten und langen systemimmanenten Vorlaufzeiten zu berücksichtigen. Falls keine Adaption vorgenommen wird, wäre daraus ein Verlust der Systemzuverlässigkeit in der Stromversorgung zu erwarten.

Die hydrologische Modellierung zeigt unterschiedliche regionale Muster. Die saisonale Verschiebung ist in allen drei Klimaszenarien sehr ähnlich: der Abfluss im Sommer nimmt ab, während jener im Winter steigt. Spezifische Effekte der Änderungen auf die Wasserkraftproduktion wurden für beispielhafte Einzugsgebiete und Laufwasserkraftwerke analysiert. Die erwartete Abnahme des mittleren Abflusses gegen Ende des 21. Jahrhunderts um bis zu 12% lässt keine Rückschlüsse auf generelle Verknappung der Kühlwasserverfügbarkeit in Österreich zu.

Die Wirkung des Klimawandels auf Raumwärme und Klimatisierung ist deutlich geringer ist als der potenzielle Hebel der Energie- und Klimapolitik. Gemessen in relativen Zahlen hat der Klimawandel eine stärkere Wirkung auf Klimatisierung als auf Raumwärme. Da allerdings der Energiebedarf für Heizen jenen für Kühlung in Österreich derzeit um mehr als zwei Größenordnungen übersteigt, reduziert der Klimawandel den absoluten, gesamten Energiebedarf für Heizen und Kühlen. Die Volllaststunden der Gebäude-Klimatisierung sind dabei deutlich geringer als jene der Raumwärmebereitstellung. Ohne Anpassung sind daher sehr hohe Lastspitzen für Kühlstrom zu erwarten. Entsprechende Anpassungsmaßnahmen (z.B. Verschattung) können diese Kühllastspitzen deutlich reduzieren.

Die Modellierung des Energiesystems zeigt, dass höhere Energieeffizienz und ein höherer Anteil erneuerbarer Energie signifikant zur Erhöhung der Resilienz des Energiesystems beiträgt, insbesondere könnte die Stromerzeugung aus Photovoltaik Kühllastspitzen in einem gewissen Ausmaß abfedern. Die Analyse der Extrem-Perioden in den Klimaszenarien zeigt, dass die Winter-Residual-Lasten in einem ähnlichen Bereich bleiben wie in der Kontrollperiode ohne Klimawandel. Allerdings steigt die Anzahl der Perioden mit hohen Sommer-Residual-Lasten bis 2050-2080 stark an, wenn nicht starke Anstrengungen zur Reduktion der Kühllasten unternommen werden.

Folgende Maßnahmen zur Erhöhung der Resilienz angesichts von Klimawandel und anderer Trends wurden identifiziert:

(1) Reduktion des Energiebedarfs;
(2) Reduktion der Kühllasten durch Gebäudeseitige Maßnahmen, z.B. Verschattung;
(3) Reduktion der Kühllasten durch verringerte interne Lasten mittels effizienter elektrischer Geräte und Anwendungen in den Gebäuden;
(4) PV-Stromerzeugung zur Reduktion der Abhängigkeiten von internationalen Rohstoffmärkten und um einen Beitrag in Zeiten hoher Kühllasten zu leisten; Sicherstellung, dass PV-Anlagen entweder an den Gebäuden mit hohem Kühlbedarf installiert sind bzw. dass die Kapazitäten zur Stromübertragung in der Lage sind, mit diesen hohen Kühllasten umzugehen;
(5) Maßnahmen zur Verschiebung von Spitzenlasten auf der Nachfrageseite;
(6) regelmäßige Analyse und Bewertung der Wirkung des Klimawandels auf das Energiesystem um die Planbarkeit langfristiger Investitionen zu ermöglichen.

Die Kosten des Klimawandels im Energiesystem sind für Österreich voraussichtlich moderat, wenn entsprechende Maßnahmen getätigt werden. Aufgrund der langen Vorlaufzeiten sind allerdings frühzeitige Schirtte erforderlich. Falls keine Anpassung erfolgt, ist ein Verlust der Zuverlässigkeit in der Stromversorgung zu erwarten.

Eine Reihe von Fragen ergab sich während des Projekts, die für weitere Forschung offen gelassen werden musste, u.a. die folgenden:

(1) die internationale Dimension des Klimawandels und der Auswirkung auf das Stromsystem;
(2) die Vulnerabilität und die Rolle der Stromnetze für ein resilientes, weitestgehend klimaneutrales Stromsystem im Klimawandel;
(3) weitere Entwicklung der Methodik zur Integration von Extremereignissen in Energiesystem-Analysen;
(4) besseres Verständnis sowie eine bessere Datengrundlage für derzeitige und mögliche zukünftige Marktdurchdringung von Klimaanlagen;
(5) Kosten, Nutzen und ökonomische Effektivität von Anpassungsmaßnahmen;
(6) weitere Bearbeitung der Wirkung von Extremereignissen, insbesondere und Klimaszenarien mit stärkeren Temperaturanstiegen;
(7) Entscheidungsverhalten von Stakeholdern und Investoren unter Unsicherheit und Krisen.

Die Erhöhung der Resilienz des Energiesystems ist eine zentrale Herausforderung. Die Ergebnisse von PRESENCE sowie weiterer einschlägiger Projekte können zu einer erfolgreichen Integration von Adaption und Klimaschutz im Zuge der notwendigen Energiesystem-Transformation beitragen.

2 Executive Summary

The current energy system is a major driver of climate change. At the same time, the energy system itself is affected by climate change. Some elements of energy supply will change the characteristics of its availability (e.g. hydro power) and a modification in energy demand will occur (e.g. heating and cooling). Climate mitigation requires the shift towards zero- and low-carbon energy solutions.

The core objective of this project is to provide measures and pathways how to increase the resilience of energy systems in the view of climate change, possible trends and energy crises as well as the transformation of our energy system into a low- carbon future for the Austrian case.

The following steps have been carried out:

- Extend and elaborate the methodological framework for the term "resilience of energy systems" in the light of climate change, social and technological change, possible crises.
- Develop a methodological framework for assessing the impact of extreme events.
- Derive key meteorological data from climate scenario ensembles. Bias correction of temperature and precipitation for scenario runs of three regional climate models (REMO-UBA, RegCM3 and Aladin-Arpege) and regionalization on a 1km x 1km grid for Austria.
- Derive the impact of climate change and related extreme events on hydro power.
- Development of a set of three possible energy policy framework conditions and analysis of the resulting energy demand and supply mix of these settings under various climate conditions. This has been applied for space heating, cooling and the electricity system.
- Investigate the impact of climate change on cooling water availability in selected industry and thermal power plant sites.
- Derive adaptation measures for an increased resilience of energy systems, assess their impact and derive conclusions and recommendations.

The overall results of the project PRESENCE show that climate change has an impact on energy systems, in particular on hydropower availability and its seasonal and spatial patterns as well as on heating and cooling energy demand and cooling peak loads. However, the changes which have to occur in order to reach climate mitigation targets are much more fundamental than the impact of climate change on the energy system. Thus, the Austrian energy system can cope with climate change at very moderate costs, if corresponding measures are taken in time. However, due to the inertia of the system and long lead times for investments early actions are required. If no adaptation takes place, a loss of reliability in the electricity supply could result.

The hydrological modelling shows distinct regional patterns of hydrological change. Seasonal changes are very similar in all three climate change scenarios: summer runoff decreasing, winter runoff increasing. Specific effects of hydrological changes for hydropower production were investigated exemplarily for selected alpine reservoirs and run-of-river power plants. The expected decrease of mean flow towards the end of the 21st century of up to 12% does not indicate general shortages of cooling water availability in Austria. Seasonal changes show runoff increases in winter and spring and decreases in summer and fall.

Regarding the impact on heating and cooling, a major finding is that the impact of climate change is much lower than the leverage of energy policy framework conditions. Our results show that the climate change impact on the annual energy needs for space heating is smaller than that for cooling, when measured in relative terms. However, since the final energy demand for heating surpasses the cooling demand by more than two decimal powers, climate change is reducing the energy demand in absolute numbers. The concurrency factor for AC systems is larger and the full load hours are smaller than that for heating. This means, that the space cooling might not be a critical issue from an annual energy balance point-of-view, but may have a major impact on electricity peaks and the design-factor of electricity grids, if no adoption measures are undertaken.

The results of the energy system modelling show that energy efficiency and a higher share of renewable energy contribute to increase the energy systems resilience: PV generation covers cooling load to some extent. The analysis of extreme periods (based on the criterion of residual loads) shows, that for most climate scenarios periods with high residual loads in winter will remain in a very similar range as for historic periods. However, in all climate scenarios such periods during summer will increase until 2050-2080 if no efforts are taken to reduce cooling loads.

The measures which we identified for increasing the resilience in the view of climate change and other trends focus on:

(1) Reduction of overall energy demand;
(2) reduction of cooling loads by implementing building related measures like shading;
(3) reduction of cooling loads by reducing internal loads through more efficient electric appliances;
(4) increase PV generation to reduce dependencies of international resource markets and to provide a positive contribution in periods of high cooling demand; make sure that PV is either situated on-site or nearby the buildings with high cooling loads or / and make sure that the capacity of electricity transmission lines copes with the high loads;
(5) implement measures for shifting of peak loads on the demand side;
(6) carry out a regular assessment of climate change impact on energy systems to prepare long-term investments.

The energy system can cope with climate change at very moderate costs, if corresponding measures are taken in time. However, due to long lead times for investments early actions are required. If no adaptation takes place, a loss of reliability in the electricity supply is very likely.

A number of open questions occurred during the project and have to be left for further research. This refers in particular to the following aspects:

(1) The international dimension of climate change and the impact on the electricity sector;
(2) the vulnerability and role of the electricity grid for a resilient low-carbon electricity system under climate change;
(3) further development of methodological approaches to integrate extreme events in energy system analyses;
(4) better understanding of current and potential future AC market penetration;
(5) costs, benefits and economic effectiveness of adaptation measures;
(6) further elaboration on extreme events and more extreme climate change scenarios;
(7) decision making structure under uncertainty and crises.

Increasing the resilience of the energy system is one of the key global and local challenges in the coming years and decades. The results of PRESENCE as well as future related research projects may contribute to the successful simultaneous integration of climate change adaptation and mitigation in the energy transition process.

3 Introduction: Starting point, objective and approach

The current energy system is a major driver of climate change. At the same time, the energy system itself is affected by climate change. Some elements of energy supply will change the characteristics of its availability (e.g. hydro power) and a modification in energy demand will occur (e.g. heating and cooling). Therefore, simultaneous mitigation and adaptation has to take place. The energy system in the next decades will face fundamental restructuring. Climate mitigation scenarios show the requirements of shifting towards zero- and low-carbon energy solutions. The availability of fossil resources (first of all oil) as well as global conflicts might cause energy shortages leading to energy crises. Demographic and social changes as well as technology developments could lead to additional challenges and opportunities.

Various trends, unexpected developments and climate change partly are potential sources of heavy vulnerability of the energy system. The question arises how mitigation efforts, adaptation measures and responses to changing side conditions might be integrated.

The core objective of this project was to provide measures and pathways how to increase the resilience of energy systems in the view of climate change, possible trends and energy crises as well as the transformation of our energy system into a low- and zero carbon future for the Austrian case.

The research questions have been investigated within the following system boundaries:

- Regional boundary: Austria. Due to the strong interlinkage of the Austrian electricity system with the Central European electricity market, and particularly with the German electricity market, the electricity sector has been modelled for Austria and Germany simultaneously.
- Time period: We investigated the impacts up to 2080, with a strong focus on the 30 year periods from 2050 to 2080.
- Sectors within the energy system: We focused on the climate sensitivity of (1) hydro power, (2) electricity system, (3) heating and cooling of buildings and (4) selected aspects of cooling water availability for thermal power plants and industrial energy related processes.

Figure 1 shows the model cluster and data flow, which has been set up and applied in the project PRESENCE. The starting point are bias corrected and localised climate scenario data of three models (REMO, RegCM3, Aladin) in the relevant time frame (WP1). For the different sector models, different aggregation levels and preparation of the climate data were provided. The hydrological model is based on monthly temperature and precipitation data and provided monthly changes of long-term runoff for 188 river basins as well as key data regarding cooling water availability (WP4, WP5). The building physics model and Invert/EE-Lab used semi-synthetic climate data for deriving heating and cooling energy demand and load profiles (WP6). The electricity and heat optimisation model HiREPS used daily temperature, radiation and hourly wind speed percentiles, the long-term run-off for 188 water basins as well as hourly load profiles for heating and cooling energy demand of the Austrian building stock by building categories in order to derive optimised settings of the future electricity and heating sector under climate change.

