Susceptibility of the European electricity sector to climate change.

Daniel R. Klein[a,*], Mady Olonscheck[a], Carsten Walther[a], Jürgen P. Kropp[a,b]

[a] *Potsdam Institute for Climate Impact Research, P.O. Box 601203, 14412 Potsdam, Germany*
[b] *Department of Earth and Environmental Sciences, University of Potsdam, Am Neuen Palais 10, 14469 Potsdam, Germany*

Abstract

The electricity system is particularly susceptible to climate change due to the close interconnectedness between electricity production, consumption and climate. This study provides a country based relative analysis of 21 European countries electricity system susceptibility to climate change. Taking into account 14 quantitative influencing factors, the susceptibility of each country is examined both for the current and projected system with the result being a relative ranked index. Luxembourg and Greece are the most susceptible relatively due in part to their inability to meet their own electricity consumption demand with inland production, and the fact that the majority of their production is from more susceptible sources, primarily combustible fuels. Greece experiences relatively warm mean temperatures, which are expected to increase in the future leading to greater summer electricity consumption, increasing susceptibility. Norway was found to be the least susceptible, relatively, due to its consistent production surplus, which is primarily from hydro (a less susceptible source) and a likely decrease of winter electricity consumption as temperatures rise due to climate change. The findings of this study enable countries to identify the main factors that increase their electricity system susceptibility and proceed with adaptation measures that are the most effective in decreasing susceptibility.

Keywords: thermal electricity production, energy security, heating and cooling electricity consumption, vulnerability, air conditioners, electricity generation by source

1. Introduction

Overwhelming evidence indicates that climate change will result in a significant increase of temperatures in Europe in the years to come [1, 2]. Due to the close relationship between the electricity sector and climate, changes in the latter will affect the entirety of the electricity sector including production, imports and exports, distribution

*Corresponding author. Tel.: +49 331 288 2579; Fax: +49 331 288 20709. E-mail address: drklein@pik-potsdam.de (D. Klein)

and consumption [3, 4, 5, 6]. Not every country will be affected in the same way due to a variety of factors that include not only temperature, but also different heating and cooling requirements and the variety of sources used for electricity generation among others [7].

A number of studies on the effects of climate change on electricity production have been conducted. A study by van Vliet et al. [8] examined the susceptibility of the thermoelectric electricity production in the United States and Europe and found significant negative effects due to reduced river flows and increased river temperatures. Work done by Rübbelke and Vögele [2], characterized the European electricity system susceptibility to climate change based principally on the availability and temperature of cooling water used for nuclear power plants. Eskeland and Mideksa [7] examined the relationship between temperature and electricity consumption demand on a European level. The study found that the net effect of climate change on electricity demand is small, but increases in summer electricity consumption and decreases in winter electricity consumption are likely, depending on the geographic location and climate of a given country. Further studies indicate that in the north and central parts of Europe, heating related electricity consumption will decrease due to warmer winter temperatures over the next decades, and will predominate over increases in cooling related electricity demand and consumption [1, 7, 9]. The opposite is true however for the south of Europe where increases in cooling related electricity consumption will outweigh any heating related decreases [1, 7].

The aim of this study is to determine the relative electricity system susceptibility of 21 European countries to climate change using both quantitative and qualitative indicators, with the goal of ultimately providing a comparative analysis of the countries based on a number of influencing factors. We examine the relationship between the electricity system and temperature as well as other influencing factors and look at the effect of different components of the electricity system on each other. For the purpose of this study, the electricity system is defined as production and consumption only (transmission is not included) and although there are many effects of climate change including precipitation changes, and sea level rise, we only examine the air temperature change effects to maintain a reasonable scope for the study. In terms of susceptibility, a general definition that is used in this study is put forward by Costa and Kropp [10] which characterizes susceptibility as a component of vulnerability that deals with "socio-economic and physical characteristics of a system that differentiate the magnitude of impacts for a given exposure". This concept can be linked to work by White et al. [11] which puts susceptibility as a component of vulnerability in a risk-hazard context as well as the work of Turner et al. [12] in terms of sensitivity in a sustainability context. The countries are referred to in this paper by their ISO (International Organization for Standardization) 3166-1 alpha-2 abbreviations.

The influencing factors chosen for this study are by no means exhaustive, but were selected as being significant in terms of their impact on the electricity system and their ability to demonstrate potential susceptibilities. An important influencing factor is the direct effect of temperature, both current and projected, which, due to climate change, has an increasingly large impact on the electricity system as a whole [2, 5, 7, 13]. The discrepancy between electricity production and consumption was considered in order to not only identify susceptibilities related to production shortfalls, but also to help characterize the electricity system [2]. The electricity production sources and their change over time of each country included in the study were also chosen as being an important influencing factor [2, 7, 14, 15]. Cooling electricity consumption is mainly dependent on air conditioner prevalence which was also included [8, 9, 16, 17, 18, 19, 20].

This paper continues from this point with the Data and Methods section (2), followed by Section 3 where the results and findings of the study are presented. Section 4 includes the discussion of the results from the previous section along with a comparison of those findings with existing studies. The paper closes with the conclusions of the study in Section 5.

2. Data and Methods

The methodology used in this study was an attempt to characterize the effects of climate change on the electricity system through the development of a ranked index. The ranked susceptibility index, as described in this section, is based on a number of influencing factors.

The daily mean temperature data (in °C) for the period 2000-2011 [21] with a resolution of 0.25° x 0.25° and covering an area of 25N-75N x 40W-75E was averaged by month and weighted by gridded population data [22] in order to account for the fact that electricity consumption, and to a lesser extent electricity production, are not distributed evenly across a country but are often concentrated in areas where people live. The population weighting of the temperature data was completed in ArcGIS [23], with the first step being the allocation of the grid cells for both the temperature and population data sets into their respective countries. The weighting was then completed for each grid cell (i) in every country (j) using equations (1) and (2).

$$W_{i,j} = \frac{pop_{i,j}}{\sum_{i=1}^{n_j} pop_{i,j}} \tag{1}$$

$$T_{mean,j} = \sum_{i=1}^{n_j} T_{i,j} \cdot W_{i,j} \tag{2}$$

$W_{i,j}$: The relative population factor.
$pop_{i,j}$: The population.
n_j : The number of grid cells.
$T_{mean,j}$: The population weighted monthly mean temperature.
$T_{i,j}$: The mean monthly temperature.

The projected temperature increase data was available from the Tyndall Centre, which included data from 9 global climate models which we averaged [24]. The data was a prediction of temperature changes for the years 1961-90 compared to 2070-99 for the IPCC (Intergovernmental Panel on Climate Change) A2 scenario.

Due to the non-linear nature of the correlation between electricity production or consumption and temperature, we divided the temperature data into three parts based on heating and cooling thresholds in between which no heating or cooling is required

[25, 26, 27]. Heating is assumed below the mean temperature threshold of 12°C [28, 29], while cooling is necessary at 21°C and above [27, 30, 31].

We used monthly electricity data per country (in GWh) for the time period January 2000 to December 2011 [32] that included production (combustible fuels, nuclear, hydro, other sources and total production), as well as imports, exports and total supply (determined by subtracting the exports from the sum of the production and imports). Due to a lack of data regarding the actual electricity consumption of a country, the electricity supplied to the grid is used as a proxy for consumption in this study and will be referred to as consumption from this point forward.

For the electricity production and consumption versus mean temperature plots created for this study, the difference from the annual mean of the electricity data was calculated. This calculation was necessary in order to facilitate the comparison between countries as well as to eliminate or minimize the overall increase in data values over the time period examined due to population and GDP (Gross Domestic Product) changes along with other factors, which would bias the results.

The residential air conditioner stock data [33] by country was divided by annual actual and projected population data [34].

