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ELECTRICITY DEMAND FORECAST FOR BAVARIA AND THE CZECH REPUBLIC UNTIL 2050: CAN VARIABLE RENEWABLES COPE WITH IT?

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ABSTRACT

The energy transition raises a need for innovative ideas to cope with the integration of high shares of variable renewable energy sources. Across political, industrial and research audiences, the idea of electricity self-sufficiency has been gaining rising interest. It might, among others, solve questions of energy security and help to avoid short term necessary investments into the electricity grids. However, while electricity self-sufficiency can be technically feasible for a large range of user types (e.g. residential, agricultural, and industrial) and cluster sizes (e.g. individuals, districts, municipalities), it becomes rapidly unfeasible when strict regulations are considered. In this study, the feasibility of electricity self-sufficiency based on free-standing photovoltaics, wind power and storage systems was evaluated for all municipalities in Bavaria (Germany) and the Czech Republic. Main focus of this paper is the calculation of the spatially distributed electricity demand of today and the future. Methods for the technology potential evaluation and the development of an optimization model to determine necessary system sizes are shortly presented referring to previous work. Results indicate that around 20% of the German and 6% of the Czech municipalities could achieve self-sufficiency today based on the considered technologies and under current Bavarian regulatory restrictions. These figures improve enormously with milder regulations for wind power installations. Furthermore, due to an expected depopulation of rural areas, a rising trend in potentially electricity self-sufficient municipalities is visible.

Keywords: renewable energy resources, spatially distributed electricity demand, demographic changes, land use changes, regional reanalysis, spatiotemporal modelling

ABBREVIATIONS

NUTS-3	Level 3 of the Nomenclature des unités territoriales statistiques
LAU-2	Level 2 of the Local Administrative Units, an addition to the NUTS

1. INTRODUCTION

In the decades to come, the European Union plans to cover the demand for electricity mainly by use of renewable energy sources. This implies an infrastructural transformation with massive technological, economical and societal changes and challenges. One idea that has earned rising attention in this context, is the electricity self-sufficiency based on variable renewable energy sources such as solar and wind power in combination with storage systems. Research results and practical examples show that this idea is technically feasible and in spite of the large capacities that are required to be installed, it represents an advantage for energy supply security. Additionally, it may even be a suitable alternative to electricity grid expansions. Studies dealing with this topic focus on detailed calculations of renewable energy potentials under current conditions, but usually follow simplified and static approaches for the determination of electricity demand. Left aside are e.g. urbanization trends or changes in consumption behavior. These are, however, key elements to be considered in the conception of decentralized fully renewable energy systems that should last for several decades. For instance, in a recent review, Lindberg et. al. [1] identified four missing elements that should be included to improve methodologies to forecast long-term electricity demand: 1) the decomposition of the

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demand into different sectors; 2) a detailed temporal granularity; 3) the integration of macro-economic drivers that influence long-term developments such as population changes; and 4) technological development and penetration in different market segments.

This paper contributes to the discussion of electricity self-sufficiency of municipalities putting emphasis on the impact of urbanization and rural depopulation as well as regulatory frameworks for renewable energy sources in Bavaria (Germany) and the Czech Republic. It suggests a novel methodology for the spatial disaggregation and forecast of electricity demand. Three (1-3) out of four recommendations made by Lindberg et. al. [1] are addressed within the here presented forecast. This study relies on previous work for the determination of electricity generation potentials of photovoltaics and wind power using high resolution spatiotemporal weather data. Results show which municipalities would be able to cover their local electricity demand solely by use of on-site renewable energy installations. Three alternative regulatory constraints for wind power deployments as well as population and land use changes until 2050 are considered.

2. MATERIAL AND METHODS

Three elements are necessary in order to calculate and evaluate electricity self-sufficiency of municipalities in Bavaria and the Czech Republic: 1) the electricity demand of each municipality, 2) the generation potential of the considered technologies and 3) an algorithm to determine if the available potential can cover the demand. The main focus of this chapter is to display the novel methodology of estimating the spatially distributed electricity demand (section 2.1). The other two elements, which were developed in previous work, are briefly described in sections 2.2. and 2.3.

2.1 Electricity Demand Estimation

The methodology is predominantly focused on the spatial (dis)aggregation of regions (r) and municipalities (m). To gather all necessary information, different datasets needed to be combined. The goal is to define the total electricity demand on the scale of municipalities, as well as the share of electricity demanded by the sectors agriculture, households and industry.