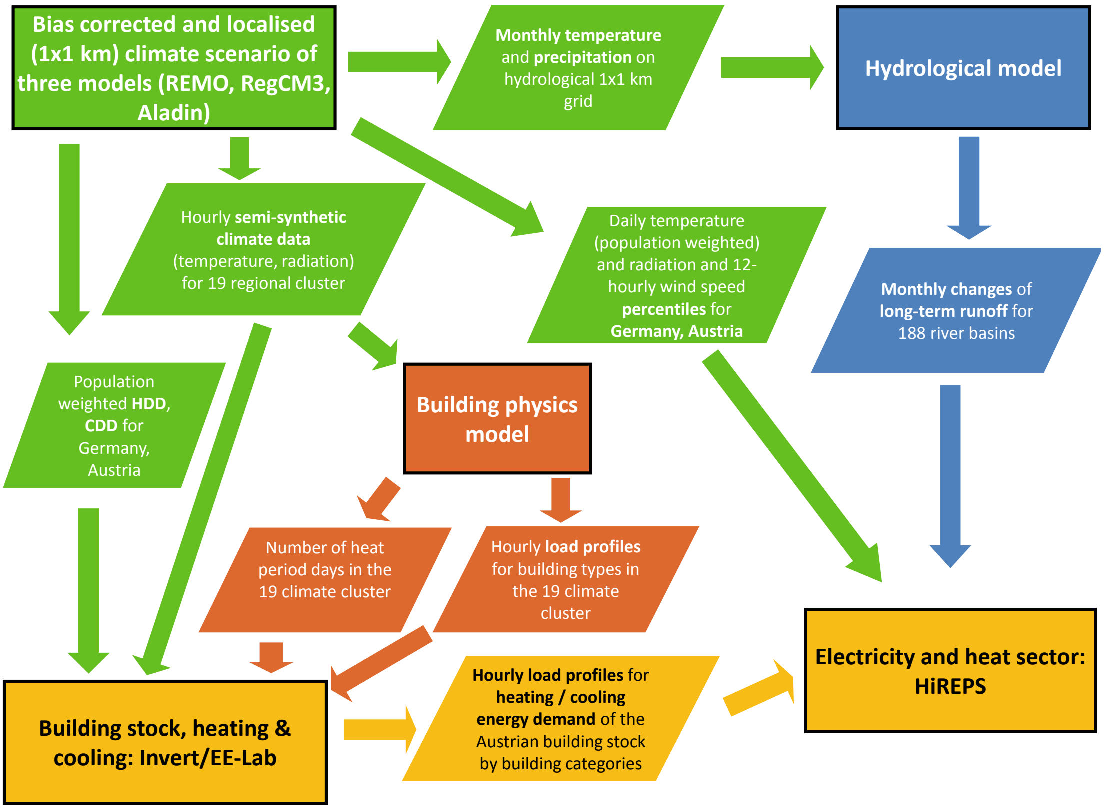

Figure 1. Model cluster and data flow chart

This modelling framework has been used to derive a set of scenarios. These scenarios can be clustered by two dimensions: first the impact on the energy system of non-climate change related variables, such as climate mitigation efforts, retrofitting rate and quality or the share of renewable energy carriers used for providing energy services. With respect to this dimension, three policy scenarios have been developed. The first policy scenario, the grey scenario, represents a business-as-usual scenario, where 2020 are reached but no major progress is made after 2020. The second policy scenario group, the green scenario, sets a focus on renewable energy carriers, but no additional focus on energy efficiency compared to the grey scenarios. Finally, compared to the green scenarios in the blue policy scenarios, an additional effort on energy efficiency is set.

And second, the impact of climate change, by applying the average historical climate for the period as well as the results of three different climate models: the regional ALADIN model (CNRM-ALADIN), driven by the global ARPEGE model and the two RCM: RegCM3 (ICTP-RegCM3) and REMO (MPI-REMO) driven by the GCM ECHAM5. In total, this leads to 12 scenarios.

The project PRESENCE has been supported by the Austrian climate and energy fund in the frame of the Austrian Climate Research Programme. It has been funded in the call 2010 and refers to the topics listed under Thematic Area 1 (Responding to Austria’s Policy Community) and Thematic Area 3 (The Economics of Climate Change).

This report gives a short summary of the project results. More details are documented in working papers of the different work packages, available at www.eeg.tuwien.ac.at/presence. Preliminary results have been discussed at three review workshops. The materials of these workshops are also available at the project website.

4 Detailed project presentation and results

Climate models and scenarios[1]

Future climate projections of the last IPCC report (IPCC, 2007) show that the global temperature will continue rising until the end of the century (Fig. 1, left). For precipitation, no changes in the annual sum are projected but for summer a decrease and for winter an increase is projected (Fig. 1, right) with significant changes in the second half of the century.

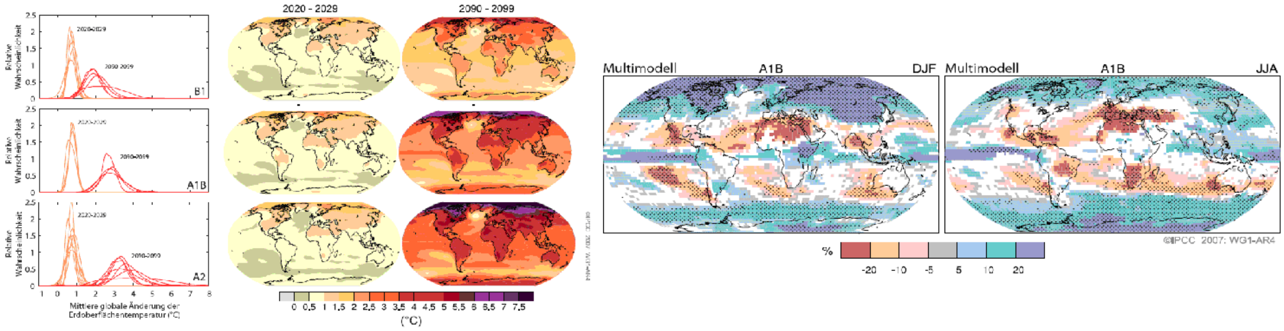

Figure 2. Left) Temperature changes for three scenarios, B1 (top), A1B (middle), and A2 (bottom) for the episodes 2020 – 2029 and 2090 – 2099 compared to the control episode 1980-1999. Right) relative changes of precipitation in percentage for the episode 2090-2099 compared to the control episode for winter (DJF) and summer (JJA) (IPCC, 2007).

For Europe, the A1B scenario projects a slight temperature increase of 0.5 to 1 °C for the near future (2011-2040) which is consistent between all three models used for this study (see below). For the future episode (2036-2065) a temperature of already up to 2.5 °C, especially in southern Europe, is projected. For the distant future (2071 – 2100) an annual temperature change of up to 3 °C in Europe is projected, for the northern regions even up to 5 °C. Annual precipitation changes show no changes for the two (near) future episodes but for the distant future the two models driven by the ECHAM5 GCM (RegCM3 and REMO) project an increase of 5 – 10% in central Europe and eastern Austria and a decrease in southern Europe whereas the CNRM model projects a decrease by the end of the century for Europe except for the northernmost parts.

The resolutions used in the ENSEMBLES project are not able to properly resolve the mountainous topography. The REMO-UBA simulations, also used within this project in context with the hydrological model, used a higher resolution but focused on Germany, Austria, and Switzerland only. Projections of the A1B scenario for Austria for the Episode 2071 – 2100 (Fig. 3) show that a significant temperature increase of up to 4.5 °C especially in the southern and western regions can be expected. For the precipitation an increase in the east but a decrease in the south and west is projected.

[1] The results of climate scenario data are documented in Schicker et Formayer, 2013, Working paper on Climate Change Scenarios.

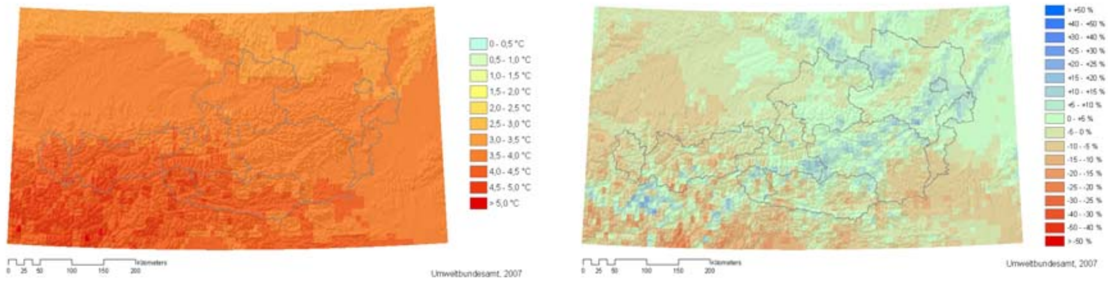

Figure 3. Left) annual temperature changes in °C and right) annual precipitation changes in percentage relative to the 1961 – 1990 control episode of the REMO-UBA simulations.

Data of three regional climate models, the Aladin, the RegCM3, and the REMO model, each driven by GCMs using the A1B scenario, were used. All three data-sets are part of the ENSEMBLES project and come with a resolution of 25 x 25 km. Two models, the REMO and the RegCM3, were driven by the ECHAM5 GCM whereas the Aladin model was driven by the ARPEGE GCM. For the hydrological part the REMO-UBA model (Jacob et al., 2008) was used instead of the REMO model.

All four model data sets were bias corrected and, depending on the data application, also localized to a higher resolved 1 km Austrian grid. The bias correction used the Quantile mapping technique (Deque, 2007) applying corrections factors which are based on the cumulative density function between model and observations. For temperature and additive correction was used, for precipitation a multiplicative correction was used. For the localization to a higher resolved Austrian grid two data sets were used, the INCA data set and a hydrological 1 km data set which was used for the input data generation for the hydrological model. More detailed information on bias correction and data localization can be found in the Deliverable 2.1.

Four evaluation episodes were defined: (1) 1981 – 2010 for the control episode, (2) 2011 – 2040 for now and the near future, (3) 2036 – 2065 for the future, and (4) 2051 – 2080 for the distant future.

With respect to the energy system, the meteorological parameters wind, precipitation, temperature, and irradiation were evaluated.

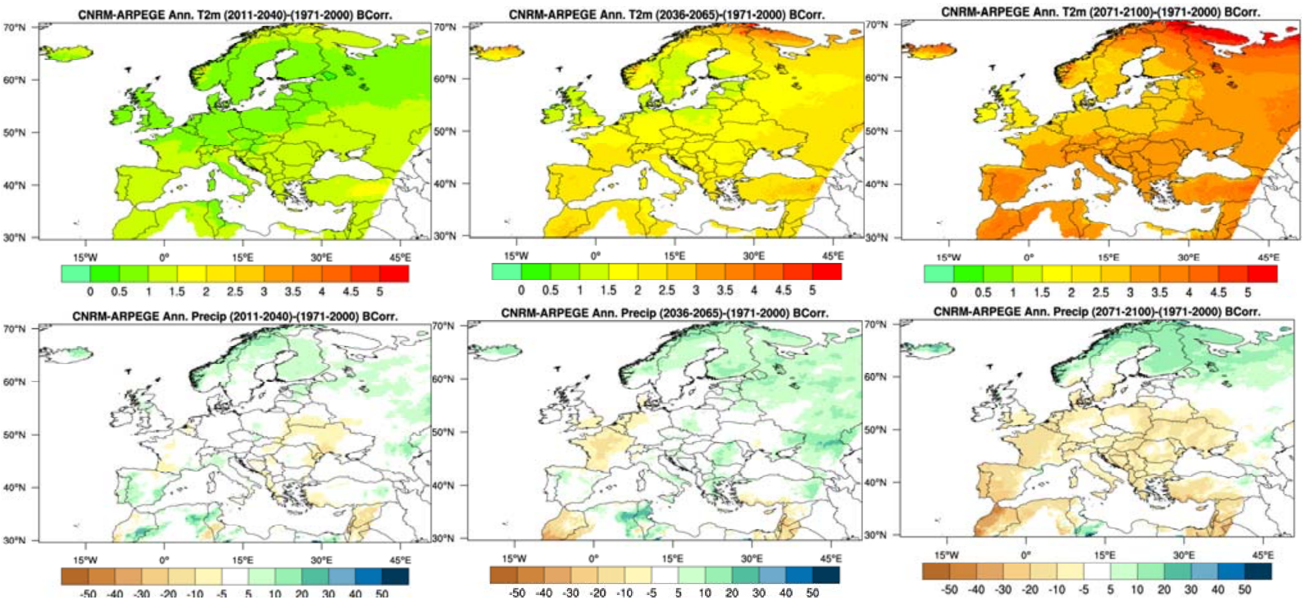

Figure 4. Top) temperature changes in °C and bottom) precipitation changes in percentage relative to the 1971 – 2000 control episode of the bias corrected CNRM model for left) 2011 – 2040, middle) 2036 – 2065, and right) 2071 – 2100.

Semi-synthetic climate data

The Institute of Building Construction and Technology needed temporally and spatially highly resolved input data for reference years for their model. To be able to represent the different climatic regions of Austria a clustering of the two important parameters, temperature and irradiation, was carried out using a gridded 1 km 30 year data set (1971 – 2000) provided by the ZAMG. Three temperature cluster and two irradiation cluster were defined for July (x < 18°C, 18°C < x < 22°C, x > 22°C, x < 50 W/m², x > 50 W/m²) and two temperature and irradiation cluster for January (x < 15°C, x > 15°C, x < 230 W/m², x > 230 W/m²). The combined temperature-irradiation cluster resulted in 19 different Austrian climate cluster. For each of those cluster a representative observation site was selected.

For the generation of the needed input data for the building model a program, the HSKD (halb-synthetischer Klima Datensatz, Heindl et al., 1990), was used. This program needs hourly data and monthly means of temperature, global radiation, relative humidity, wind speed, and diffusive radiation. Monthly means for the localized scenario data episodes was calculated and served as input in addition to long time series of observed station data.