2.1. Influencing Factors

Influencing factors considered for the ranked susceptibility index are described in the following sections. The influencing factors themselves were divided into groups for the sake of explanation.

2.1.1. Group 1: Production, Consumption and Mean Temperature Slope

Group 1 consists of four influencing factors. The slope values for data points both above and below the heating and cooling thresholds were determined for the electricity production and consumption percent difference from the annual average data against mean temperature. Countries reaching the cooling threshold were considered to be more susceptible currently, and those with steeper slopes have a higher susceptibility. Countries that do not reach the cooling threshold, or with fewer than 10 months that did, were deemed to be currently unaffected in terms of susceptibility. For the values below the heating threshold however, a steep slope was deemed to decrease susceptibility due to a more rapid decline of the winter peak as temperatures increase.

2.1.2. Group 2: Production and Consumption

Group 2 includes four influencing factors: the correlation and the discrepancy between production and consumption calculated for the summer (June, July, August) and winter (December, January, February) months. In terms of susceptibility, stronger correlation between electricity production and consumption was determined to indicate lower susceptibility, as it implies a greater ability to deal with changes in the electricity system. The percentage discrepancy value characterizes the system by identifying countries that are net producers or consumers and to what extent. Net producing countries were determined to be less susceptible due to the fact that they meet or exceed their consumption demand with inland production on average.

2.1.3. *Group 3: Thermal Electricity Production Share*

The thermal electricity production group includes two influencing factors: the current (2011) annual average percentage of total electricity production that is generated by thermal sources (combustible fuels and nuclear) and the difference between the 2011 and 2000 percentage of thermal source electricity production. The former being a measure of the current percent of production sources in a country that are deemed to be more susceptible and the latter was included in order to address changes in thermal electricity production share over time. Countries experiencing decreases in the share of thermal electricity production have lower susceptibility than those experiencing increases.

2.1.4. *Group 4: Projected Temperature Increase*

Summer temperature increases were assumed to increase susceptibility due to probable increases in consumption for cooling, while increases in winter temperatures were deemed to decrease susceptibility, as heating electricity requirements are likely to decrease.

2.1.5. *Group 5: Air Conditioner Prevalence*

The per capita air conditioner prevalence group included the projected 2030 air conditioner stock and the percentage increase of air conditioner stock between 2005 and 2030. The 2030 data gives an indication of the magnitude of potential warm weather electricity consumption in the future, while the growth data provides information on the potential change from the current consumption. Susceptibility increases with higher values for either influencing factor due to the increasing effects of air conditioner use on electricity consumption. It is important to note that the air conditioner factor is a proxy for all electricity cooling, including for example, industrial cooling for which there is no available data. There was no data for NO (Norway) and CH (Switzerland), therefore both influencing factors in this group were excluded from the index calculations for those countries.

2.1.6. *Group 6: Imports and Exports*

In order to take into account the magnitude of imports or exports per country we used the summer and winter absolute export values subtracted from the corresponding import values (2000-2011). The difference was then divided by total electricity production in order to determine the extent to which a country is a net importer or exporter. Countries reliant on electricity imports for part or all of the year were determined to be more susceptible as they often do not have the inland production capacity to meet their electricity demand and are therefore reliant on exports from other countries. Countries that are net exporters were assumed to be less susceptible because of their ability to meet or exceed their demand.

2.2. *Influencing Factor Correlation*

The correlation between all of the influencing factors was determined in order to identify and eliminate redundant factors (Table 1). Based on the results of the Spearman correlation, Group 6, which includes the summer (6.1) and winter (6.2) discrepancy between imports and exports correlated highly (over 0.95) with the summer (2.3) and winter (2.4) discrepancy between production and consumption and was therefore excluded from the index calculations. This makes sense due to the inherent relationship between production and consumption, and imports and exports, as well as the calculations used to determine the consumption.

Table 1: Influencing Factor Correlation Table. Note: Starred (*) influencing factors do not include CH or NO in their calculation due to lack of data availability. Bold values indicate correlation above 0.95.

Influencing Factor	1.1	1.2	1.3	1.4	2.1	2.2	2.3	2.4	3.1	3.2	4.1	4.2	5.1*	5.2*	6.1	6.2
1.1	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.2	0.73	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1.3	0.02	0.08	1.00	-	-	-	-	-	-	-	-	-	-	-	-	-
1.4	-0.03	0.09	0.94	1.00	-	-	-	-	-	-	-	-	-	-	-	-
2.1	0.11	0.02	-0.33	-0.33	1.00	-	-	-	-	-	-	-	-	-	-	-
2.2	0.26	0.12	-0.25	-0.23	0.89	1.00	-	-	-	-	-	-	-	-	-	-
2.3	-0.13	0.41	0.11	0.17	-0.21	-0.26	1.00	-	-	-	-	-	-	-	-	-
2.4	0.34	0.31	0.07	0.10	-0.13	-0.08	0.60	1.00	-	-	-	-	-	-	-	-
3.1	0.10	0.31	0.08	0.13	-0.19	-0.33	0.15	-0.20	1.00	-	-	-	-	-	-	-
3.2	0.48	0.29	-0.15	-0.18	0.36	0.36	0.05	0.50	-0.21	1.00	-	-	-	-	-	-
4.1	-0.16	-0.15	0.30	0.29	-0.39	-0.37	0.07	0.11	0.16	-0.38	1	-	-	-	-	-
4.2	0.39	0.25	0.26	0.35	0.13	0.27	-0.15	0.12	0.07	0.25	0.07	1.00	-	-	-	-
5.1*	0.02	0.13	0.60	0.53	0.17	0.07	0.15	0.12	0.02	-0.06	0.29	0.36	1.00	-	-	-
5.2*	-0.13	-0.18	-0.50	-0.54	0.21	0.12	0.18	0.17	-0.20	0.18	-0.28	-0.49	-0.22	1.00	-	-
6.1	-0.08	0.42	0.09	0.13	-0.16	-0.19	**0.98**	0.64	0.09	0.13	0.08	-0.14	0.15	0.14	1.00	-
6.2	0.30	0.28	0.08	0.11	-0.09	-0.06	0.60	**0.99**	-0.22	0.52	0.11	0.09	0.14	0.13	0.66	1.00

2.3. Final Methodological Structure

The remaining influencing factors (Groups 1-5) are presented in Figure 1. It is important to note that both influencing factors in Group 6 are not included in this figure as it is not part of the study from this point onward based on its exclusion due to the correlation calculations from the previous section.

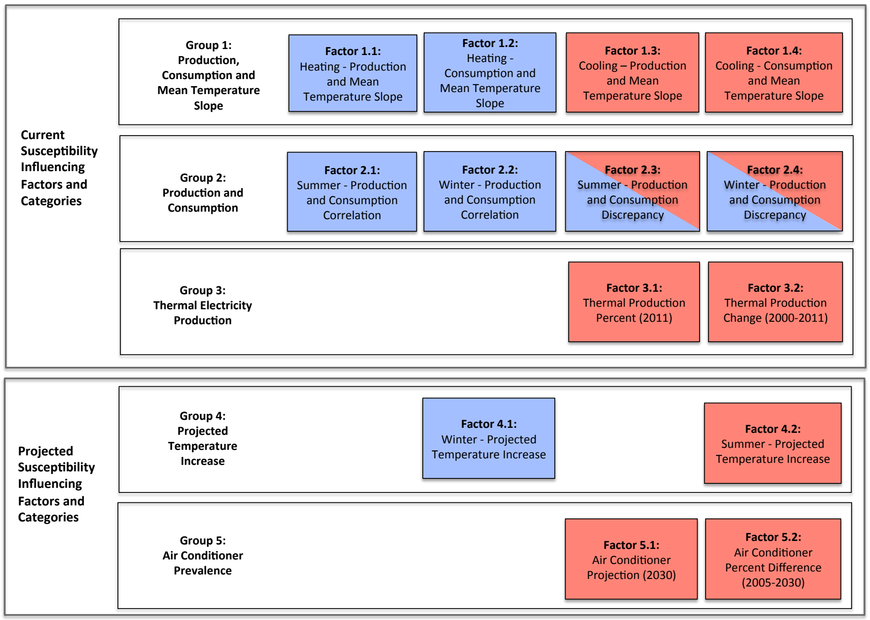

Figure 1: Influencing Factors (Blue = influencing factors that decrease susceptibility, Red = influencing factors that increase susceptibility)