2.1.1 Germany

The total electricity demand of Bavaria (d_r), the total electricity demand per municipality in Bavaria (d_m) as well as the final electricity consumption of households per municipality (fd_m^h), is provided by the Bavarian Environment Agency [2]. The electricity demand for agriculture, however, is only given by use of the average size (l_g^a) and energy consumption (d_g^a) per farm (denoted by $_g$) [3]. Therefore, the estimated average agricultural electricity demand per km² was applied to all areas that are utilized for agriculture on the regional level (l_r^a) following equation 1.

$$(1)\quad d_r^a = \frac{d_g^a}{l_g^a} * l_r^a$$

The resulting electricity demand for agriculture in Bavaria (d_r^a) needs to be distributed to the different municipalities on hand of the share of agricultural areas in every municipality (l_m^a). Like this, the electricity demand for agriculture of each municipality (d_m^a) is gained:

$$(2)\quad d_m^a = \frac{l_m^a}{l_r^a} * d_r^a$$

The share of the electricity demand needed by the industry (d_r^i) was provided only on a regional scale [4]. This source (denoted by ^{c}) is a different one than the one containing the previously mentioned household electricity demand information. It provides also a slightly different total regional electricity demand (d_r^c) than the former one (d_r). These two different total regional electricity demand figures are aligned by calculating the municipal electric energy needed for the industry (d_m^i). Herein, the first step was to multiply the share of industrial regional electricity demand ($\frac{d_r^i}{d_r^c}$) (calculated by use of the second source) with the total regional electricity demand of the first source (d_r). Secondly, this resulting regional demand of industrial electricity was allocated to each municipality by dividing the respective industrial municipal area (l_m^i) by the industrial area of the whole region (l_r^i).

$$(3)\quad d_m^i = \frac{d_r^i}{d_r^c} * d_r * \frac{l_m^i}{l_r^i}$$

By combining different data sources and executing the mentioned calculations, a size of electricity demand per sector, municipality and region is now given. However, as the different numbers arose from diverse sources, they only provide an approximation to the real electricity demand for the different subjects under observation. Therefore, when aggregating the newly calculated municipal electric energy demand, it exceeds the regional electricity demand that stems from official statistics [2]. It can be assumed that the diverging numbers result from discrepancies between the industrial and agricultural electric energy estimations. To overcome this problem, first the household electric energy demand is deducted from the total municipal electricity demand (equation 4) and secondly, a ratio between industrial and agricultural electricity demand is estimated (equation 5).

$$(4)\ d^u_m = fd^h_m - d_m \qquad (5)\ r_m = \frac{d^i_m}{d^a_m}$$

Finally, by use of the created ratio (r_m), the missing final agricultural (fd^a_m) and industrial (fd^i_m) electricity demand per municipality is calculated (equation 6 and 7).

$$(6)\ fd^a_m = \left(1 - \frac{r_m}{r_m+1}\right) * d^u_m \qquad (7)\ fd^i_m = \left(\frac{r_m}{r_m+1}\right) * d^u_m$$

2.1.2 Czech Republic

The Czech Republics’ Energy Regulatory Office (ERU) provides yearly “Reports on the Operation of the Electricity Grid” [5]. From those, the net electricity consumption by economic sector (industry (d^i_r), farming and forestry (d^a_r), households (d^h_r)) as well as the total electricity demand (d^t_r) per region (NUTS-3) for the year 2016 can be extracted.

This database covering the sectoral distribution and total regional demand, satisfies the needs for further processing and makes equations (1, 2 and 3) unnecessary for the Czech case. To apply a similar methodology as far as possible for both countries and to be able to compare the results within the regions, equations (4,5,6 and 7) were applied to the Czech Republics’ case. These calculations lead to the final agricultural (fd^a_m) and industrial (fd^i_m) electricity demand. No further calculation is necessary to determine the demand of households since this is provided in the original data set.

2.1.3 *Forecast for 2030 and 2050*

In order to forecast the electric energy demand on hand of population as well as land use related future changes, information from the LUISA Territorial Modeling Platform provided by the European Commission [6] was used. The Platform provides data on how the land use in the European Union could change in steps of ten years from 2010 onwards until 2050 and in a spatial resolution of 1 km^2. Furthermore, projections of the population development (number of inhabitants) are given for the same time steps and spatial resolution.

The first step within the forecasting of electricity demand for each municipality, is to calculate the current electricity density (ed) for agricultural, industrial and household electricity demand. This is done by dividing the respective sector (^{s}) by the specific LUISA (LU) Dataset (equation 8). Afterwards, this density is multiplied with the sector specific municipal area of the years under observation (y) as presented in equation 9. The results display the future electricity demand per sector and municipality for the years 2030 and 2050.

$$(8)\ ed^s = \frac{fd^s_m}{LU^s_m} \qquad (9)\ fd^s_{my} = LU^s_{my} * ed^s$$

Besides the spatial adaptations as described above, also the temporal resolution needed to be considered. This step was executed by use of standard load profiles provided by the German Federal Association of Energy and Water Management (BDEW- Bundesverband der Energie- und Wasserwirtschaft). These load profiles consider both daily and seasonal variations and are available in 15-min time steps for 11 different types of users.