Climate scenarios for the HiRePs model

For the energy system model HiRePs a different input data set was needed. Here, one value for Austria and one value for Germany of the parameters temperature, irradiation, and wind speed was needed. For all three meteorological parameters the highest available temporal resolution of the RCM data was used. Also, the higher alpine regions above 1250 m were removed from the Austrian and the German grids. For wind speed and radiation monthly percentiles of the hindcast were calculated and then assigned to the control and scenario data to generate look-up tables for the HiRePs model. As radiation the global radiation calculated by the models was used. For wind speed the u and v components at a height of 850 hPa was used to calculate the third power of wind speed for Austria and Germany for each grid cell, then averaged over the entire domain and then the cubic root was calculated to be used as input for the HiRePs model. For temperature a similar approach was used as for the radiation but an additional weight using the population density of the lspop (1x1 km, Dobson et al., 2000) was applied.

Input for the hydrological model

The RCM data of the three climate models was localized to the provided 1 km Austrian grid and the climate change signal for temperature and precipitation for the three scenario episodes and one control episode. Here, the control episode was selected as 1961 – 1990. In addition to the three scenario time slice two time slices covering 2041 – 2070 and 2061 – 2090 were selected.

HDD and CDD for the energy sector

Additionally, the population weighted heating degree days (HDD) and cooling degree days (CDD) for each of the models and for each of the five selected episodes were calculated using the bias corrected data sets. Different HDD and CDD groups were selected.

Three different regions were calculated separately: Austria, Germany, and the 27 European countries. For every grid cell and HDD/CDD cluster the population sum was calculated using similar clusters. The additional, second, Austrian data set used a different kind of clustering and a population weight was applied. The climatic condition clustering used for this set is similar to the one used for the HSCD data. This new cluster data set was weighted with the lspop population data set using the conditions of x < 50 inhabitants/km² (= 0) and x > 50 inhabitants/km² (= 1) and intersected with the Austrian community shapes. These population weighted community climatic clusters were then applied to the HDD/CDD data. For every Austrian community a climatic cluster and the corresponding population is now available.

Methodological approaches to assess extreme events[2]

Energy demand and supply services, in particular a potential future renewable energy system, are sensitive to extremes in temperature, wind, and precipitation. These effects on the energy system occur on the local scale but also further downstream of the extreme event which also needs to be taken into account. The definition of extreme events for the energy system heavily depends on the vulnerability of the different energy supply systems and cannot be defined only as meteorological extreme events. Thus, an extreme event in terms of the energy system can be defined as a short term event including increased heating/cooling energy needs or decreased supply of energy due to extreme weather such as strong storms or floodings or a combination of several small scale events. Long term events affecting the energy system in the future can be related to a changed storm track location or longer dry/wet spells.

In this work package, methodological approaches to deal with this question were identified and developed for further application in the project (and beyond).

Three different methods can be used to assess extreme events:

- Parametric method: use return period analyses to determine which events can be expected to occur within a defined amount of time (5y,..), peak over threshold methods where cluster of exceedances of observations exceeding a threshold are defined as events, and a block maxima method where an extreme value distribution is used for the return values.
- Non-parametric method: here, indices as the frequency, the intensity, a combination relating the aforementioned indices, quantiles, medians, for single parameters but also for a combination of meteorological parameters etc. are used.
- Impact-related method: defines extreme events using their impact on the society in terms of costs of protection against extreme events and of loss due to the occurrence of certain extreme events.

Changes in the extreme events are caused by three main reasons: (1) change of the mean, (2) change of the variance, and (3) change of the mean and the variance. A quantification of the extreme events is crucial. First, critical situations for the energy system are defined, also in terms of climatic conditions. Then, the probability of climatic conditions is determined and an evaluation of these probabilities is carried out using the BIAS corrected climate scenarios. Empirical statistics as e.g. quantiles or the interquantile range of the meteorological parameters and possible their combinations which have caused the extreme event are calculated for different time slices of 30 years: 1951 – 1980, 1981 – 2010, 2011 – 2040, 2036 – 2065, and 2051 – 2080. Events evaluated will not go beyond the five year event margin. Furthermore, a comparison of the future time slice results to the statistics derived from the climate scenario control runs is carried out. In this step the results of the empirical statistics of the future time slices will be compared to their occurrence in the control period. Results of the probability of the climate conditions can then be applied to the energy system.

Resilience concept and application to the energy sector[3]

Originally resilience was first used in medical and material sciences, related to the ability to recover from physical stress or strain, respectively. To date, the most common notations of “traditional” resilience in material sciences occurs as the modulus of resilience, computed as the area under the elastic curve-segment of a stress-strain curve.

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[2] The different options for assessing extreme events and the developed methodologies were described and discussed in the review document for the first reviewing workshop of the project PRESENCE (Matzenberger J., Kranzl, L., Totschnig, G., Redl, C., Schicker I., Formayer H., Gorgas T. Extreme Events and Resilience Concept. Working Paper for the First Review-Workshop on 3rd September 2012).
The results for for assessing the probability of extreme events in the electricity sector are described below (2.2.4.6) and are summarized in the working document “Totschnig G., Mueller A., Kranzl L., Hummel M., Hirner R., Nachtnebel H.-P., Stanzel P., Schicker I., Formayer H. 2014. Climate change impact on the electricity sector: the example of Austria.”

[3] The concepts and possible approaches for assessing resilience of energy systems were described and discussed in the review document for the first reviewing workshop (Matzenberger J., Kranzl, L., Totschnig, G., Redl, C., Schicker I., Formayer H., Gorgas T. Extreme Events and Resilience Concept. Working Paper for the First Review-Workshop on 3rd September 2012).
The energy crises and shocks to be tested in the frame of PRESENCE were described and discussed in the review document for the first reviewing workshop (Matzenberger J., Kranzl, L., Totschnig, G., Redl, C., Schicker I., Formayer H., Gorgas T. Extreme Events and Resilience Concept. Working Paper for the First Review-Workshop on 3rd September 2012).

More recently a wider concept of resilience has emerged. It has been taken up by Holling (1973) to describe ecosystems and has since then increasingly been used in other contexts, such as in social sciences to describe community or individual resilience. The concept of resilience has been refined from its original use in material sciences, first taken up in ecosystem sciences, and is now used in a wide range of scientific disciplines. It can be rendered as a "collection of ideas about how to interpret complex systems" (Wilson 2012).

A definition of resilience that can be used for energy systems (used by Coaffe 2008, Rose 2009) is "the ability of an entity or system to maintain function (e.g. continue producing) when shocked" (Rose 2007) With respect to above defined properties of resilient energy systems, one important shortcoming of this definition should be addressed: i.e. to take into account in an integrative approach not only the maintenance of function to external stress or disaster but also the possibility (probability) to adapt to opportunities or innovation. As resistance may not only act as an opposing force, but may also act as a catalyst and lead to a tipping point of changing behavior, a more resilient system is also enabled to adapt to newly emerging patterns. From an engineering point of view this might be interpreted as the ability to adapt to technological change or innovation; whereas the traditional notion of engineering resilience would assume the system to return to pre-defined steady state after disturbance. Hence, also the time span or response time of energy systems is of importance. For example, even traditional energy systems evolved and have been reorganised given enough time. However, modern energy systems may be able within their duty cycle, not only return to service but also incorporate adaptability and hence could re-configure. Energy is inextricably linked to the social characteristics of a context. Thus, change in any aspect of one will have either a positive or negative implication on the other. In accordance with O'Brien and Hope (2010) resilience of energy systems is framed as: ''*A resilient energy system exhibits adaptive capacity to cope with and respond to disruptions by minimising vulnerabilities and exploiting beneficial opportunities through socio-technical co-evolution. It is characterized by the knowledge, skills and learning capacity of stakeholders to use indigenous resources for energy service deliver*y.''

Resilience is very much interlinked with adaptive capacity and vulnerability. It has been argued for resilience as the overarching concept, making it a function of adaptive capacity and vulnerability (Matzenberger, 2013). Increasing adaptability or reducing vulnerability causes higher system resilience (see also the definition from IPCC SRREN above). It is thus proposed that resilience measurement could take into account these two dimensions of indicators (see also Matzenberger 2013). This concept is based on the development of indicators. Other options include the modelling of shocks on energy systems and evaluating the impact of these shocks in terms of costs, loss of system functions and period until the full functioning is regained after the shock.

Based on the discussions and inputs during the review workshops, we decided to select a concept based on testing the resilience of energy systems by introducing shocks to energy system models (see below).

Hydrology and cooling water availability[4]

Due to the high relevance of hydropower generation for the Austrian electricity sector, the impact of climate change on river runoff and resulting hydropower generation was a key aspect of this project. The objective of the corresponding work packages was to assess the expected impact of climate change on the terrestrial water cycle and the resulting changes in river runoff in Austria.

The main tool to achieve this objective is a detailed spatio-temporal hydrological model for Austria. The model is a continuous conceptual water balance model that considers the relevant hydrological processes: interception, snow accumulation and snow melt, glacier melt, evaporation, storage in the soil, runoff separation into fast and slow components. The spatial resolution is based on a 1x1km grid and 188 Austrian catchments are represented explicitly. Simulation results are calculated for monthly time steps. After calibration for a period in the 20th century, the model is run with climate change scenario input data for the 21st century. Climate scenarios provided by three Regional Climate Models (RCMs) – REMO, RegCM3 and Aladin, based on A1B greenhouse gas emission scenarios – were prepared and corrected in WP 1 (Climate models and scenarios). For the hydrological simulations, REMO-UBA version of REMO is used and results from A2 and B1 emission scenarios are applied in addition to A1B data.

Trends in runoff in the resulting hydrological scenarios are analysed, with special focus on impacts on hydropower production and cooling water availability. The simulated time series of runoff are also used as input in subsequent detailed modeling of hydropower production in an energy model based on an inventory of all major

[4] The results of this work are described in detail in the report Nachtnebel H.P., Stanzel P., Hernegger M. 2013, Contributions to Work packages 4 – Hydrology and hydropower, 5 – Availability of cooling water for thermal power plants and the industry.

hydropower stations in WP 7 (The impact of climate change on a low-carbon electricity supply system). In addition to the detailed investigation of expected changes in hydrology and hydropower production in Austria, external factors related to hydropower production in Europe are investigated and summarized.

Results

Spatial patterns of changes in runoff in Austria induced by climate change differ according to the applied climate model. REMO-UBA and RegCM3, which are driven by the same GCM (ECHAM5), lead to hydrological scenarios with decreasing runoff in the south and west of Austria and small increases in the north-east. Aladin-Arpege scenarios result in decreasing runoff all over Austria, but more pronounced in the south and west.

Simulated runoff time series are analysed in detail for four rivers. Along the large alpine rivers Enns, Mur and Drau, several run-of-river hydropower plants are located and substantial discharge from thermal power plants and industry is expected. Results from the river Ager are analysed to investigate the situation for smaller rivers with less alpine influence.

In simulations with the REMO-UBA model, mean runoff differs according to the greenhouse gas emission scenario. The A2 scenario, with higher precipitation, leads to higher runoff than the drier A1B scenario. Both scenarios show a decreasing trend within the 21st century. Similar trends are simulated by the other two models (both only with A1B scenarios). Stronger decreases are projected by Aladin-Arpege. The expected changes are very similar along the entire Austrian reaches of Enns, Mur and Drau. The simulated decrease in mean runoff until the period of 2061-2090 is around 10%, which does not indicate general shortages of cooling water, but results in an overall reduction of hydropower production.

Seasonal changes are simulated consistently between models, scenarios and basins, with runoff increases in winter and spring and decreases in summer and fall. The summer runoff decrease is more severe in the scenario A1B. Increases in winter runoff are less pronounced in the simulations with Aladin-Arpege. With earlier and less snow melt, the peak of seasonal runoff in Enns, Mur and Drau is expected to be lower and occur one month earlier. This change is more pronounced in alpine upstream catchments with stronger influence of snow processes. For the Ager, the projections for changes in the seasonal peak in early spring differ between the models. The trend towards a less pronounced runoff seasonality in all rivers with Alpine influence has positive effects for hydropower production, as the divergence between production and demand diminishes.

In the rivers Enns, Mur and Drau, low flow occurs mainly in winter. Increasing winter runoff therefore leads to increasing low flow runoff. This increase in low flow discharge is projected consistently by RegCM3 and in all REMO-UBA scenarios. Simulations with Aladin-Arpege do not show relevant changes in low flow runoff for these three rivers. For the Ager, all models expect significant reductions in low flow runoff.

Low flow periods are expected to partly shift to earlier months, from winter to autumn for Enns, Mur and Drau, from autumn to summer for the Ager. For the Ager and similar rivers, the more frequent occurrence of low flow periods in summer together with increasing water temperature can have negative effects for cooling water use. Concerning the duration of low flow periods, no clear conclusions can be drawn from the conducted analyses.