2.4. *Index Calculations*

The absolute influencing factor values were not used in the index calculation; instead each of the influencing factor values was normalized by the maximum value in the group. For indicators that have a potentially positive effect on susceptibility, the range from -1 to 0 is used. Similarly, for influencing factors that potentially have a negative effect on susceptibility, the range from 0 to 1 is taken. The susceptibility influencing factors were grouped based on similarities; of which three are current measures of susceptibility (Groups 1-3) while two are projected (Groups 4 and 5). Because the discrepancy influencing factors (2.3 and 2.4) could possibly increase or decrease susceptibility, the countries were first separated based on whether they were net producing countries (with values >1) or net consuming countries (with values <1). Both subgroups were then normalized by their maximum value respectively. The 14 influencing factors were averaged for each country giving a ranked susceptibility index (equation (3)).

$$I = \frac{\sum_{x=1}^{k} v_n}{k} \tag{3}$$

I : The ranked index value.
v_n : Influencing factor n (index value).
k : The number of influencing factors.

Each of the influencing factors was weighted equally for the index calculation, the most common weighting for composite indicator calculations [35]. While statistical weighting of the influencing factors could have been possible, it does not add understanding or legitimacy to the index, as statistical approaches do not include content based argumentation. A review of possible statistical weighting options revealed that there are many possibilities available, leading to quite different ranked index results. Furthermore, a PCA (Principal Component Analysis) was conducted on the data in order to determine if the influencing factors themselves were sufficiently independent and to identify the possibility of significant factor overlap [35, 36]. The results of the PCA can be seen in the supplementary materials, which show that the variation of the data can be explained using 5 composite component factors (representing only about 80% of the variation in the data), and only a small number of influencing factors had factor loadings that were high enough to be noticeable. These results demonstrated the sufficient independence of the influencing factors, and therefore support the use of equal weighting among factors.

2.5. Sensitivity Analysis

A sensitivity analysis of the influencing factors included in the ranked susceptibility index was conducted by calculating the sum of the squared difference between the original index value and the new index value (calculated using the average influencing factor value for all countries for the factor in question). The method was taken from a study by Fraiman et al. [37] and calculated using equation (4).

$$S_i = \sum_{i=1}^{n} [I_{i,c} - I_c]^2 \tag{4}$$

S_i : Sensitivity value for influencing factor i.
n : The total number of countries.
$I_{i,c}$: Index value calculated with influencing factor i removed, for country c.
I_c : Original index value including all influencing factors for country c.

3. Results

3.1. Ranked Index Values

This section presents the results for each of the influencing factors included in the study, separated into groups. The ranked susceptibility actual and index values for each influencing factor can be seen in the supplementary materials.

3.1.1. Group 1: Production, Consumption and Mean Temperature Slope

Influencing factors 1.3 and 1.4 show that GR (Greece), ES (Spain), IT (Italy) and PT (Portugal) are highly susceptible due to the fact that they experience temperatures that surpass the cooling threshold (Figure 2). On the other hand, for influencing factors 1.1 and 1.2, the Scandinavian countries are among the least susceptible, however PT, FR (France) and GB (United Kingdom) are also relatively less susceptible, due to steep slopes below the heating threshold (Figure 2).

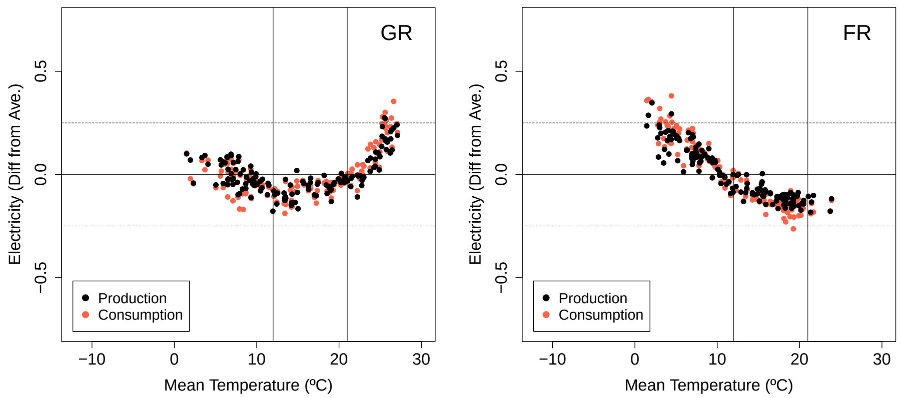

Figure 2: Production and consumption by mean temperature - Slope examples (All countries available in the supplementary material). Source: adapted from European Climate Assessment and Dataset [21] and IEA [32].

3.1.2. Group 2: Production and Consumption

In terms of the production and consumption correlation, ES and GB are notable countries for both the summer and winter influencing factors (2.1 and 2.2) because they have consistently strong correlation between electricity production and consumption. On the other hand, SK (Slovakia) and CH have a consistently weak correlation between production and consumption.

Regarding the percentage discrepancy, LU (Luxembourg) is the most extreme example of a net consuming country for both summer and winter (influencing factors 2.3 and 2.4) (Figure 3). Only half of the electricity consumption of LU is met by inland production. CZ (Czech Republic) and FR are notable as well due to their large production surplus that is consistent for both summer and winter (2.3 and 2.4) (Figure 3). The majority of the countries experience seasonal differences and parts of the year are net consumers and other times net producers, most notable are AT (Austria), CH and DK (Denmark).

3.1.3. Group 3: Thermal Electricity Production Share

The thermal electricity production share (percentage of electricity production from combustible fuels or nuclear) provides information about the current susceptibility of a countries' inland electricity generation mix (Figure 4). DK and PT are less susceptible, due to their decline in thermal share over time (influencing factor 3.2). HU (Hungary), PL (Poland) and NL (Netherlands) produce greater than 95% of their inland electricity from thermal sources and have the highest current influencing factor values (3.1). All of the countries produce greater than 40% of their electricity from thermal sources, with the exception of NO (<%4). In terms of changes in the percent share of thermal production over time, LU has by far experienced the greatest rise in thermal use while DK, PT and IE (Ireland) have experienced the greatest decline.

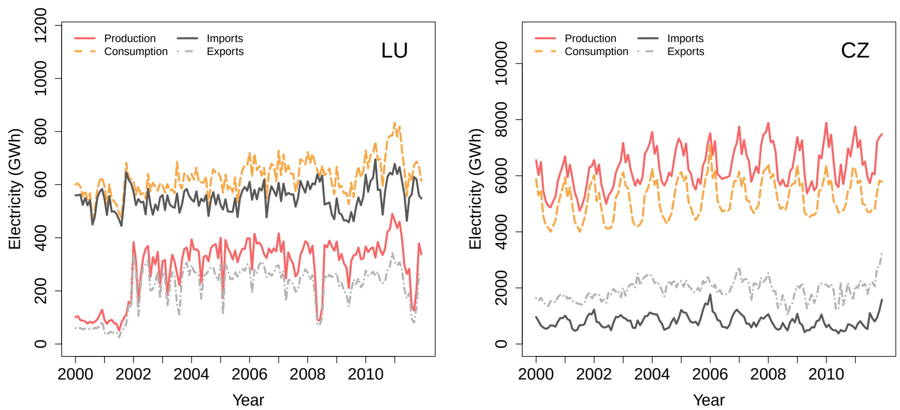

Figure 3: Monthly production, consumption, imports and exports over time - Percentage discrepancy examples (All countries available in the supplementary material). Source: adapted from IEA [32].