2.2 Electricity Generation Estimation

To estimate the spatial potential for a deployment of free-standing photovoltaics (PV) and wind power installations, a standard approach of area exclusions is applied. In the case of PV, all unbuilt areas in a 100 m stripe around highways are considered as suitable for deployment. For wind power, the restriction guidelines concerning protection areas, land uses and buildings as presented in [7] are followed. The only exception is that the proximity to buildings is calculated for three alternative regulatory constraints (the distance to buildings is either 10, 5 or 3 times the height of the turbines). This is calculated for small, medium and large turbines sizes (10m, 50m and 137m). In order to determine a time series of possible generation capacities of each suitable area, validated regional reanalysis data [8] and the procedure as explained in [9] and [10] are employed.

2.3 Self-sufficiency feasibility

The supply system sizing and the calculation of self-sufficiency feasibility is performed using a mixed integer-linear program that optimizes a hybrid PV+Wind+Battery system by minimizing costs. The optimization model with its necessary parameters is presented in detail in [9,10] Here, it is computed for each municipality in Bavaria and the Czech Republic.

In total, 81 scenarios per country were calculated. Common to all scenarios is the use of an hourly time series of a year with average weather conditions, which is used to estimate the potential energy generation capacities. Additionally, the evaluation of self-sufficiency using the hourly demand data for all types of users is

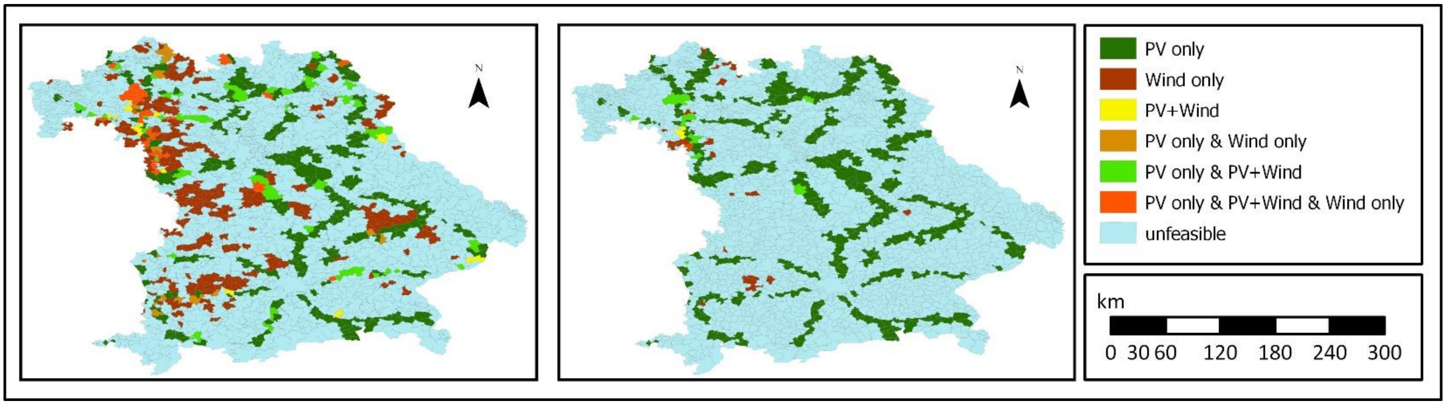

Figure 1 Bavaria in the year 2050. Left map shows municipalities under h3 wind jurisdictions. Map on the right displays self-sufficient municipalities under h10 wind jurisdiction.

cumulated. The scenarios are created by performing individual evaluations on: a) the years 2010, 2030 and 2050, b) three different sizes of wind turbines (10m, 50m and 137m), c) three regulatory constraints for wind power installations (distance to buildings several times the height of the turbines, namely h3, h5 and h10) and d) three different sets of prices for PV and wind power installations. The first set of prices correspond to current average prices for each technology including installation and maintenance. This should produce an optimal mix between PV and wind power to cover the demand of each municipality. In the second set, the prices of the wind turbines are set one thousand times higher than the current costs so that the optimization model finds a solution where the use of PV is prioritized. In the last of the price sets, the cost of PV is set thousand times higher than in the first one, obligating the model to select wind instead of PV. Self-sufficiency is considered feasible when, at least under one of the cost sets, the required installed capacity to fulfill the energy demand calculated by the optimization model, is lower than the available energy potential in a particular municipality.