These results have been taken as a basis for investigating the impact of climate change of cooling water availability for the Austrian manufacturing industry. Industry uses water for cleaning, heating and cooling, to generate steam, to transport dissolvent substances or particles, as a raw material, as a solvent and as a constituent part of the product itself. In Austria water is mainly used in the sectors iron and steel, chemical industry and pulp and paper production together accounting for over 90% of the total industrial water demand. The major part of the Austrian industrial water demand is supplied by the Danube basin, followed by the Mur and Drau basins. As already stated above for the rivers Mur and Drau the hydrological simulations do not show a risk for the cooling water availability, which accounts for the major part of industrial water demand in these regions. However, for industrial plants demanding large amounts of water for direct process use the calculated decrease of groundwater recharge in the Mur basin could potentially lead to supply difficulties in this region. In the southeastern region of Austria in the basins of the Raab, Rabnitz and Leitha only a minor part of the Austrian industry is located, however demanding essential amounts of groundwater for process use. The simulations of the groundwater recharge for these rivers only in case of the Raab basin show a significant decrease for all regional climate models. For the other two river basins even an increase in groundwater recharge is possible according to the hydrological simulations. The analyses of the effects of climate change on the industrial water demand in Austria do not indicate a significant scarcity of process nor cooling water for most parts of the Austrian industry. However, the effects of fundamental changes in the structure of industry due to climate change mitigation have not been investigated in this study.

Inflow into alpine reservoirs is assessed for three reservoir systems. While inflow in **s**ummer decreases under climate change conditions, spring inflow increases. The peak in monthly runoff is less pronounced and occurs one month earlier under climate change compared to the reference climate period. The main cause for this is that snow melt starts earlier, which leads to higher snow melt runoff in spring, and also ends earlier, which leads to less snow melt contributions in summer. More ice melt runoff from glacierized areas in summer months partly compensates the decreasing snow melt contributions. Towards the end of the 21st century, ice melt runoff decreases again, due to the advanced loss of glacier ice volumes. The projected changes in high alpine areas are triggered by temperature change to a high extent and are therefore subject to less uncertainty than changes driven by precipitation changes. Especially glacier development, however, is also highly sensitive to the (smaller) differences in temperature projections.

A literature review of possible changes in runoff and hydropower production in Europe shows expected increases in northern and north-eastern Europe, especially in Scandinavia, the Baltic countries and Russia. Decreases are expected in southern and central Europe, notably in Spain, the Balkan countries, Turkey and Ukraine. A more balanced seasonal course of runoff and power production is generally expected, with streamflow increasing in winter and decreasing in summer. In southern Europe, as e.g. in the Ebro basin, general decreases of streamflow throughout the year can be expected. Seasonal changes are more pronounced in regions with stronger influence of snow processes, as in the Alps or in northern Europe. In these areas, annual peaks of runoff are projected to decrease and to occur one to two months earlier. Low flow runoff, which mainly occurs in winter in snow dominated regions, is expected to rise. For regions with low flow in summer a decrease of low flow runoff is expected.

In Austria as well as in an overall view of Europe, it is expected that climate change might lead to a moderate decrease in hydro power generation. As the production is rather concentrated in mountainous areas with high influence of snow processes, the decrease in annual production is related with favorable changes towards less pronounced runoff seasonality. In these regions, cooling water availability is generally not at risk. In lowland areas, however, low flow periods with less runoff are expected to occur more frequently in summer. Together with increasing water temperature this can increase the vulnerability to cooling water shortages.

Heating and cooling[5]

Heating and cooling energy demand is directly related to weather and climatic conditions. Thus, the analysis of climate sensitivity of heating and cooling of buildings and related energy demand was a major element of the project PRESENCE. The objective of the related work package was to assess the impact of different climate change scenarios on heating and cooling energy demand and to investigate the effect of various adaptation measures, first of all thermal building renovation and low-carbon heating and cooling technologies.

Building stock description and heating and cooling energy demand and load profiles on building level

The following properties where chosen to describe a building and its construction: Location, type of roof, cellar, gross floor area, gross building volume, number of storages, proportion of window area, year of construction, year of last big renovation, type of shading, type of construction.

The model for the calculation of the supply, distribution and storage losses of the heating and cooling system is based on energy expenditure factors which depend on the following inputs: ventilation system, heating system, hot water system, year of the construction of the heating/hot water system, cooling system, year of the construction of the cooling system, lighting system.

The usage considers the household / operational electricity demand and the presents of the users itself. Because of the big influence of internal loads, like electricity demand for household appliances and users themselves, on the energy demand for heating and cooling it's important to have a high quality input of the usage to your simulation. The electricity demands of different building types and usages in the model are based on synthetic

[5] Preliminary results of this WP have been documented in "Kranzl, L., Matzenberger J.,Totschnig, G., Toleikyte, A., Schicker I., Formayer H., Gorgas T., Stanzel P., Nachtnebel H. Bednar T., Gladt M., Neusser M., 2013, Modelling climate change impact on energy systems. Working Paper for the Second Review-Workshop on 19th June 2013".
Based on the results of this review workshops, the work has been revised in the working paper "Mueller A., Kranzl L., Hummel M., Toleikyte A., Neusser M., Bednar T., Schicker I., Formayer H., 2013. Climate change impact on heating and cooling: the example of Austria".
The literature review on climate sensitivity of heating and cooling in selected other European countries is documented in "Toleikyte A., Hummel M., Kranzl L., 2013, Working paper: Discussion of climate sensitive scenarios for the heating and cooling sectors in selected European countries"

load profiles from EWE NETZ GmbH which are based on both synthetic standard load profiles of the Association of Energy and Water Industries (BDEW) and own synthetic load profiles.

Figure 5 shows the method for calculating the Energy demand of electricity and other energy sources on an hourly basis. According to the Austrian standard ÖNORM EN ISO 13790:2008 a monthly balance method with thermal coupled zones is implemented to estimate the Energy demand on a monthly basis.

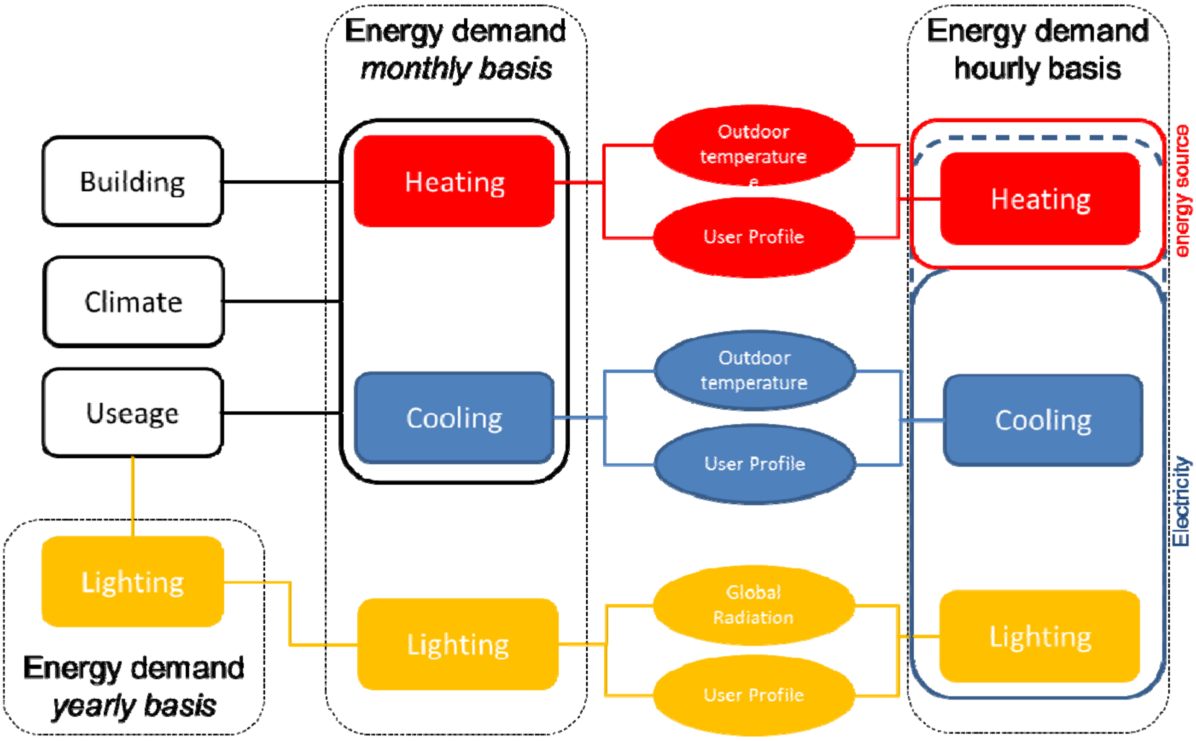

Figure 5. System diagram calculation of heating and cooling energy needs

Climate sensitive scenarios of heating and cooling energy demand in Austria (EEG)

The basic methodology for deriving climate sensitive scenarios for heating and cooling energy demand in Austria is the use of the bottom-up model Invert/EE-Lab for the heating and cooling energy demand. This model within PRESENCE has been extended in various ways in the project PRESENCE. The two most important issues are: First, climate regions (see WP1) were implemented and a detailed calibration process was carried out on level of the nine Bundesländer. Second, we developed a special module for simulating the diffusion of air conditioning. This module uses data on operative indoor temperature for different building classes from the building physics model. The building physics model assesses the energy needs and delivered energy for heating, cooling and domestic hot water for a specific building under given climate conditions, associated load profiles on an hourly basis as well as analyzing indoor room temperatures for the case that non active space cooling is applied (based on the model framework explained above). The method for the estimation of the energy demand for heating, cooling and lighting is based on an enhanced multi-zone monthly balance calculation with thermal coupling between the zones according to the European standard EN ISO 13790:2008. To estimate the energy needs on an hourly basis a weight for every hour is determined with the temperature difference between the outdoor temperature and the heating threshold temperature. A multiplication of the computed weights and the monthly energy demand gives the energy needs for heating, cooling in the considered hour. For the domestic hot water load curve, daily user profiles are used. Another result this model delivers is the number of days under certain climate conditions, for which the average daily indoor temperature exceeds certain threshold temperatures. Theses parameters were used to get a view on the diffusion of air conditioning systems into the market and the Austrian built environment and how it is affected by the change of the outdoor temperature. The approach here is to perform dynamic simulations of typical variations of individual rooms and extract the maximum indoor operative temperatures.

Based on the presented model and data framework we developed a set of scenarios until 2080: various climate scenarios were combined with three scenarios of the energy system, depending on the level of activities in promoting energy efficiency and renewables.

The scenarios we have calculated can be clustered by two dimensions: first the impact on the energy consumption by non-climate change related variables, such as retrofitting rate and quality or the share of renewable energy carriers used for providing the required heat. With respect to this dimension, three policy scenarios have been developed. The first policy scenario, the grey scenario, represents a business-as-usual scenario with no particular focus on renewable energy carriers and ambitious effort for high quality building retrofitting programs. This scenario applies the policy settings of the "with existing measures (WEM 2013)" scenario (Müller and Kranzl, 2013). The second policy scenario group, the green scenario, sets a focus on renewable energy carriers, but no additional focus on building refurbishments compared to the grey scenarios. Finally, compared to the green scenarios in the blue policy scenarios, an additional effort on refurbishments is set. In the blue scenario, the policy settings of the "with additional measures (WAM 2013)" scenario (Müller and Kranzl, 2013) are applied .

And second, the impact of climate change, by applying the average historical climate for the period 1981 until 2000 as well as the results of three different climate models: the regional ALADIN model (CNRM-ALADIN), driven by the global ARPEGE model and the two RCM: RegCM3 (ICTP-RegCM3) and REMO (MPI-REMO) driven by the GCM ECHAM5. In total, this leads to 12 scenarios.

Depending on the applied scenario results of the RCM descripted above, the energy needs for heating decrease until 2080 by 20 % to 25 % compared to the EOBS 1981-2010 data. Cooling is more sensitive to the climate signal. In our scenarios, the cooling needs increase by 60 % to 100 % in 2080, again compared against the scenarios using constant climate signal. Although, the policy scenario setting have an impact on the absolute energy needs and demand numbers, they do not significantly change the relation between constant and changing climate. Climate change is not just expected for future periods, but has been already observed in the past (see (Haylock et al. 2008) EOBS data for the period 1951-1980 against the period 1981-2010), Müller et al., 2013, heating degree days for the period 1990-2012). Based on the results of the applied results from the RCM and the EOBS 1981-2010 data, the impact of the already occurred changing climate for a recent decade (1995 – 2005) has been estimated. The results indicate, that the energy needs for heating decreased by about 2.5 %, while the cooling needs increased by 6 %.

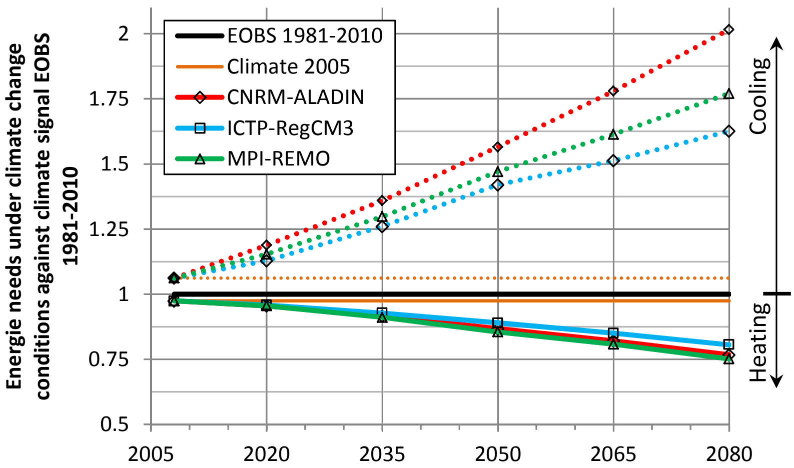

Figure 6. Impact of the change climate signal on the energy needs for heating and cooling of the Austrian built environment.