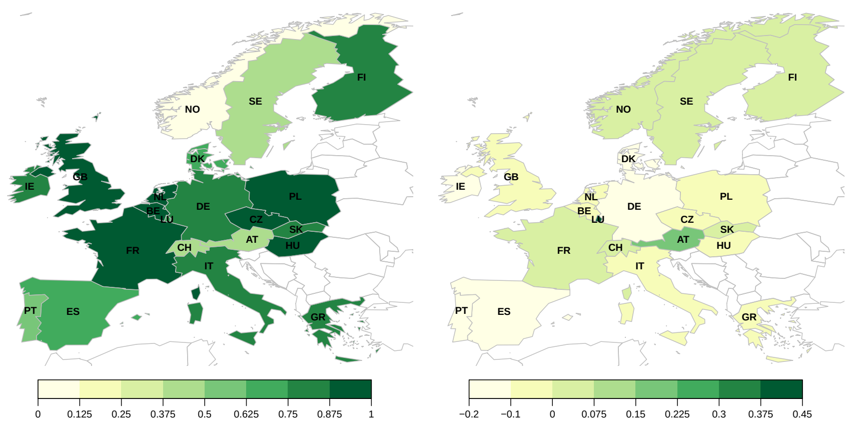

Figure 4: Thermal Electricity Production Share (2011) (Left) and Percent Change (2000-2011) (Right) Maps. Note: Darker colors indicate higher susceptibility. Source: adapted from IEA [32].

3.1.4. Group 4: Projected Temperature Increase

The projected temperature increase influencing factors give a relative indication of the magnitude of temperature increase expected for both winter and summer (4.1 and 4.2). FI (Finland), SE (Sweden) and NO will see the greatest rise in winter temperatures (4.1), while ES, HU and CH will see the greatest rise in summer (4.2). IE and GB will experience the smallest future temperature changes for both seasons. The geographical susceptibility trend of the actual summer and winter temperature values is evident from the maps in Figure 5 where a clear north-south gradient is present.

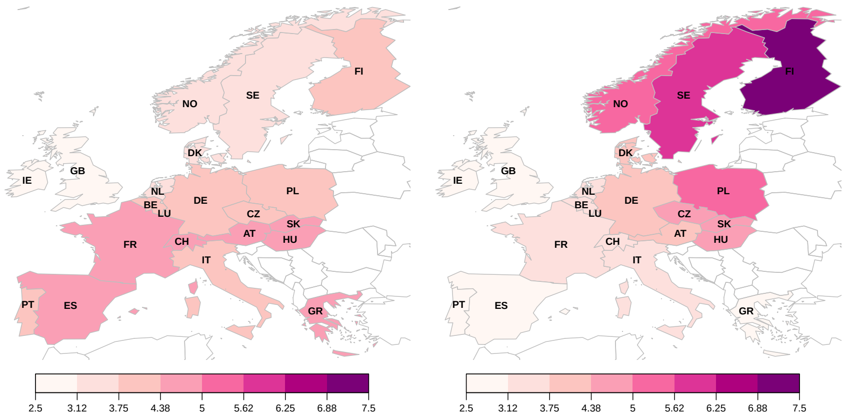

Figure 5: Actual Summer (Left) and Winter (Right) Temperature Increase Maps (°C) (Scenario A2 1961-90 to 2070-99). Note: Darker colors indicate higher susceptibility for the Summer map (Left) but lower susceptibility for the Winter map (Right). Source: adapted from Mitchell et al. [24].

3.1.5. Group 5: Air Conditioner Prevalence

Countries that historically reach the cooling threshold would logically be the most likely to have the highest air conditioner prevalence due to their warmer temperatures. This is not true in all cases however, PT being the exception with relatively few air conditioners, and limited growth projected in the future (influencing factor 5.2). IT, GR and ES are projected to have a large stock by 2030 (influencing factor 5.1), however with moderate or low growth (due to saturation). The countries with higher projected growth (for example FI, SE and GB) will likely see greater than three times the current air conditioner stock by 2030 (influencing factor 5.2). A map of the actual projected air conditioner prevalence and projected air conditioner stock difference can be seen in Figure 6.

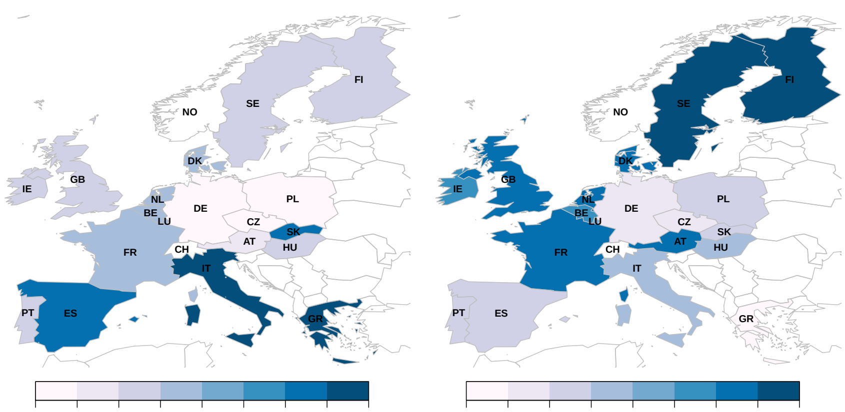

Figure 6: Projected Air Conditioner Prevalence Map (per capita, 2030) (Left) and Projected Air Conditioner Percent Difference (2005-2030) (Right) Maps. Note: No data was available for CH or NO. Darker colors indicate higher susceptibility. Source: adapted from Adnot et al. [33].

3.2. Ranked Susceptibility Index

The ranked susceptibility index (Table 2, Figure 7) is an average of the influencing factor index values. The index is therefore a deductive relative indication of the susceptibility of each country to climate change with equal weighting of each of the 14 included factors.

It is important to note that the least susceptible country in the index is the least susceptible relative to the other countries in the index, but does not necessarily have no susceptibility. LU is relatively the most susceptible country by a significant margin, followed by GR, while NO is the least susceptible in the index.

Table 2: Relative Ranked Susceptibility Index.

Country	Mean Index Value
LU	0.249
GR	0.136
SK	0.091
IT	0.078
HU	0.065
NL	0.064
AT	0.047
FI	0.030
BE	0.022
SE	-0.020
CH	-0.029
ES	-0.041
GB	-0.078
PL	-0.093
FR	-0.100
IE	-0.103
DE	-0.112
DK	-0.136
PT	-0.163
CZ	-0.195
NO	-0.215

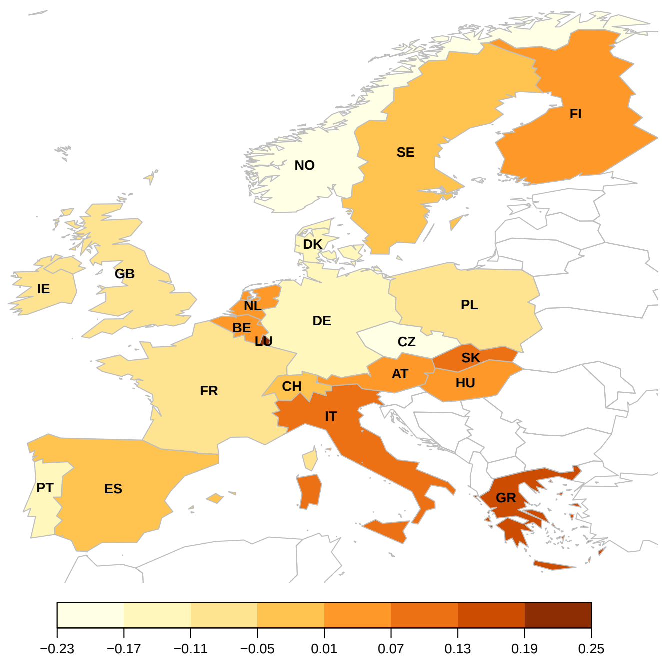

Figure 7: Relative Ranked Susceptibility Index Map. Note: Darker colors indicate higher susceptibility.