3. RESULTS

Maps were generated to present the above mentioned scenarios in form of different combinations of years, wind turbine sizes and regulatory constraints. Divided by country, these maps display the self-sufficiency feasibility of each municipality. It is differentiated if self-sufficiency can be achieved in case of one particular scenario or in several of them at the same time. An example is presented for Bavaria in figure 1, representing the year 2050 and the two different regulatory constraints h3 and h10.

In all Bavarian and Czech scenarios, it is striking that the most influential factor of self-sufficiency for a municipality is the legal condition under which a wind turbine is allowed to be build. Considering 10m wind turbines, the jurisdictions do not have a strong impact. However, when considering 50m or 137m wind turbines, the difference between municipalities being able to cover their electricity demand using Wind only or PV and Wind is considerably lower in the h10 scenario compared to h3. This can also be very well noted in figure 1.

The rest of the results are rather different between Bavaria and the Czech Republic. In Bavaria, around 20 % of the municipalities could achieve electricity self-sufficiency with a rising trend of up to around 30% in 2050. Furthermore, in Bavaria there are about 180 additional municipalities that are unincorporated areas and do not yield any energy demands. In the Czech Republic the number of self-sufficient municipalities is stable and only at around 6% with a slight downward trend over the years.

The opposing trends between the two countries can mainly be explained by the higher expected rural depopulation and urbanization tendencies in Bavaria. This leads to a decreased population in many municipalities of Bavaria, and thus a decrease in energy demand that allows the available potential of renewable resources to supply the estimated demand of the future.

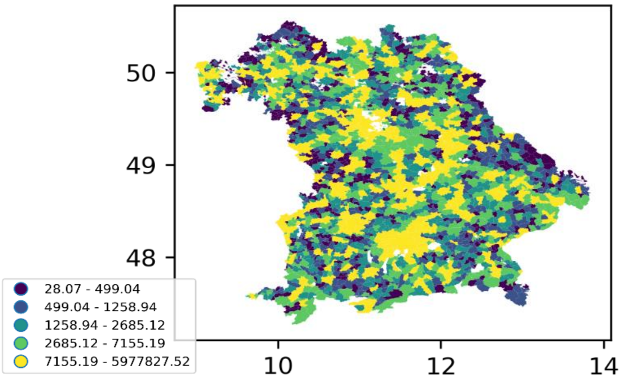

Figure 2: Projected electricity demand in the year 2050 in Bavaria. Values are in MWh. Classified into quintiles.

Figures 2 and 3 allow a graphical comparison of projected demand and supply in one specific scenario. The figures present the year 2050 with 50m high wind turbines and the h3 wind jurisdiction. The white areas in the plots mean there is either no demand or no potential supply from the considered renewables in this municipality. While multiple rural municipalities with decreasing population over the years become able to supply their own demand, larger agglomerations with relatively large renewable electricity generation potential would no longer be able to fulfill their demand merely based on free standing PV, Wind power and storage systems.

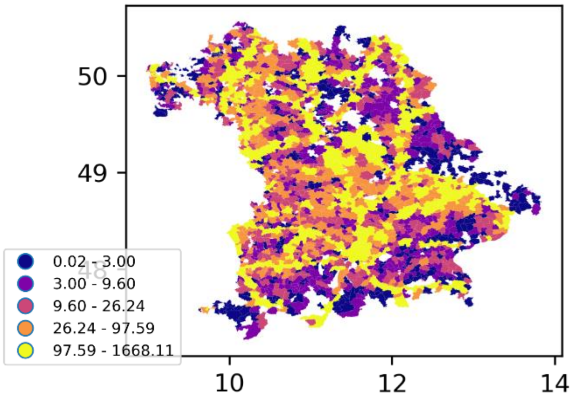

Figure 3: Projected electricity supply potential in Bavaria in the year 2050. Technologies considered are PV and 50m wind turbines under the h3 wind jurisdiction. Values are in MW. Classified into quintiles.

4. CONCLUSION

The estimation of the current and future electricity demand in a spatially explicit way is not an easy task. The proposed method provides a possibility to get around the missing data issues and estimate energy demand figures for municipalities based on logical assumptions and critical estimations.

While the self-sufficiency assessment presented here is simplified to only two supply technologies and storage systems, the results reveal that even under these very limited conditions, self-sufficiency might be feasible for multiple municipalities in Bavaria and the Czech Republic. It is apparent that regulations are the main driver for or against the potential electricity self-sufficiency of the municipalities and that estimated rural depopulation has a bigger effect on the number of potential self-sufficient municipalities in Bavaria than in the Czech Republic.

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