Currently, the annual final energy demand for heating, DHW and cooling in Austria is about 100 TWh. Roughly half of it is delivered by fossil energy carriers, about 40 % by renewable energy and district heat. In our scenarios with constant climate conditions, the final energy demand, associated with the heat supply (space heating and DHW), decreases by 25% (Grey and Green scenario) and 40 % (Blue scenario) until 2050. The share of fossil energy carriers decrease by 60 % (Grey scenario) to 80 % (Blue scenario) within the next 4 decades. Although there is still a potential for reducing it further, this share is already at a level of saturation. It becomes also clear that the policy setting assumptions used for these scenarios are not sufficient to trigger a strong role of local RES heat. The average impact of climate change scenarios on the final energy demand for heating and DHW is even less than the effect on the energy needs for this area. In average the effect amounts to 14 %.

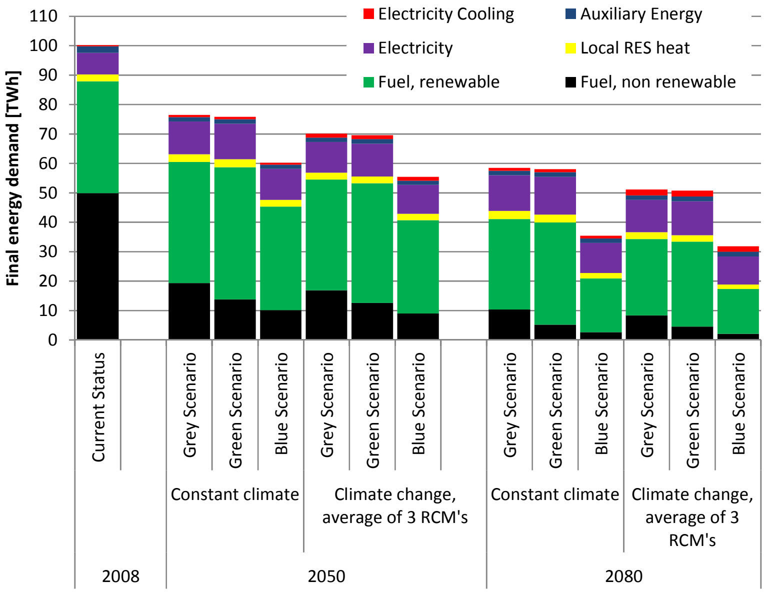

Figure 7. Final energy demand per scenario cluster.

Although, the final energy demand for space cooling is increasing rapidly in our scenarios, it is still in 2080 much lower than the final energy demand (and delivered energy) for space heating and domestic hot water. Starting with an electricity consumption for space cooling of about 350 GWh, the delivered electricity increases in our scenarios to about 940 to 980 GWh under constant climate conditions until 2080, and 1890 to 1990 GWh in 2080, if changing climate conditions are applied.

We want to emphasize that – despite of our new and more comprehensive approach – there are high uncertainties regarding the future market penetration of AC in different building classes. Even more, there are also considerable uncertainties regarding the current electricity consumption for space cooling.

Despite of the moderate electricity consumption levels, resulting peak loads due to cooling are very high due to a high simultaneity of demand and low full-load hours of cooling devices. This will play a major role for the investigation of the electricity sector below.

Discussion of climate sensitivity of heating and cooling in selected other European countries

Two types of the approaches were investigated in this literature review: top-down and bottom-up. Four papers which use a bottom-up approach and six papers which use a top-down approach were investigated. The analysis covers the following countries: Switzerland, Germany, Slovenia, Greece, Spain, Italy, EU-15, EU-17, Finland, Netherland, France and Spain.

All the investigated papers which use a bottom-up approach show the identical future trend: decrease of heating energy demand in winter and increase of cooling energy demand in summer. In Germany decreases heating energy demand of around 81% occurs between 2010 and 2060 under scenario “3˚C warming and 3% retrofit rate and around 56% under the scenario “1˚C warming, 1% retrofit rate”. Cooling energy demand in the scenario “high energy demand” increases by 235% between 2010 and 2060. The results of residential buildings in Switzerland show that heating energy demand goes down by 8-13% in the climate scenario C (+1 ˚C temperature) and by 33-44% in the scenario D (+4.4 ˚C temperature). The cooling energy demand increases by 365-1050% in scenario D (+4.4 ˚C temperature), while in reference scenario energy demand increases by 223-457%. The results for Greece show energy reduction of heating energy of 22.4% for scenario A1B (2041-2050). A significant energy reduction of almost 42% can be achieved regarding scenario A2 (2091-2100). For scenario A1B (2041-2050) an increase of 83% and for scenario A1B (2091-2100) of 167% is estimated. The main factors of these trends in all investigated countries is the increase in temperature. The decrease in heating energy demand is mainly related to technical building standards in the future in all considered countries. The increase in cooling energy demand is also related to building standards, although the standards lead to differences between south and middle European countries, e.g. in Switzerland buildings with high insulation levels correlate to higher cooling energy demand, while in Greece passive residences correlate to lower cooling energy consumption. Despite the significant increase of cooling energy consumption in all countries, cooling energy consumption is still lower than heating energy consumption.

The results made in the papers which use a top-down approach show similar trends compared to papers mentioned above. The papers, however, consider the macroeconomic indicators (gross domestic product (GDP), prices), climatic conditions and investigate only electricity demand. The increase in cooling energy demand is related to the increase in comfort standards and greater use trend of air-conditioning and its market penetration. The steady increase in summer electricity demand is estimated to be greatest in southern European countries in recent years. A change in air temperature becomes a significant role especially in the urban areas, where this trend is strengthened by the urban heat island effect. The results made for 16 continental European countries show the ratio between absolute decrease in heating and absolute increase in cooling electricity demand of 2:1 and 6:1depending on the climatic scenarios.

Low carbon electricity system[6]

Electricity supply is affected by climate change, in particular in case of renewable electricity generation. On the other hand, heating and cooling and related electricity consumption (as far as electricity based heating systems are applied) are climate sensitive. Therefore, the relevant aspects have been investigated in an integrated optimization approach of the Austrian (and due to the interlinkages with the central European electricity market also German) electricity sector. The objective of the related work package was to assess the impact of climate change on the Austrian (and German) electricity system by using a dynamical technology rich optimization model, working on an hourly basis. The results provide the basis for deriving policy recommendations for the strategic planning of a robust power system, which is resilient to climate change and energy crises. In order to achieve this objective, the model HiREPS has been enhanced and applied in this work package. HiREPS is a dynamical simulation and optimization model of the electricity and heating system. The focus of the model is to analyze the integration of fluctuating renewable electricity generation into the power system - by specifically including endogenously the important system constraints[7].

In Figure 8 the mean monthly power generation for all 3 climate models (REMO, RegCM3, Aladin) is depicted for the control period 1971 – 1989 and the A1B-scenario period 2051 – 2080. One can observe that little change is simulated by the climate models for photovoltaic and wind power generation.

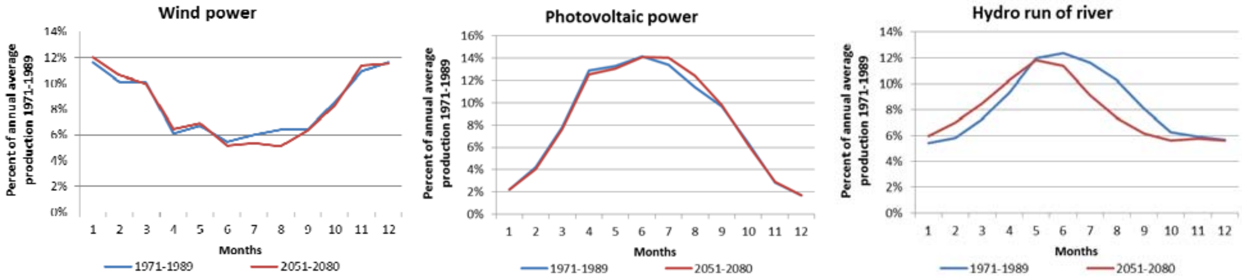

Figure 8: Mean monthly electricity generation for the control period 1971 – 1989 and the A1B-scenario period 2051 – 2080 given as mean of the 3 climate models REMO-UBA, RegCM3 und Aladin-Arpege. The values are normalized in regard to the mean annual generation in the control period.

The mean annual run of river hydro power production for Austria and Germany decreases by 5.5% in 2051 – 2080 period and also a clear shift from summer to spring is observable.

[6] The results of this work package are documented in the working paper of this project: "Totschnig G., Mueller A., Kranzl L., Hummel M., Hirner R., Nachtnebel H.-P., Stanzel P., Schicker I., Formayer H. 2014. Climate change impact on the electricity sector: the example of Austria."

[7] A more detailed documentation and description of the model is given in: Totschnig, G., Kann, A., Truhetz, H., Pfleger, M., Ottendörfer, W., Schauer, G., 2013. AutRES100 – Hochauflösende Modellierung des Stromsystems bei hohem erneuerbaren Anteil – Richtung 100% Erneuerbare in Österreich. Endbericht im Rahmen des Programms Neue Energie 2020. Wien. (http://eeg.tuwien.ac.at/AutRES100/Endbericht.pdf)

The following paragraph gives a short description of the scenario assumptions for the electricity sector:

Green scenario: Focus on renewable energies, a strict CO_2 emission limit for the heating and electricity system of 75 million ton CO2, the electricity demand (without cooling and power to heat) is assumed to grow by 22%[[8]] to 752 TWh for Austria and Germany.

Blue scenario: Focus on renewable energies and energy efficiency, a 43 million ton CO_2 emission limit for the heating and electricity system, the electricity demand(without cooling and power to heat) is assumed to decrease by 25% compared to 2010 to 462 TWh in 2050 for Austria and Germany.

Grey scenario: 41 Euro/tCO2 carbon tax for all heating and electricity generation technologies, the installed capacities of photovoltaic and wind power are fixed at the 2020 targets (see Table 1), the electricity demand (without cooling and power to heat) is assumed to grow by 22% to 752 TWh for Austria and Germany.

Table 1: 2020 Targets for Austria and Germany.

	Wind Onshore GW	Solar-Photovoltaik GW	Quelle
Österreich	3	1.2	Ökostromgesetz 2012 [[9]]
Deutschland	36	52	NREAP DE[[10]]

In the following the results of the HiRPES model runs are presented for the different scenarios and sensitivity cases. The basic assumption in all scenarios (Blue, Green, Grey, see explanation above in the sector heating and cooling) is, that the energy system infrastructure is optimized for the average future year, but that the secured electricity and heating capacities are chosen to be sufficient so that for all 3 climate model runs and for all years 2051-2080 the energy provision is secured.

The RegCM3 year 2071 was selected as the most average year compared to the 3 climate model runs (REMO, Aladin, RegCM3) for the simulated years 2051-2080. The selection of the average year was based on 6 parameters: annual wind power generation, annual photovoltaic power generation, annual hydropower generation, annual heating demand, annual cooling demand and annual residual load. For the simulation of a constant climate the year REMO 1976 was selected as the most average regarding these 6 parameters for the constant climate runs with REMO, Aladin, RegCM3 for the years 1971-1989.

In Table 2 electricity generation mix 2050 is shown for the green scenario for the average year RegCM3 2071. This mix is a result of the HiREPS optimization for the year RegCM3 2071 but it also includes the required secured capacities for the most extreme years of 2051-2080 simulated by all 3 climate models REMO, Aladin, RegCM3.

8 Primes-Referenzszenario 2011

9 Das Ökostromgesetz 2012 (ÖSG 2012), BGBl. I Nr. 75/2011 http://www.ris.bka.gv.at/Dokumente/BgblAuth/BGBLA_2012_I_11/BGBLA_2012_I_11.pdf

10 National renewable energy action plans(NREAP): http://ec.europa.eu/energy/renewables/action_plan_en.htm

Table 2: Power generation in the green scenario 2050 for Austria and Germany

	Installierte Leistung [GW]	Jahreserzeugung [TWh]	Volllaststunden
Simple cycle gasturbine	59	2.4	41
Gas combined Cycle	83	188	2264
Solid biomass	1.2	5.6	4668
Biogas	0.8	1.8	2395
Waste funace	1.3	9.0	6903
Hydropower	36	59	
Wind	286	536	1871
Photovoltaik	180	159	882
Gesamte Stromerzeugung:		960.0	

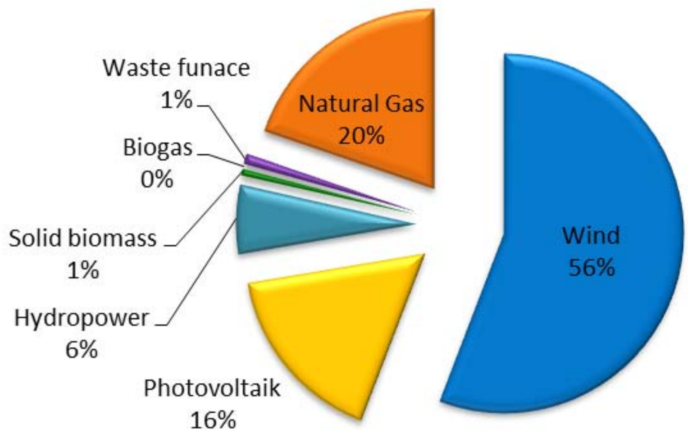

Figure 9: Electricity generation mix for the green szenario 2050 for an average weather year

In the year 2011 the specific CO2 Emissions for electiticty generation in Austria and Germany was 518 gCO2/kWh. In the green scenario this emissions are reduced by 87% to 70 gCO2/kWh. The average electricity generation costs in this scenario are 76 Euro/MWh. This is only 8% higher costs than in the fossil dominated grey scenario with average electricity generation costs of 71 Euro/MWh and specific CO2 Emissions for electiticty generation in Austria and Germany of 394 gCO2/kWh (see also Table 3).

