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Climate change impact and resilience in the electricity sector: The example of Austria and Germany

G. Totschnig[a,*], R. Hirner[a], A. Müller[a], L. Kranzl[a], M. Hummel[a], H.-P. Nachtnebel[b], P. Stanzel[b], I. Schicker[c], H. Formayer[c]

[a] Vienna University of Technology, Institute of Energy Systems and Electrical Drives, Energy Economics Group, Gusshausstrasse 25-29/370-3, 1040 Vienna, Austria

[b] University of Natural Resources and Life Sciences, Institute of Water Management, Hydrology and Hydraulic Engineering, 1190 Vienna, Austria

[c] University of Natural Resources and Life Sciences, Institute of Meteorology, 1190 Vienna, Austria

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ABSTRACT

The purpose of this paper is to investigate the resilience of possible future electricity and heating systems in regard to climate change and fuel price shocks. The dynamical simulation model HiREPS of the Austrian and German electricity, heating and cooling sectors was used for this analysis. The electricity generation cost and changes in the required secured capacity were used as indicators for the resilience of the energy system. The results show, that the analysed changes in the natural gas price have larger impact on the electricity generation cost than weather variability between different years or climate change. Especially the fossil fuel based scenario showed high sensitivity to the gas price. Analysis of the required secured capacity shows, that in the last quarter of the 21st century the annual maximum residual loads are growing and are dominated by strong cooling demand peaks. Promoting passive cooling options, efficient building designs and options for a controlled down regulation of cooling devices seems to be advisable to avoid installing large thermal power plant backup capacities. The evaluated climate model simulations show only small changes in photovoltaic, wind and hydro power generation for 2051–2080 in Austria and Germany.

1. Introduction

Climate change affects both electricity supply and demand. In particular the renewable electricity generation and the heating and cooling and related electricity consumption are climate sensitive. The topic of this paper is to investigate the resilience of possible future electricity systems in regard to climate change and fuel price shocks. For this end the resilience of three energy system scenarios are investigated for three different climate model simulations: Two energy system scenarios with strong reductions in the CO2 emissions from electricity and heating sectors and with high shares of renewable energies, and one more fossil fuel based scenario, where the installed wind and photovoltaic capacities are limited to the 2020 targets. Since Austria and Germany are highly linked in the central European electricity market, the detailed dynamical simulation model HiREPS of the Austrian and German electricity and heating sectors was used for this analysis. Different options of coupling of the electricity and heating sectors are implemented in the HiREPS model. The aim was to identify options for integrating renewable energies at lower costs and at the same time reduce the CO2 emissions of the electricity and heating sectors.

There are numerous effects of climate change on the electricity sector. In this paper, we will focus on the climate change impact on renewable energy resources (hydropower, wind, solar), changing heating, cooling and electricity demand patterns and changes in the power plant operation and optimal power plant portfolio. Required changes in the electricity grid infrastructure are simulated only in a simplified way and will require more detailed future research. The results provide the basis for deriving policy recommendations for the strategic planning of a robust power and heating system, which is resilient to climate change and fuel price shocks.

Exposure of the electricity system to climate change is mainly driven by the type and location of infrastructure, the number of thermal and nuclear power plants relying on cooling water availability and the number of hydropower plants. Moreover, the relevance of air conditioning is also a major driver of summer peak loads and related exposure. Several authors have discussed the issue of growing electricity peaks in summer periods, in particular in countries with higher

* Corresponding author.
E-mail address: totschnig@eeg.tuwien.ac.at (G. Totschnig).

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cooling loads. (Beccali et al., 2008) point out that summer electricity consumption in the building sector in Italy has grown steadily. According to the annual reports published by the Italian National Grid Operator, summer peak load for 2000–2005 showed a rise of 25%, or 8.38 GW. Temperature and corresponding adjusted electricity demand for Spain have been discussed by (Moral-Carcedo and Vicéns-Otero, 2005). (Pechan and Eisenack, 2014) discuss the impact of the 2006 heat wave on electricity spot markets. They found that over a two week period in Germany, the heat wave and the resulting reduction in the availability of cooling water led to an average price increase of 11% and to additional costs of 15.9 m€.

Chapter 2 describes the overall approach and methodological concepts in the fields of climate scenarios, hydrological modelling, energy system modelling and scenario assumptions. Chapter 3 shows the results, first for the Hydrological run off simulation and then the assessment of climate change impacts on the electricity and heating system for Austria and Germany 2050. Chapter 4 derives conclusions and policy implications.

2. Methodology

Three regional climate models (RCM), namely the ARPEGE, the RegCM3, and the Remo model, were used to perform climate simulations for a control period, 1971–1989, and for a future time slice episode from 2051 to 2080 (see Section 2.1). Monthly averages of temperature and precipitation were used as input for a hydrological model which calculated the long-term runoff for 188 river basins as well as key data regarding cooling water availability. The calculated run off data was an input in the hydropower unit commitment simulation with the HiREPS model for the 400 detailed modelled individual hydropower plants. A quantile mapping approach was used for the bias correction of the wind speed and global irradiation from the RCM simulations to calculate wind power and photovoltaic power time series. The bias corrected RCM air temperature data was also used for calculating the hourly heating and electricity profile for the HiREPS model and to calculate the space heating, space cooling and domestic hot water demand with the Invert/EE-Lab model. These demands are required a inputs for the HiREPS model, which in turn simulates the hourly resolved electricity and heat generation for the scenarios and the cost and resilience impacts analysed in this paper. In the following sections the methodology is explained in more detail.