3.3. Sensitivity Analysis

The sensitivity analysis completed for each influencing factor can be seen in Table 3, and shows the relative effect of each factor on the susceptibility index ranking and values. The index is most susceptible to the projected summer temperature increase (4.2). Both the slope for production and consumption with mean temperature for the cooling values (1.3 and 1.4) have the least effect on the index. Some countries are more susceptible to relative changes in their rank based on the effects of the influencing factors (this can be seen in the sensitivity analysis figure in the supplementary materials). NO is consistently among the least susceptible for each influencing omission, while LU is consistently the most susceptible (see figure in the supplementary materials).

Table 3: Sensitivity Analysis Values. Note: Factors are listed in increasing order, the index is the most sensitive to the last factor listed.

	Influencing Factor	Sensitivity Value
1.3	Production and Mean Temperature Slope (Cooling)	0.0058
1.4	Consumption and Mean Temperature Slope (Cooling)	0.0061
2.4	Production and Consumption Discrepancy (Winter)	0.0189
2.3	Production and Consumption Discrepancy (Summer)	0.0192
1.1	Production and Mean Temperature Slope (Heating)	0.0216
3.2	Thermal Production Change (2000-2011)	0.0253
5.1	Air Conditioner Projection (2030)	0.0254
1.2	Consumption and Mean Temperature Slope (Heating)	0.0257
4.1	Projected Temperature Increase (Winter)	0.0375
5.2	Air Conditioner Percent Difference (2005-2030)	0.0442
2.1	Production and Consumption Correlation (Summer)	0.0567
2.2	Production and Consumption Correlation (Winter)	0.0636
3.1	Thermal Production Percent (2011)	0.0676
4.2	Projected Temperature Increase (Summer)	0.0707

4. Discussion

This section will attempt to identify and explain the underlying reasons for the relative susceptibilities of selected countries, discuss the reasons certain countries are more susceptible than others, and examine these results in comparison with existing findings. Due to the highly complex nature of the electricity system in general, and its very pronounced subjectivity to country specific conditions, explaining the behavior of the system is difficult and the findings presented in this report are an attempt to break down and characterize the effect of some of the most important influencing factors, but are by no means the entire picture [38].

4.1. Discussion of the Results

4.1.1. Discussion of Selected Countries

LU. LU is, by a wide margin, the most susceptible country in terms of the ranked susceptibility index. Inland production in LU meets less than half of the consumption demand (influencing factors 2.3 and 2.4) which increases susceptibility, as well as makes the country reliant on imports [39]. This is most likely due in large part to the small size of the country as well as the high level of industrial electricity consumption [39]. In 2002, LU experienced a drastic shift in its electricity system due to a capacity increase when gas-fired electricity production was introduced which effectively increased production by 200%, increasing the countries' susceptibility due to greater reliance on thermal electricity production (influencing factors 3.1 and 3.2) [40]. LU has one of the highest per capita electricity consumption rates in the world, and is securely positioned within the Central-West Europe electricity market which may account for the country putting little emphasis on increasing inland production [39].

Additionally, LU primarily utilizes combustible fuel as its electricity production source which will likely experience climate change related decreases in capacity during prolonged heat waves or droughts [15]. However, almost a third of the country's production is from hydro, which may help increase electricity security depending on future precipitation patterns, which in northern Europe will likely be an increase, enhancing hydro capacity [19, 41, 42]. Between 2000 and 2011 however, the share of thermal electricity production of LU has increased by more than 40% [43].

Electricity production and consumption below the heating threshold in LU on the other hand are not particularly steep in terms of slope to temperature (influencing factors 1.1 and 1.2) and therefore the effects of projected temperature increases will not decrease susceptibility by a significant margin in terms of electricity savings from heating. Many of the countries examined, including LU, experience large volumes of tourists at different time periods in the year. The potential effects of the temporary increase or decrease in population due to tourism on electricity consumption could act as a small factor in decreasing consumption during summer months for LU where trips surpass arrivals during that period [34].

GR. GR is the second most susceptible country in the relative index and due to the fact that it already reaches the cooling threshold (influencing factors 1.3 and 1.4). Similar to LU, electricity production and consumption have a steep slope in relation to temperature, meaning that as temperatures rise, so too does electricity consumption, primarily due to the high number of air conditioners (influencing factors 5.1 and 5.2). Furthermore, the expected temperature changes due to climate change indicate a distinct warming during the summer that outweighs any winter warming meaning that cooling related electricity consumption will probably increase (influencing factors 4.1 and 4.2). GR is a net consumer of electricity in both summer and winter months and therefore a consistent net importer of electricity by a large margin (influencing factors 2.3 and 2.4).

FR. FR is considered to have moderate susceptibility in terms of the ranked index, which is not higher due largely to its production surplus (influencing factors 2.3 and 2.4). FR is striving for energy security and has an investment body, which identifies electricity production needs to aid in this endeavor [44]. Furthermore, and what might explain at least part of the production surplus in FR is that while base load electricity consumption can easily be met, peak consumption is ever increasing, which requires more production capacity [44].

Currently, FR does not exceed the cooling threshold, however with projected temperature increases for summer months (influencing factor 4.2) and increases in air conditioner stock in the future (influencing factor 5.1), susceptibility will likely increase. FR may face further problems in the future due to its reliance on thermal electricity production, mainly nuclear (influencing factors 3.1 and 3.2). Over the past decade, a number of extreme weather events, which are likely to increase in frequency with climate change, were problematic to the FR electricity system [2, 7]. The summers of 2003 and 2009 proved particularly problematic due to heat waves impacting cooling water for nuclear power plants in terms of amount and temperature [2, 14]. In 2009, a third of the nuclear electricity plants in FR were shut down due to the summer heat wave, forcing FR to import electricity [2].

CH. CH is moderately susceptible relative to other countries in the ranked index and total values (no air conditioner data was available however), but behaves uniquely, with seasonal differences in the system. Electricity consumption and production in CH are highly correlated (influencing factor 2.1 and 2.2) and CH has a production surplus during summer months (influencing factor 2.3), due to its utilization and management of hydro. Hydro reservoirs are often filled during periods of higher precipitation and glacier melting (spring months) and stored in summer until times of need or for export during ideal market conditions [42, 45]. Electricity production for CH also varies greatly by year however, which is primarily due to precipitation changes affecting hydro electricity production, leading to further discrepancy between production from consumption [41]. Nuclear electricity production decreases during summer months, while hydro production increases, indicating that nuclear is used to help meet the winter peak while hydro is used for export. This seasonal shift of production sources may add to the variability of the system, due to the fact that CH produces the most in times when it can easily meet its own consumption needs, and thus it has no electricity security issues for that period. Thus, CH is the only country with a positive correlation between electricity production and mean temperature for the values below the heating threshold.