	Specific CO2 emissions of electricity generation	Average electricity generation costs
Green scenario average year	70 gCO_2/kWh	76.2 Euro/MWh

From Table 2 one can see that the gas combined cycle power plants have only 2300 full load hours per year. In order to ensure the provision of secured capacity at these low operating hours some kind of capacity payment mechanism is required. One popular suggested mechanism is to oblige the balance groups(German term: Bilanz Gruppen) to provide 100% of the needed secured capacity for their customers. The HiREPS simulation shows that required capacity payments to ensure sufficient secured electricity generation capacity are 48€/kW per year. For the 163GW required secured capacity in the green scenario this capacity payments amount to 8% of the total annual costs of electricity and heat provision (or 11% of the electricity generation costs). So the costs for ensuring a secured capacity are not prohibitive expensive. Figure 10 shows the results of the optimization with the HiREPS model for the provision of the secured capacity for the green scenario (see also Table 2).

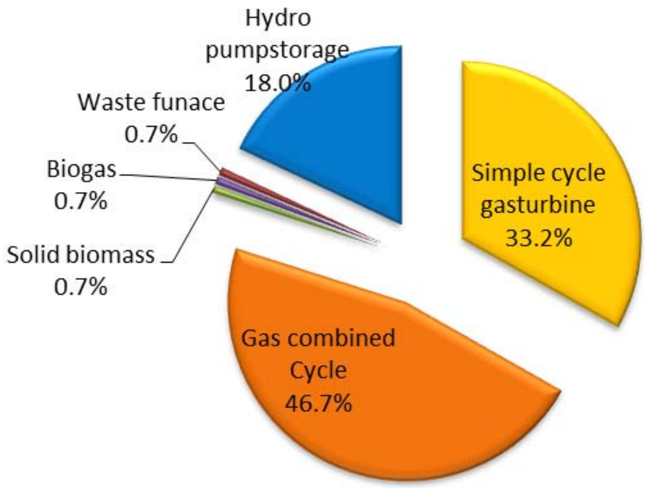

Figure 10: Provision of secured capacity in the green scenario. In total 163 GW.

The year with the highest demand for secured capacity was in all three scenarios (Blue, Green, Grey) the year 2077 of REMO (see Figure 11). In this year a very high cooling demand causes a very large residual load. In Figure 11 the highest residual load for the Green scenario is obtained on 06.08.2077 for the REMO run at 6pm (CET). In Figure 12 it can be seen that the photovoltaic generation cannot completely compensate for the cooling demand, because the cooling demand extends into the night hours. So, in all three szenarios (Blue, Green, Grey) the maximum required secured electricity generation capacity is determined by the cooling demand in the REMO run at 06.08.2077. The maximum required secured capacity is defined as the maximum overall hours of the year of electricity demand + cooling electricity demand + heat pump electricity demand – photovoltaic generation. Wind power and run of river hydropower generation are not included in the formula since there is no correlation between wind power (and run of river hydropower generation) with high cooling demand.

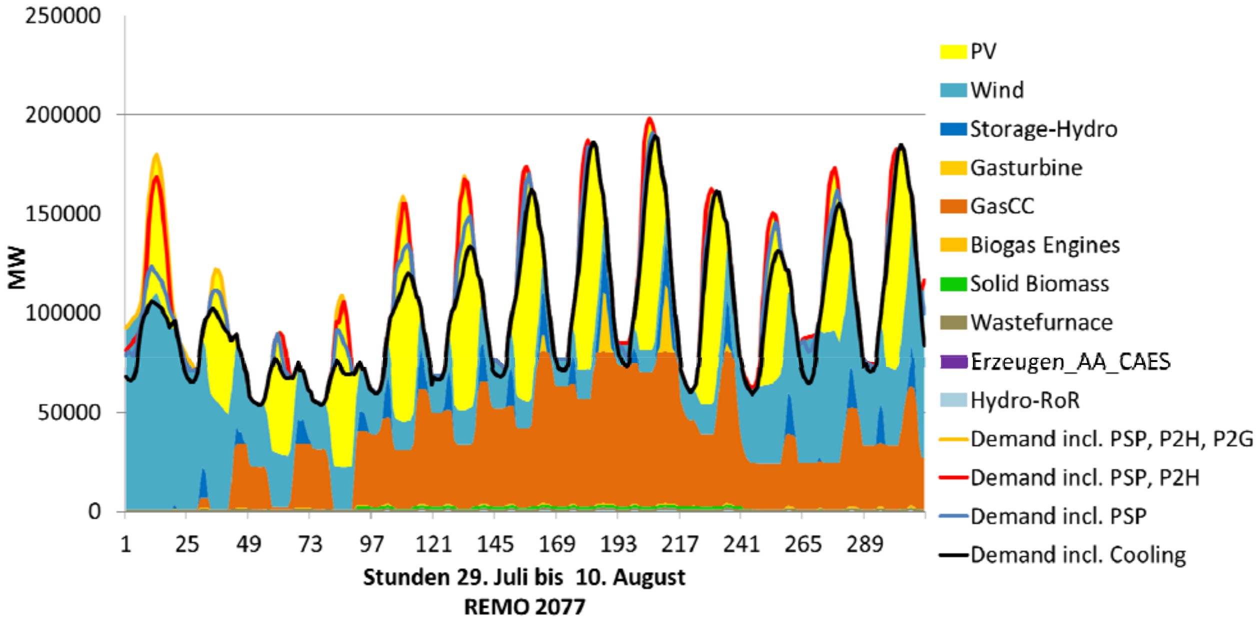

Figure 11. Electricity demand and generation mix under the conditions of the green scenario in summer 2077, REMO climate data.

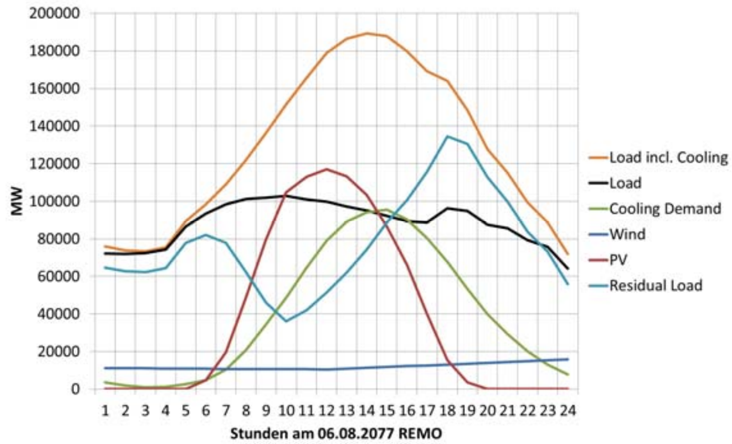

Figure 12. Maximum residual load (and its components) on 06.08.2077 in the green scenario, REMO climate data.

The required secured capacity for the different scenarios is listed in Table 3. The years with the most expensive energy generation are the years with very high annual average residual loads. I.e. years with low wind power, hydropower and photovoltaic power generation but high demand. In these years thermal power plants have to supply the missing renewable generation and this causes extra fuel and operation costs. The years with the most expensive energy generation are the year 2077 RegCM3 for the blue scenario, the year 2054 RegCM3 for the green scenario and the year 2070 ARPEGE for the grey scenario. This is not the same year for all scenarios, since the installed PV and Wind capacities and also the electricity, heating and cooling demand differ between the scenarios. From Table 3 it can be seen that for the blue and the green scenario the electricity generation costs for these most expensive years are 15-17% above the average year. For the Grey scenario the electricity generation cost increase only by 8%. But the electricity generation cost also decrease stronger for the Blue and Green scenarios for years with above average renewable electricity generation. In terms of total cost of Electricity and Heat generation the difference between the scenarios is less.

Table 3. Scenario comparison in terms of costs, emissions, required secured capacity and wind and PV installations.

	Total Cost Electricity and Heat [Billion Euro]	Electricity Generation Costs [Euro/MWh]	Emission Factor [gCO2/kWh]	CO2 Emissions [Mio t/CO2]	Required Secured Capacity [GW]	Wind [GW]	PV [GW]
Blue Average Year	57.3	79.2	64	43			
Blue most expensive Year	63.5	90.7	116	71	126	173	83
% Diff Expensive-Average Year	11%	15%	82%	66%			
Blue Av. Year Cooling Dem. 2080	59.8	83.4	63	43	142	173	91
Blue after 1stStep assuming ConstantClimate	57.4	79.5	64	43	126	178	79
% Cost of 1st Step	0.2%	0.4%					
Green Average Year	93.6	76.2	70	75			
Green most expensive Year	100.9	89.5	105	108	163	286	180
% Diff Expensive-Average Year	8%	17%	50%	44%			
Green Av. Year Cooling Dem. 2080	95.6	79.0	70	75	197	280	193
Green after 1stStep assuming ConstantClimate	93.7	76.7	70	75	163	290	176
% Cost of 1st Step	0.1%	0.7%					
Grey Average Year	81.0	70.8	394	359			
Grey most expensive Year	86.5	76.8	426	383	179	39	53
% Diff Expensive-Average Year	7%	8%	8%	7%			
Grey Av. Year Cooling Dem. 2080	84.1	74.1	394	362	228	39	53
Grey after 1stStep assuming ConstantClimate	81.13	70.97	394	359	179	39	53
% Cost of 1st Step	0.1%	0.3%					

Note that costs in this table include costs for heating and electricity generation (investment costs and fuel costs). However, they do not include investment costs for efficiency measures which in particular play a role in the blue scenario.

The total costs listed in Table 3 includes the annual depreciation costs for the complete power and heating system infrastructure, the operation and maintenance costs and the fuel costs. Not included are the electivity and district heating grid infrastructure costs or the costs of energy efficiency measures. In the electricity generation costs the CO_2 price is not included since a CO_2 tax is not a cost, but a regulatory tax used for steering the energy system planning. Overall is the costs effect of the 90 different simulated weather years (3 climate model runs REMO, Aladin, RegCM3 for the years 2051-2080) rather small.

In Table 4 the consequence of a natural gas price shock is analysed. If the natural gas prices would increase from 41€/MWh to 100€/MWh then the annual total costs of electricity and heat generation would increase very strongly in the grey scenario (90% cost increase). In the green and blue scenarios the costs of the gas price shock are reduced to 50% of the grey scenario. The effect of gas price change is therefore much larger than the effect of weather variability between different years or climate scenarios.

Table 4: Consequences of a natural gas price shock for an average weather year.

	Annual extra cost due to natural gas price shock: rise form 41€/MWh to 100€/MWh [Billion Euro]	Annual extra cost due to natural gas price shock in % of annual electricity and heat total costs [%]
Green	37	39%
Blue	21	37%
Grey	72	89%

In order to quantify the importance to include climate change into the energy system planning for each scenario the energy system investments were optimized under the assumption of a constant climate. In a second step the energy system, with an energy infrastructure based on the constant climate assumption, is confronted with the climate simulations and additional new investments can be done to compensate the changing energy demands. The assumption in the first step of a constant climate causes a non-optimal energy infrastructure for the climate change scenarios. From

Table 3 it can be seen, that these costs of imperfect planning are very small(<1%) for all three scenarios.

In Figure 13 the energy system of the green scenario 2050 (i.e. 22.6GW heatpumps, 286GW Wind, 180 GW PV, 13.06 TWh cooling demand DE+AT in an average year) is confronted with different weather simulations by the 3 climate models (Arpege, RegCM3, Remo) and for the constant climate period 1971-1989 and for the climate change scenario period 2051-2080. So the values e.g. for 1971 in Figure 13 represents the energy system of green scenario 2050 subject to the weather simulated by the climate model runs of 1971. Herby we analyse the effect of the changing climate (1971-2100) on the energy system of the green scenario 2050. The increasing temperatures due to climate change are likely to cause an increased penetration of cooling appliances and therefore a stronger than the temperatures growing cooling demand. This is not reflected in Figure 13 since the energy system for this figure is fixed to the green 2050 scenario and only the weather simulations change in Figure 13.

One can see form Figure 13, that the annual maximal residual loads vary from year to year. The hydrological climate simulation data for this project was only available till 2080. Therefore residual loads could be calculated only till 2080. Other data (temperature, wind, PV) was available till 2100. The maximal residual load are either in the summer due to a strong cooling demand or in the winter due to a strong power to heat demand in combination with the general strong winter electricity demand. The maximal value of the residual load does not change much over the simulated period 1971-2080. Exceptional is only the year REMO 2077.