2.1. Climate scenarios and developing climate input data for electricity sector modelling

The purpose of the paper is to examine the resilience of different Energy systems (scenarios green, blue, grey: see Section 2.5) in Austria and Germany in regard to climate change and fuel price shocks. In order to show possible resilience issues of different energy systems, energy system effects (see Section 3.2) of a high emission baseline scenario are compared to a “constant climate” scenario. As high emission scenario the A1B illustrative marker scenario of the Special Report on Emissions Scenarios (SRES) by the Intergovernmental Panel on Climate Change (IPCC) (Nakicenovic et al., 2000) was selected based on data availability at the time of starting this research. Newer Emission scenarios were developed in the framework of the IPCC Fifth Assessment Report (2014) (IPCC AR5 2014). The A1B scenario clearly is not within the scope of the emission reduction target of the Paris Agreement.[1] But the success of the Paris agreement is not guaranteed and choosing a strong mitigation scenario with low climate change effects, would have only low informative value regarding climate change resilience of the analysed possible future energy systems.

Three regional climate model (RCM) simulations using three different climate models within the ENSEMBLES project (Kjellström et al., 2010), based on the A1B SRES scenario by IPCC, were applied to estimate future conditions of climate change: the Aladin model (“The ALADIN project: Mesoscale modelling seen as a basic tool for weather forecasting and atmospheric research, ” 1997), operated by CNRM and driven by the results from the ARPEGE global climate model (GCM) (Voldoire et al., 2013), the REMO model (The Regional Model – REMO, n.d.), operated by MPI and driven by ECHAM5 GCM (Roeckner et al., 2003), and the RegCM3 model (RegCM3, 2006, p. 3), operated by ICTP and driven also by the ECHAM5 GCM. The data sets were bias corrected using the E-OBS (Haylock et al., 2008) gridded observation data and, additionally, the (Frei and Schär, 1998) gridded precipitation data set.

As input to the hydrological model the monthly RCM data of temperature and precipitation was localized to the 1×1 km grid of the hydrological model. The hydrological model provided monthly changes of long-term runoff for 188 river basins as well as key data regarding cooling water availability.

The electricity and heating system simulation model HiREPS needed, besides run off values from the hydrological model, additionally temperature, global irradiation, and wind speed with as high temporal resolution as possible for two domains, Austria and Germany.

The modelled u (east-west component of the wind) and v (north-south component of the wind) components, of the 850 hPa pressure level were used to calculate the wind speed and its third power. The country average of the third power of the wind speed was calculated and the cubic root applied to derive the area averaged wind speed for Austria and Germany. A quantile mapping approach was used for bias correction of the area averaged wind speeds and global irradiation values. The area averaged wind speeds for Austria and Germany were quantile mapped to the simulated wind power generation in Austria and Germany, assuming a 3 MW Enercon E101 with 100 m hub height on all locations in Austria or Germany where at least 1760 full load hours are achievable. The wind power generation simulation was based on the hourly COSMO-EU analysis data of historic (2005–2009) wind speeds at 100 m above ground. The global irradiation values were quantile mapped to the simulated photovoltaic power generation in Austria or Germany, assuming 30 ° inclined south oriented modules spread over the countries proportional to the population density and based on Meteosat data of the historical global and diffuse irradiation of the years 2005–2012. As a result for all three climate models a bias corrected wind power generation and photovoltaic generation time series was calculated for Austria and Germany 1971–2100. This time series is scaled according to the installed capacities as simulated by the HiREPS model.

For temperature, a population weighted temperature for Austria and Germany using the population density of the lspop data set (1×1 km) (Dobson et al., 2000) was calculated. The temperature time series for all 3 climate models for Austria and Germany 1971–2100 was used in the different regression models to calculate the heating, cooling and electricity demand.

2.2. Hydrological run off modelling

For water balance simulations, a continuous conceptual hydrological model (Nachtnebel et al., 1993) was applied, which covers the whole of Austria. It represents the main hydrological processes of interception, snow and glacier processes, evaporation, storage in the soil, runoff separation into fast and slow components. Spatial discretization of the hydrological model relies on a 1×1 km grid and basin boundaries of 188 catchments. The model uses precipitation and temperature as input data and runs in monthly time steps. The model version applied here was adapted from a model applied for the Hydrological Atlas of Austria (“Hydrologischer Atlas Österreichs”, 2005), which was extensively calibrated in a regional calibration procedure for the period of 1961 1990 (Kling, 2006). After adaptations

[1] https://en.wikipedia.org/wiki/Paris_Agreement