CZ. CZ is a less susceptible country in the index mainly due to a large production surplus (influencing factors 2.3 and 2.4). Furthermore, CZ is not expected to substantially increase its currently low air conditioner stock in the future (influencing factors 5.2), and will experience only a moderate temperature increase (influencing factors 4.1 and 4.2), which is greater in winter than summer. The combustible fuel and nuclear electricity production sources on which CZ is almost complete reliant (influencing factors 3.1 and 3.2) will likely be negatively affected by climate change in the future, which will inevitably increase susceptibility. However, CZ currently has a large reserve of domestic resources (primarily coal and uranium) that is easily accessible and readily used for electricity production, which will maintain electricity security in the near future [46].

NO. The least susceptible country in the ranked index is NO with low susceptibility in the majority of the influencing factors. It is important to note however, that there was no air conditioner data available for NO, and therefore, the index ranking value is lower. That being said NO has low relative susceptibility for influencing factors 1.1 and 1.2, meaning that as the climate changes, electricity production and consumption will decrease during the winter months. Furthermore, NO will benefit the most from the temperature changes, with the winter rise in temperature being far greater than the summer increase (influencing factors 4.1 and 4.2). NO has almost no electricity production from thermal sources (influencing factors 3.1 and 3.2), and relies almost exclusively on hydro electricity which will experience greater capacity due to precipitation increases in the future in the course of climate change, which will therefore be beneficial for electricity production in the country [1]. Finally, NO is a net producer of electricity in both summer and winter (influencing factors 2.3 and 2.4) and therefore has the ability to export the excess.

Universal Trends. All of the countries, to differing degrees, show an increase in monthly electricity consumption from February to March, which for most countries is against the generally decreasing electricity production and consumption trend in spring. This can be likely explained by the 1 hour clock change for daylight savings time, usually done in March [47]. Daylight savings are designed to increase the number of daylight hours and therefore reduce electricity consumption due to decreases in heating and lighting, however studies show that for the first few weeks after the change in spring, consumption increases due to earlier wake up times which require more heating [48, 49].

Day length (the number of daylight hours) varies seasonally and geographically, and has a potential significant effect on electricity consumption due to lighting requirements. Lighting accounts for approximately 10% of household electricity use on average in European countries, however the monthly variation of consumption share is more important than the average [16]. Koroneos and Kottas [50] demonstrate that for GR, electricity consumption for lighting peaks in the months of January and December, and is the lowest in the months of June and July. Their study reinforces the seasonal variation and possible influence of lighting on electricity consumption, especially considering that GR is one of the southernmost countries examined in this study, which means it would experience the least variation of day length throughout the year.

The monthly electricity production and consumption from 2000-2011 demonstrates an overall increasing trend of the variables over time. This increase could be due to a number of factors, most notable are a rise in GDP and rise in population (except DE (Germany) and HU experienced no consistent population increase during the time period) [34]. However, the time frame of only 11 years (due to data availability) does not provide enough for a sound statement regarding an increasing trend especially due to the GDP decrease seen among most countries (with the exception of BE (Belgium)) around 2008/2009, which is most likely due to the global financial crisis [51].

4.1.2. Results Correlation with Existing Studies

The ranked susceptibility index correlates well with a number of existing studies, however no previous work examines the electricity system in the same way or utilizes the same set of influencing factors. The index aligns well with a study by Eskeland and Mideksa [7] which identifies the relative effects on heating and cooling due to climate change in Europe. The study concludes that climate change will induce less heating in northern European countries, while increasing cooling in southern European countries. Ultimately, the study identifies GR, IT and ES as countries that will experience cooling increases that outweigh heating decreases due to climate change. Thus correlating with the higher susceptibility ranking of GR and IT seen in our index. ES on the other hand is only moderately susceptible in our ranked index, something that is due to the inclusion of a wider range of influencing factors especially the production and consumption correlation, which decreases the susceptibility of ES.

A study by Gnansounou [52], assesses the susceptibility of the energy sector as a whole (including the electricity sector) on a country level in terms of a much wider scale which take into account a number of influencing factors including energy intensity, oil and gas import dependency, CO_2 content of primary energy supply, electricity supply weaknesses and non diversity in transport fuels. Despite the very different influencing factors considered and wider range of countries examined, the ranked index of susceptibility presented in the study is similar to the findings of this study. GR, LU and IT were found to be very susceptible, while NO, FR and GB are considered relatively less susceptible. Obviously, due to the examination of the energy, as opposed to electricity sector, there are some differences to our relative index ranking, and only NO is consistent with the lower susceptibility, GB is more susceptible in our index mainly due to a strong projected increase in air conditioner stock in the future. The reasons for the increase of susceptibility in FR are explained in Section 4.1.1.

Studies by Rübbelke and Vögele [2] and van Vliet et al. [8] examine the negative effects of climate change on the electricity production ability in Europe, specifically on the most susceptible electricity production source, thermoelectric generation. Southern and southeastern Europe are identified as being particularly susceptible to climate change related problems which correlates well with the index for GR and IT, however not for PT which has very low air conditioner stock [8]. The potential issues are however, also present for any countries in the index that utilize thermoelectric production sources, which includes some of the least susceptible countries in the index, most notably CZ.

4.1.3. Sensitivity Analysis

The goal of the sensitivity analysis is to identify the relative sensitivity of each influencing factor on the ranked susceptibility index. The sensitivity analysis helps identify which influencing factors have the most effect on the index value and therefore ranking. The index is the least sensitive to the slope of electricity and mean temperature for the cooling values (1.3 and 1.4). This may be explained by the fact that only five countries reach the cooling threshold. The projected temperature increase in summer (4.2) has the most effect on the index, likely due to the fact that summer temperatures increases will have a profound effect on electricity consumption, partly due to air conditioner use for warmer countries, and decreases in heating trends in colder countries. In both cases, the summer temperatures will largely dictate future susceptibility. The thermal production percent (3.1) also has a large effect on the index; this can be explained by the higher susceptibility of countries with heavy reliance on thermal production.

4.2. Limitations

The major limitation of this study was the access and availability of data. The only available monthly electricity data for a wide range of European countries included only the period from 2000 to 2011, and did not cover the entire continent (only 21 countries). Daily electricity data for that period would have been quite useful however no such data was found. This is particularly pertinent due to the well documented 2003 summer heat wave in Europe which caused a number of problems for some countries in terms of meeting electricity demand and forced changes to the electricity system, but did not appear in the monthly data due to the shorter time scale of the event [7, 14, 19, 53].

One specific limitation was the air conditioner data, which was published in 2008, and therefore only the 2005 data values were measured, while the others were projections. Moreover, the data only reveal information about the number of air conditioners that exists in a country, and not how or when they are used. The assumption is then that countries with a lot of air conditioners put them to use when the temperature exceeds the cooling threshold, however this is not necessarily true. Furthermore, the air conditioner data did not provide values for CH and NO; meaning that the integration of that data could change the index.

Despite the fact that all electricity generation sources are affected in some way by climate change, there is no relative quantitative data on the effects on electricity production. Therefore, based on the available research, only thermal electricity production (combustible fuels and nuclear) was considered to be susceptible [14, 19]. Studies concerning the 2003 heat wave in Europe cite thermal power plant output as being problematic [2, 19, 54]. Furthermore, and perhaps the most compiling evidence of the increased susceptibility of combustible fuel electricity production is the political and social objection to these emission intensive and controversial electricity production sources. Due to an increasing push for lower greenhouse gas emissions by a number of European countries as well as historical and recent nuclear power disasters, nuclear and fossil fuel phase out plans have been made. Most notably, DE has planned to close all of its nuclear power plants by 2022, along with the remaining black coalmines by 2018 [55, 56]. Ultimately, even a country with ample electricity production now, may see its surplus diminish as thermal production decreases with growing environmental, social and political pressure, something that will probably not be the case for hydro or renewable production sources.

Hydro electricity generation is also susceptible to extreme events and changing precipitation patterns due to climate change, however research into the specific effects associated with this phenomenon yields contradictory results and the susceptibility may increase or decrease [6, 18, 19]. Furthermore, the complex interaction between climate and hydro electricity requires a detailed geographically specific analysis in order to quantitatively determine susceptibility.