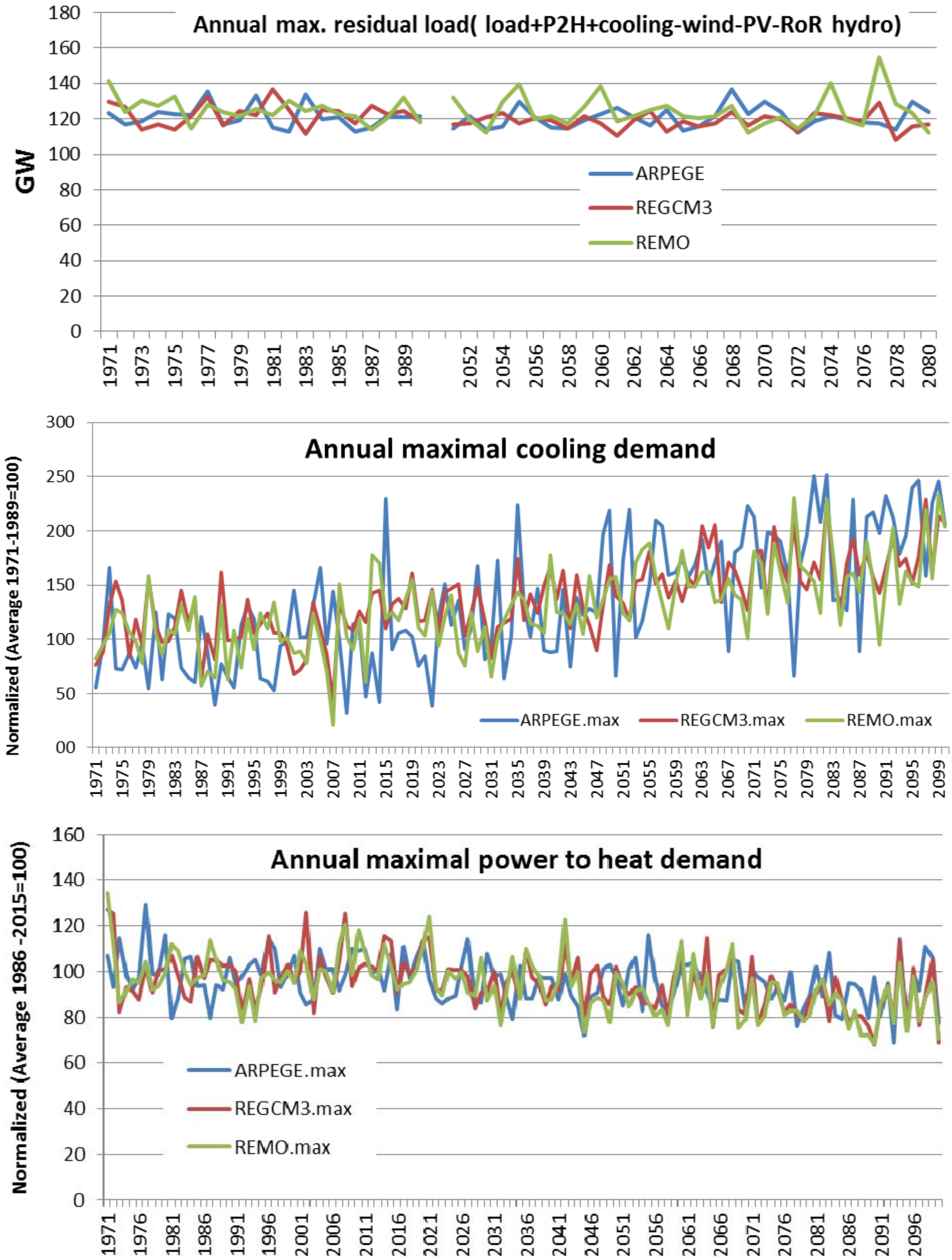

Figure 13: Annual maximal residual load (i.e: load incl. cooling and power to heat minus wind power, minus photovoltaic power, minus hydro run of river) for the green scenario with constant climate weather conditions (1971-1989) and for 2051-2080 simulations.

The reason is explained by the simulated sequence of the annual maximum cooling demand and of the annual maximum power to heat demand. One can clearly see that the annual maximal cooling demand peaks strongly increase at the end of the 21st century(especially after 2077), whereas the annual maximal power to heat demand peaks decrease. For many years the maximum residual loads in the winter are equal to the maximum loads in the summer. Under the given assumptions on the market penetration of electric cooling devices, only in the last quarter of the 21st century(2075-2100) the cooling demand does start to dominate the maximum residual load.

However, crucial questions arise in this context:

1) The assumption of this test was, that the decision makers in the electricity system know right in advance (and with lead times long enough to react) about the increasing peak loads and demandIf this assumption would not hold, this could strongly impact the reliability of the electricity supply in the critical periods. Especially since very high annual maximal residual loads do occur rather irregular with possibly 1-2 decades in between. So, if the high peak loads would not be expected (as it was our assumption in this perfect foresight optimization approach), blackouts or near-blackouts would be a consequence. Related literature suggests that the corresponding costs could be very high compared to the average electricity generation costs. So regarding the cooling demand a monitoring of the installed capacities, simulation of possible extreme weather events and options for a controlled down regulation of cooling devices might be necessary at the end of the 21st century.
2) Our analysis did not include costs and requirements for electricity transmission grid in the different scenarios and under climate change. This has some important implications. E.g. in periods of high PV generation and high cooling loads, we assumed that PV could contribute to cooling electricity demand. However, this assumption would only be justified if (1) PV generation takes place near the demand (or even on-site) or (2) if transmission grids capacities would be available in a sufficient amount. Given the very high peak loads compared to current peak loads, option (2) would require substantial additional grid investments. This question is left for further more detailed research in this respect.

5 Conclusions and recommendations

Our analysis covered the impact of a changing climate on the overall energy system, and in particular on hydropower, energy needs and final energy demand for space heating, domestic hot water supply and space cooling and the resulting effects for the electricity system.

The overall results of the project PRESENCE show that climate change has an impact on energy systems, in particular on hydropower availability and its seasonal and spatial patterns as well as on heating and cooling energy demand and cooling peak loads. However, the changes which have to occur in order to reach climate mitigation targets are much more fundamental. Moreover, effects of potential future energy crises might be much more severe than the impact of climate change on the electricity system in Austria. Thus, the energy system can cope with climate change, if corresponding measures are taken in time. Although the project did not include a full economic assessment of adaptation measures, the results indicate that the additional costs for adapting to climate change are moderate. However, due to the inertia of the system and long lead times for investments early actions are required. If no adaptation takes place, high cooling peak loads could occur potentially leading to a loss of reliability in the electricity supply.

From the hydrological analyses, it turned out that spatial patterns of changes in runoff induced by climate change differ according to the applied climate model. REMO-UBA and RegCM3, which are driven by the same GCM, lead to hydrological scenarios with decreasing runoff in the south and west of Austria and small increases in the north-east. Aladin Arpege scenarios result in decreasing runoff all over Austria, but more pronounced in the south and west.

Seasonal changes are simulated consistently between models, scenarios and basins, with runoff increases in winter and spring and decreases in summer and fall. The summer runoff decrease is more severe in the scenario A1B. Increases in winter runoff are less pronounced in the simulations with Aladin Arpege. With earlier and less snow melt, the peak of seasonal runoff in Enns, Mur and Drau is expected to be lower and occur one month earlier. This change is more pronounced in alpine upstream catchments with stronger influence of snow processes. For the Ager, the projections for changes in the seasonal peak in early spring differ between the models. The trend towards a less pronounced runoff seasonality in all rivers with Alpine influence has positive effects for hydropower production, as the divergence between production and demand diminishes.

Long-term persistence and periodicity in runoff time series is more pronounced in simulations for the second half of the 21st century with A1B emission scenarios than under reference conditions. This effect is small in simulations driven by RegCM3 and Aladin-Arpege, but considerable in REMO-UBA results. This weak coincidence and the fact that persistence in simulations with climate model control run data and with observations is similar might indicate that longer periods of persistent runoff can be expected under climate change conditions. With A2 data, however, no such change in persistence behaviour is detected.

The analysis of climate sensitivity of the Austrian industry's water demand led to the following conclusions: The major part of the Austrian industrial water demand is supplied by the Danube basin, followed by the Mur and Drau basins. The rivers Mur and Drau do not show a risk for the cooling water availability, which accounts for the major part of industrial water demand in these regions. However, for industrial plants demanding large amounts of water for direct process use the calculated decrease of groundwater recharge in the Mur basin could potentially lead to supply difficulties in this region. In the Raab basin only a minor part of the Austrian industry is located, however demanding essential amounts of groundwater for process use. The simulations of the groundwater recharge for these rivers in case of the Raab basin show a significant decrease for all regional climate models. Overall, the analyses of the effects of climate change on the industrial water demand in Austria do not indicate a significant scarcity of process nor cooling water for most parts of the Austrian industry. However, the effects of fundamental changes in the structure of industry due to climate change mitigation have not been investigated in this study.

For the energy system analysis we developed at set of three possible policy framework conditions and analysed the resulting energy needs and energy consumption of these settings under 5 climate conditions. Two of these climate settings constitute constant climate conditions (EOBS 1981-2010) and the 2005 base climate, the three other climate data are calculating the regional conditions which are consistent with a global A1B development (2.8 °C best estimate temperature increase until 2090-2099 compared to 1980-1999).

Regarding the impact on heating and cooling, a major finding is that the impact of climate change is much lower than the leverage of energy policy framework conditions. The settings applied for our scenarios span a bandwidth of 40 % to 65 % final energy demand reduction compared to the current level until 2080. Other scenario settings (Müller et al., 2012) indicate that these reductions are already plausible until 2050. Hence, we want to emphasize that the focus of this paper was not to show a maximum of energy efficiency improvement or CO2-mitigation. Rather, the scenarios were designed to show the impact of climate change under a range or reasonable and relevant policy framework conditions.

We developed an approach for modelling the market penetration of air conditioning subject to indoor temperature levels. However, there is still high uncertainty regarding the future uptake of air conditioning in different building types with and without impact of global warming. Even more, there is also considerable uncertainty regarding the current penetration of air conditioning and related energy demand. Data availability is still poor since it is not explicitly indicated in official energy statistics.

Our results show that the climate change impact on the annual energy needs for space heating is smaller than that for cooling, when measured in relative terms. While the energy needs for heating decrease by 20 % to 25 % compared to constant climate conditions, those for cooling increase by 60 % to 100 %.

However, since the final energy demand for heating surpasses the cooling demand by more than 2 decimal powers, climate change is reducing the energy demand in absolute numbers. The concurrency factor for AC systems is larger and the full load hours are smaller than that for heating. This means, that the space cooling might not be a more issue from an annual energy balance point-of-view, but eventually will have a major impact on electricity peaks and the design-factor of electricity grids, if no adoption measures are undertaken.

In this context, a focus on passive shading solar measures should be set when refurbishing buildings. Compared to the assumptions underlying our efficiency scenario (Blue scenario), consequently applied shading could reduce the energy needs for cooling by about 1/3.

Climate change affects the electricity system due to a change in overall hydropower generation as well as in the seasonal pattern of hydropower generation. Moreover, electricity consumption for heating decreases and for cooling increases. One of the most crucial impacts however is the possible increase of electricity peak loads in summer due to cooling, if no corresponding adaptation measures are taken. Although the absolute amount of cooling energy demand is still limited in all scenarios compared to heating energy demand the peak loads might play a considerable role, due to the high degree of simultaneity and the low number of full load hours of cooling devices. Although we could show that there is an impact of climate change on energy systems, the main driver of changes are energy policy framework conditions and the decision regarding the general direction of the future energy system’s pathway.

The results of the energy system modelling clearly shows that energy efficiency and a higher share of renewable energy can significantly contribute to increase the energy systems resilience: PV generation covers cooling load to some extent. However, due to building inertia there is no perfect simultaneity of PV generation and cooling demand. Thus, additional storage capacity or fossil peak load power plants are required. Moreover, it has to be guaranteed that PV generation take splace on-site or nearby the buildings with corresponding cooling loads or that electricity transmission lines are able to cope with high cooling loads. In the blue scenario, where ambitious renewable energy use and higher energy efficiency standards are combined running and investment costs for the supply of heating and cooling can be strongly reduced compared to the grey and green scenario.

The analysis of extreme periods (based on the criterion of residual loads) shows, that for most climate scenarios periods with high residual loads in winter will remain in a very similar range as for historic periods. However, in all climate scenarios such periods during summer will significantly increase until 2050-2080 if not significant efforts are taken to reduce cooling loads.

Increasing the resilience of systems usually is associated with some costs. According to Casti (2012), “there is no free lunch”, which means that increasing the resilience might make it necessary to increase redundancy, i.e. to loose economic effectiveness. This loss is price of a higher resilience and can be regarded as an insurance against extreme events (of which type they might ever be). However, we could show that the additional costs of increasing the resilience of the energy system can be very low and – even more important show synergies with climate mitigation efforts.

The measures which we identified for increasing the resilience in the view of climate change and other trends focus on:

(1) Reduction of overall energy demand;

(2) reduction of cooling loads by implementing building related measures like shading; this has to be even more integrated into the corresponding building codes and regulations;
(3) reduction of cooling loads by reducing internal loads through more efficient electric appliances;
(4) increase PV generation to reduce dependencies of international resource markets and to provide a positive contribution in periods of high cooling demand; make sure that PV is either situated on-site or nearby the buildings with high cooling loads or / and make sure that the capacity of electricity transmission lines copes with the high loads;
(5) implement measures for shifting of peak loads on the demand side;
(6) carry out a regular assessment of climate change impact on the energy system in order to prepare for long-term planning of investments.

In more detail, the results have shown that cooling under climate change might lead to high cooling peak loads. Thus, an important adaptation activity is shading. Our assumptions on the present status are, if aggregate, comparable with building stock fully applying internal shading. This measure reduces the cooling demand by about 1.9 TWh (-0.14 %) compared against the situation, where no solar shading is applied at all. However, if external shading would be applied on total building stock, the cooling needs could be reduced by about 3.5 to 5.8 TWh (-30 % to -50 %). In the policy scenarios drawn we assume that passive solar shading will be applied to a somewhat higher extent. In 2080, the Grey and Green Scenario exploit 55% of the additional energy saving potentials external shading offers compared to internal shading; the Blue Scenario exploits about 70% of the potential. Still there is a large room for further improvements. By applying radiation controlled solar shading devices on the total building stock, another 35 % of the energy needs for cooling could be spared.

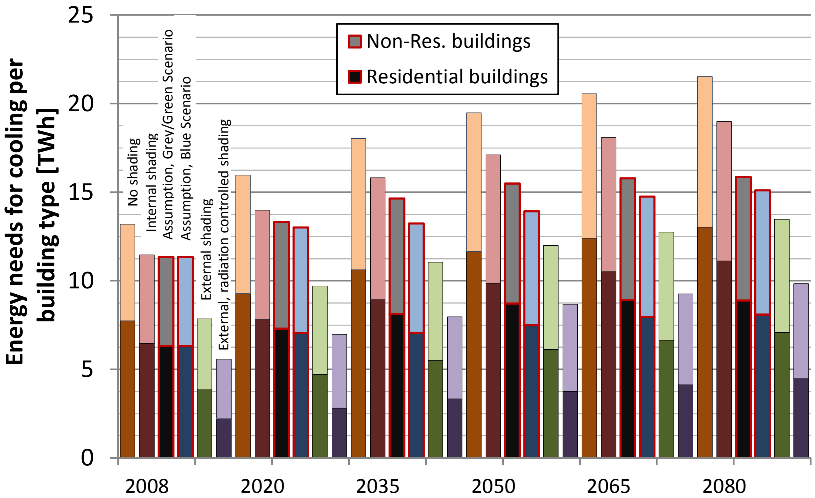

Figure 14. Impact of passive solar shading measures on the energy needs for cooling under constant EOBS 1981-2010 climate conditions.

Another important measure with a high simultaneous effect on climate adaptation and climate change mitigation is the efficiency improvement of electric appliances. A higher efficiency of electric appliances reduces internal heat loads and thus cooling load. Moreover, it potentially reduces overall electricity demand. The relevance of a strongly reduced electricity consumption has been shown in the “blue” scenario above compared to the grey scenario without any efficiency improvements: The impact of climate change can be strongly reduced and resilience increases.

PV has the potential to increase the resilience of the electricity system under climate change due to the good correlation of PV generation with cooling loads. However, the results (see Figure 11) have shown that cooling load in general occur slightly delayed due to building inertia compared to PV generation. This means that PV is not a perfect substitute for measures reducing cooling energy demand like shading. Moreover, in order to make sure that PV can contribute to high cooling peak loads, it has to be guaranteed that either PV is producing on-site or nearby the buildings with high cooling load or that corresponding and sufficient electricity grid capacities are available.

In general, the high peak loads and volatilities do not only cause challenges and difficulties to the electricity generation but also to the electricity grid. This aspect has not been treated within this study. However, considering the results and the high peak loads, the relevance of the electricity grid's resilience is evident for the whole electricity supply system.

Although the authors are aware of the limited scope of the analysis, the results indicate that acceptable additional costs would be required to adapt the electricity and heating system to climate change. However, if the changes, challenges and in particular increasing cooling peak loads would not be expected, the stakeholders and decision makers would not have the chance to adapt in time (and if this would only mean investment in corresponding peak load electricity generation capacities if not more ambitious energy efficiency measures or measures for peak load shifting). Since costs of blackouts (and near blackouts) are considerably high in industrialized economies, the relevance of adaptation becomes relevant.

A number of open questions occurred during the project and have to be left for further research. This refers in particular to the following aspects:

1) The role of district heating and CHP under climate change.
2) The international dimension of climate change and the impact on the electricity sector, e.g. regarding cooling water availability for nuclear and thermal power plants in other EU countries
3) The vulnerability and role of the electricity grid for a resilient low-carbon electricity system under climate change.
4) Further development of methodological approaches to integrate extreme events in energy system analyses, e.g. by stochastic modelling and optimisation.
5) Better understanding and data for current and potential future AC market penetration
6) Costs, benefits and economic effectiveness of adaptation measures
7) Further elaboration on extreme events and more extreme climate change scenarios.
8) Decision making structure under uncertainty and under high oil prices; how do households, industry, energy utilities and policy makers behave under energy crises and how could this affect short, mid and long term decisions?

Increasing the resilience of the energy system is one of the key global and local challenges in the coming years and decades. The results of PRESENCE as well as future research projects dealing with the open questions above may contribute to the successful simultaneous integration of climate change adaptation and mitigation in the energy transition process.

C) Project Details

7 Work plan

The work in the project PRESENCE was structured according to Figure 15. The project started with the elaboration of climate data based on existing scenarios (WP1) and the basic methodological framework cluster, which included the development of approaches to deal with extreme events (WP2) and the discussion of the resilience concept of energy systems. A core part of the project was the hydrological and energy system modelling cluster which included the elements hydrology and hydropower (WP4), cooling water availability (WP5), heating and cooling (WP6) as well as the overall energy system modelling (WP7). In WP8 we developed adaptation measures for increasing the resilience of energy systems.

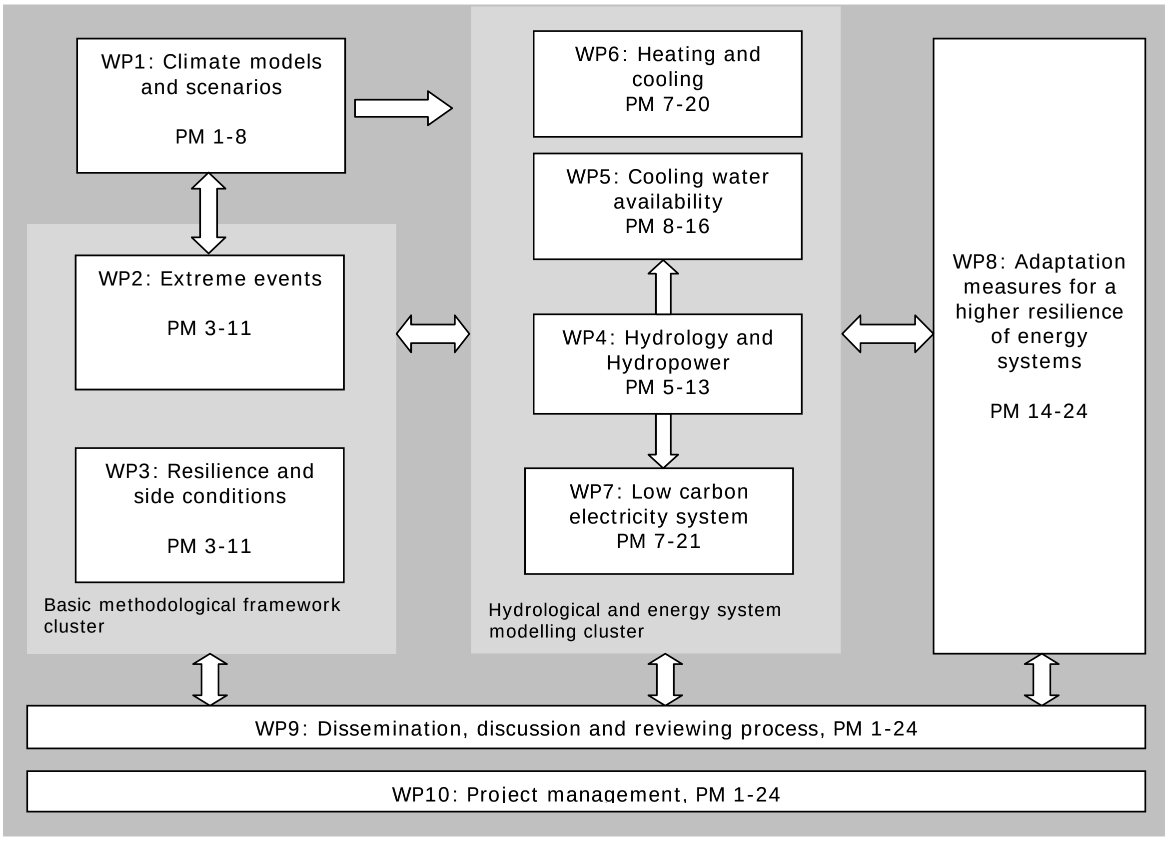

Figure 15. Project structure and work packages.

The project started in March 2011 and was scheduled to take 24 months. Due to unexpected difficulties and high challenges in setting up the numerous model interfaces, the project was extended until September 2013.

8 Publications and dissemination activities

The following presentations and publications were elaborated:

- Poster presentation at the Klimatag 2012
- Presentation at the KLIEN ""Klimafolgenforschung in Österreich: Aktuelle Projekte im Überblick" on 18 May 2011
- Oral presentation at the Klimatag 2013
- Matzenberger, J., 2012: Resilience of Energy Systems. In Graz: 2nd Sustainable Development Symposion.
- Stanzel, P. und Nachtnebel, H.P. 2013. Klimaeffekte: Auswirkungen des Klimawandels auf die Wasserkraft. In: Wasser, Energie und Klimawandel - Herausforderungen, Rahmenbedingungen und Chancen für die Wasserwirtschaft. Österreichischer Wasser- und Abfallwirtschaftsverband.
- Gerhard Totschnig: Ausfallsicherheit des heimischen Energiesystems unter Berücksichtigung des Klimawandels und einer Veränderung der Primärenergieproduktion – Aktueller Stand der Presence-Studie. 13. März 2013, Österreichischer Wasser- und Abfallwirtschaftsverband, Tagung "Wasser, Energie und Klimawandel Herausforderungen, Rahmenbedingungen und Chancen für die Wasserwirtschaft"
- Presentation on "A novel approach to assess resiliency of energy systems" has been given at the Sustainability Symposium 2012, on 16.2.2012 at the Technical University Graz in Graz, based on the working paper „The concept of resilience in the energy system and resilience indicators" (Deliverable D3.1)
- Presentation: P. Stanzel und H.P. Nachtnebel (2011): Klimawandel und Wasserkraft: Trends im 21. Jahrhundert. In: Klimaforschungsinitiative AustroClim und Klima- und Energiefonds gemeinsam mit Universität für Bodenkultur Wien und Climate Change Centre Austria, Tagungsband des 12. Österreichischen Klimatags – Klima, Klimawandel, Auswirkungen und Anpassung in Österreich
- Matzenberger, J., 2012: Indicating resilience of energy systems - A novel assessment framework. In Bregenz: European Roundtable on Sustainable Consumption and Production ERSCP. Available at: http://www.erscp2012.eu/papersession3.htm.
- Oral presentation at the "Symposium Energieinnovation TU-Graz, 2014": "The Impact of Climate Change and Energy Efficiency on Heating and Cooling Energy Demand and Load"
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- Totschnig G., Mueller A., Kranzl L., Hummel M., Hirner R., Nachtnebel H.-P., Stanzel P., Schicker I., Formayer H. 2014. Climate change impact on the electricity sector: the example of Austria (submission to the journal "energy")
- Three reviewing workshops took place:
    - First review workshop: "Extreme events and resilience concept" 3rd September 2012. For this workshop, we invited Geoff O'Brien and Harald Katzmaier, two extraordinary and internationally accepted experts in the field of extreme events and resilience research. We provided a review document (Matzenberger J., Kranzl, L., Totschnig, G., Redl, C., Schicker I., Formayer H., Gorgas T. Extreme Events and Resilience Concept. Working Paper for the First Review-Workshop on 3rd September 2012) which was sent to the experts for external reviewing.
    - Second review workshop: "Modelling climate change impact on energy systems" 19th June 2013. For this workshop, three outstanding international experts were invited: Birger Mo, Diana Ürge-Vorsatz and Stefan Vögele. Again, we provided a review document (Kranzl, L., Matzenberger J.,Totschnig, G., Toleikyte, A., Schicker I., Formayer H., Gorgas T., Stanzel P., Nachtnebel H. Bednar T., Gladt M., Neusser M., 2013, Modelling climate change impact on energy systems. Working Paper for the Second Review-Workshop on 19th June 2013) which was sent to the experts before the meeting in order to allow a comprehensive review process.
    - Third review workshop (Energiesystem im (Klima-)Wandel, 16.9. 2013) focused on the adaptation measures and the policy component. Persons from other institutions and events, in particular representatives of the Austrian climate adaptation strategy contributed to the workshop (presentations are available on the project website www.eeg.tuwien.ac.at/presence).
- Ö1 broadcast on 16th October 2013, 7 pm, about 10 Minutes about the project PRESENCE in "Dimensionen, die Welt der Wissenschaft"
- Interview in Radio Orange on "The future role of heating and cooling in the energy system", taking into account some of related PRESENCE results, May 2013.
- Throughout the project, the website www.eeg.tuwien.ac.at/presence was online presenting the state of the project including working papers or workshop materials. After the end of the project, the working papers and all outcomes will remain online at this place.
- There is a strong reference in the ACRP project COIN to the project PRESENCE. Without PRESENCE, the results in the chapters "electricity" and "construction and buildings" would not have been possible in this level of detail.

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