The EU, as a whole has been undertaking extensive integration of renewable electricity production, which exceeded 20% in 2010, meeting a 2001 target [57]. An even more ambitious EU renewable electricity target for 2030 has been requested by industry, with the goal of decreasing emissions as well as improving energy security in the EU, both of which require a move away from traditional thermal electricity production [57]. It is likely that along with the planned electricity and energy targets for the EU, substantial electricity production changes will be undertaken in most countries in the upcoming years, unfortunately any kind of future calculations or quantification in terms of the projected impacts of those changes on the electricity system susceptibility would require extensive country specific analysis.

Electricity storage capacity could affect the susceptibility of the electricity system of a given country strongly, but was not integrated in this study due to lack of adequate data [42]. CH utilizes hydro electricity greatly and has a number of planned and existing hydro pumped storage plants which, if integrated in this study would decrease its index susceptibility ranking [58]. Besides hydro pumped storage there are a number of energy storage technologies which, if available, bridge production and consumption fluctuations [59].

5. Conclusions

Assessing the susceptibility of European electricity systems to climate change on a country level is a complex issue with a wide variety and number of influencing factors. It is clear however, that many countries are not only susceptible to climate related stresses currently, but will become more susceptible in the future. This study provides an overall outlook of the susceptibility of 21 European countries to climate change, something that has not been previously undertaken to this degree in terms of geographic scope and specific influencing factors examined, but builds on the findings of existing studies. Ultimately, a ranked susceptibility index was presented that provides a quantitative relative indication of susceptibility among the countries included. The study was successful in identifying those countries that are susceptible to climate change, along with the specific aspects of their electricity system that are vulnerable. No distinct pattern was evident in terms of electricity system characteristics or susceptibility influencing factors between countries ranked higher or lower in the index. This lack of similarity between countries highlights the complexity and distinct nature of each country's electricity system and its relation to climate. The index utilized influencing factors, both current and projected, all of which were significant enough to affect the ranking.

The findings of this study are useful in a number of ways. In terms of decreasing susceptibility, policy makers, scientists and energy managers can examine the most important influencing factors that increase susceptibility and focus their adaptation efforts on those areas. Furthermore, due to the relative nature of the susceptibility index, countries with higher susceptibility can identify countries with less susceptible electricity systems and use them as a guide to decrease their own susceptibility. Further work incorporating more influencing factors such as the influence of prices and the electricity market on consumption, the political and social outlooks and decision making processes in regard to the electricity system, as well as specific energy plans for each country could all be beneficial. The inclusion of those additional factors would add an additional level of understanding to the overall understanding of susceptibility within the system. We feel that the findings of this study are an important first step towards a comprehensive analysis of the susceptibility of European countries to climate change.

6. Acknowledgments

The authors acknowledge the financial support of the German Federal Ministry of Education and Research (PROGRESS, Grant # 03IS2191B). We wish to thank the helpful comments of the anonymous reviewers and are greatly indebted to the members of the PIK Climate Change and Development working group who provided data and calculations as well as many valuable comments, discussions and remarks.

[1] J. Alcamo, J. M. Moreno, B. Nováky, M. Bindi, R. Corobov, R. Devoy, C. Giannakopoulos, E. Martin, J. r. E. Olesen, A. Shvidenko, Europe, in: M. Parry, O. Canziani, J. Palutikof, P. van der Linden, C. Hanson (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge Uniceristy Press, Cambridge, UK, 2007, pp. 541–580.

[2] D. Rübbelke, S. Vögele, Impacts of climate change on European critical infrastructures: The case of the power sector, Environmental Science & Policy 14 (1) (2011) 53–63.

[3] G. R. McGregor, C. A. T. Ferro, D. B. Stephenson, Projected Changes in Extreme Weather and Climate Events in Europe, in: K. Wilhelm, B. Menne, R. Bertollini (Eds.), Extreme Weather Events and Public Health Responses, Springer, 2005, Ch. 2, pp. 13–23.

[4] A. Michaelowa, H. Connor, L. E. Williamson, Use of indicators to improve communication on energy systems vulnerability, resilience and adaptation to climate change, in: A. Troccoli (Ed.), Management of Weather and Climate Risk in the Energy Industry, Springer, 2010, pp. 69–87.

[5] S. Mimler, U. Müller, S. Greis, B. Rothstein, Impacts of Climate Change on Electricity Generation and Consumption, in: W. Leal Filho (Ed.), Interdisciplinary Aspects of Climate Change, Peter Land Scientific Publishers, Frankfurt, 2009, pp. 11–37.

[6] The World Bank, Europe and Central Asia Region - How Resilient is the Energy Sector to Climate Change?, Tech. rep., The World Bank (2008).

[7] G. S. Eskeland, T. K. Mideksa, Electricity demand in a changing climate, Mitigation and Adaptation Strategies for Global Change 15 (8) (2010) 877–897.

[8] M. T. H. van Vliet, J. R. Yearsley, F. Ludwig, S. Vögele, D. P. Lettenmaier, P. Kabat, Vulnerability of US and European electricity supply to climate change, Nature Climate Change 2 (7) (2012) 1–6.

[9] M. Olonscheck, A. Holsten, J. P. Kropp, Heating and cooling energy demand and related emissions of the German residential building stock under climate change, Energy Policy 39 (9) (2011) 4795–4806.

[10] L. Costa, J. P. Kropp, Linking components of vulnerability in theoretic frameworks and case studies, Sustainability Science 8 (1) (2012) 1–9.

[11] P. White, M. Pelling, K. Sen, D. Seddon, S. Russell, R. Few, Disaster risk reduction : a development concern. A scoping study on links between disaster risk reduction, poverty and development. (2005).

[12] B. L. Turner, R. E. Kasperson, P. a. Matson, J. J. McCarthy, R. W. Corell, L. Christensen, N. Eckley, J. X. Kasperson, A. Luers, M. L. Martello, C. Polsky, A. Pulsipher, A. Schiller, A framework for vulnerability analysis in sustainability science., Proceedings of the National Academy of Sciences of the United States of America 100 (14) (2003) 8074–9.

[13] B. Psiloglou, C. Giannakopoulos, S. Majithia, M. Petrakis, Factors affecting electricity demand in Athens, Greece and London, UK: A comparative assessment, Energy 34 (11) (2009) 1855–1863.

[14] M. Flörke, I. Bärlund, E. Kynast, Will climate change affect the electricity production sector? A European study, Journal of Water and Climate Change 3 (1) (2011) 44.

[15] B. Hoffmann, S. Häfele, U. Karl, Analysis of performance losses of thermal power plants in Germany A System Dynamics model approach using data from regional climate modelling, Energy 49 (2013) 193–203.

[16] P. Bertoldi, B. Atanasiu, Electricity Consumption and Efficiency Trends in European Union, Tech. rep., European Commission, Joint Research Centre, Institute for Energy, Luxemburg (2009).

[17] M. Hekkenberg, R. Benders, H. Moll, A. Schoot Uiterkamp, Indications for a changing electricity demand pattern: The temperature dependence of electricity demand in the Netherlands, Energy Policy 37 (4) (2009) 1542–1551.

[18] K. Rademaekers, J. van de Laan, S. Boeve, W. Lise, C. Kirchsteiger, Investment needs for future adaptation measures in EU nuclear power plants and other electricity generation technologies due to effects of climate change, Tech. Rep. March, European Commission, Brussels (2011).

[19] D. Rübbelke, S. Vögele, Distributional Consequences of Climate Change Impacts on the Power Sector : Who gains and who loses ?, Tech. Rep. 349, Centre for European Policy Studies, Brussels (2011).

[20] T. J. Wilbanks, V. Bhatt, D. E. Bilello, S. R. Bull, J. Ekmann, W. C. Horak, Y. J. Huang, M. D. Levine, M. J. Sale, D. K. Schmalzer, M. J. Scott, Effects of Climate Change on Energy Production and Use in the United States, Tech. Rep. February, U.S. Climate Change Science Program (2008).

[21] European Climate Assessment and Dataset, E-OBS Gridded Dataset, retrieved: 25/6/2012 (2012).
URL http://eca.knmi.nl/download/ensembles/download.php\#datafiles

[22] EUROSTAT, GEOSTAT 1km2 population grid dataset, retrieved: 2/7/2012 (2006).
URL http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco_Geographical_information_maps/popups/references/population_distribution_demography

[23] ESRI, ArcGIS Desktop (2011).

[24] T. Mitchell, M. Hulme, M. New, Climate data for political areas, Tech. rep., Tyndall Centre (2002).

[25] M. Hekkenberg, H. Moll, a. S. Uiterkamp, Dynamic temperature dependence patterns in future energy demand models in the context of climate change, Energy 34 (11) (2009) 1797–1806.

[26] D. J. Sailor, J. R. Muiqoz, Sensitivity of electricity and natural gas consumption to climate in the U.S.A. - Methodology and results for eight states, Energy 22 (10) (1997) 987–998.

[27] E. Valor, V. Meneu, V. Caselles, Daily Air Temperature and Electricity Load in Spain, Journal of Applied Meteorology 40 (2001) 1413–1421.

[28] A. Matzarakis, F. Thomsen, Heating and cooling degree days as an indicator of climate change in Freiburg, Tech. rep., University of Freiburg, Freiburg (2007).

[29] M. Christenson, H. Manz, D. Gyalistras, Climate warming impact on degree-days and building energy demand in Switzerland, Energy Conversion and Management 47 (6) (2006) 671–686.

[30] R. Engle, C. Mustafa, R. J, Modelling and forecasting daily series of electricity demand, Journal of Forecasting 11 (1992) 241–251.

[31] M. Prek, V. Butala, Base temperature and cooling degree days, Tech. rep., University of Ljubljana (2010).

[32] IEA, Monthly Electricity Statistics Archives, retrieved: 12/4/2012 (2012).
URL http://www.iea.org/stats/surveys/elec_archives.asp

[33] J. Adnot, L. Grignon-Masse, S. Legendre, D. Marchio, G. Nermond, S. Rahim, P. Riviere, P. Andre, L. Detroux, J. Lebrun, J. L'Hoest, V. Teodorose, J. L. Alexandre, E. Sa, G. Benke, T. Bogner, A. Conroy, R. Hitchin, C. Pout, W. Thorpe, S. Karatasou, Preparatory study on the environmental performance of residential room conditioning appliances (airco and ventilation) - Economic and Market analysis, Tech. rep., The European Commission (2008).

[34] EUROSTAT, Energy Statistics Database, retrieved: 12/4/2012 (2012).
URL http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database

[35] M. Nardo, M. Saisana, A. Saltelli, S. Tarantola, A. Hoffman, E. Giovannini, Handbook on Constructing Composite Indicators: Methodology and user's guide, oECD (2005).

[36] J. C. Lam, K. K. Wan, T. N. Lam, S. Wong, An analysis of future building energy use in subtropical Hong Kong, Energy 35 (3) (2010) 1482–1490.

[37] R. Fraiman, A. Justel, M. Svarc, Selection of Variables for Cluster Analysis and Classification Rules, Journal of the American Statistical Association 103 (483) (2008) 1294–1303.

[38] R. Schaeffer, A. S. Szklo, A. F. Pereira de Lucena, B. S. Moreira Cesar Borba, L. P. Pupo Nogueira, F. P. Fleming, A. Troccoli, M. Harrison, M. S. Boulahya, Energy sector vulnerability to climate change: A review, Energy 38 (1) (2012) 1–12.

[39] IEA, Energy Policies of IEA Countries: Luxembourg 2008 Review, Tech. rep., International Energy Agency, Paris (2009).

[40] European Commission, Luxembourg - Energy Mix Fact Sheet, Tech. rep., European Commission (2007).

[41] IEA, Energy Policies of IEA Countries: Switzerland 2007 Review, Tech. rep., International Energy Agency, Paris (2007).

[42] M. Semadeni, Energy storage as an essential part of sustainable energy systems - A review on applied energy storage technologies, Tech. Rep. 24, Centre for Energy Policy and Economics, Zürich (2003).

[43] IEA, Energy Policies of IEA Countries: Spain 2009 Review, Tech. rep., International Energy Agency, Paris (2009).

[44] IEA, Energy Policies of IEA Countries: France 2009 Review, Tech. rep., International Energy Agency, Paris (2010).

[45] F. Paul, A. Kääb, W. Haeberli, Recent glacier changes in the Alps observed by satellite: Consequences for future monitoring strategies, Global and Planetary Change 56 (1-2) (2007) 111–122.

[46] IEA, Energy Policies of IEA Countries: The Czech Republic 2010 Review, Tech. rep., International Energy Agency, Paris (2010).

[47] European Parliament and Council, DIRECTIVE 2000/84/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 19 January 2001 on summer-time arrangements (2001).

[48] R. Kellogg, H. Wolff, Does Extending Daylight Saving Time Save Energy? Evidence from an Australian Experiment, Tech. rep., Institute for the Study of Labor (IZA), Bonn (2007).

[49] M. J. Kotchen, L. E. Grant, Does daylight saving time save energy? Evidence from a natural experiement in Indiana, working Paper (2008).

[50] C. Koroneos, G. Kottas, Energy consumption modeling analysis and environmental impact assessment of model house in Thessaloniki (Greece), Building and Environment 42 (1) (2007) 122–138.

[51] European Commission, Economic Crisis in Europe : Causes , Consequences and Responses, Tech. rep., Economic and Financial Affairs, Luxembourg (2009).

[52] E. Gnansounou, Assessing the energy vulnerability: Case of industrialised countries, Energy Policy 36 (10) (2008) 3734–3744.

[53] M. Rebetez, O. Dupont, M. Giroud, An analysis of the July 2006 heatwave extent in Europe compared to the record year of 2003, Theoretical and Applied Climatology 95 (1-2) (2008) 1–7.

[54] H. Förster, J. Lilliestam, Modeling thermoelectric power generation in view of climate change, Regional Environmental Change 10 (4) (2009) 327–338.

[55] A. Breidthardt, German government wants nuclear exit by 2022 at latest, retrieved: 23/8/2012 (May 2011).
URL http://uk.reuters.com/article/2011/05/30/us-germany-nuclear-idUKTRE74Q2P120110530

[56] C. Dougherty, Germany finds solution to its withering coal mines, retrieved: 23/8/2012 (Jun. 2007).
URL http://www.nytimes.com/2007/06/14/world/europe/14iht-coal.4.6143627.html?_r=1

[57] EWEA, EU met its 2010 Renewable electricity target - ambitious 2030 target needed, retrieved: 4/9/2012 (2012).
URL http://www.ewea.org/index.php?id=60\&no_cache=1\&tx_ttnews\%5Btt_news\%5D=1928\&tx_ttnews\%5BbackPid\%5D=1\&cHash=4b7e762152ac15e75a14d10ccd960778

[58] C. Huber, C. Gutschi, Pump-Storage Hydro Power Plants in the European Electricity Market, Tech. rep., Institute for Electricity and Energy Innovations, Graz University of Technology, Graz (2010).

[59] C. Naish, I. McCubbin, O. Edberg, M. Harfoot, Outlook of Energy Storage Technologies, Tech. Rep. January 2004, European Parliament, Brussels (2008).