Concept of Evaluating Chances and Risks of Grid Autarky

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***Abstract*—The energy transition in Germany stimulates regions and municipalities to set renewable energy share or CO_2-emission reduction targets. This paper presents a conceptual approach to evaluate the chances and risks of high degrees of grid autarky which arises as a result of these targets. This concept is achieved by combining energy system modelling and socio-economic analysis, which focuses on factors of grid autarky and their synergies. In terms of the energy system analysis, emphasis is given to the integration of power flow constraints and grid extension algorithms within an optimization model. Within this paper first results of a pre-analysis of the regions are presented, which gives an insight into factors that influence the local energy transition. It was identified that support schemes, besides providing financial incentives, serve as a good basis in developing the self-supplying regions by facilitating knowledge and experience exchange. The current renewable self-supply rate and the potential of self-supply on district level enable a clustering of the regions for the system modelling.**

***Index Terms*—autarky, energy system modelling, grid planning, renewable energy regions, system optimization**

I. Introduction

In the context of transition of the energy system the share of decentralized electricity generation technologies is increasing [1]. On the one hand these observations are expected since single stakeholders invest in renewable energy technologies, which have decentralized characteristics. On the other hand there is a high number of communes, cities, or even regions that set own targets for their energy balance to contribute on a local level to the national and international CO_2 reduction targets, which often implies a local deployment of renewables [2]. The targets are often set within a climate protection program. They can include development targets of renewable energy technologies, the increase of energy efficiency, a sustainable restructuring of the transport sector, CO_2-reduction targets and a set plan for the target realisation. As a consequence a rapid increase of the renewable energy technologies are observed within these regions and the potentials are used more intensively.

This leads to the question as to which effects on the energy system result from these self-supplying trends? Are the potentials utilised in the best way or do even additional costs, for example by an intensified grid extension, arise?

II. Methodology

A. *Research Questions*

To address a concept of evaluating the chances and risks of grid autarky the following research questions need to be defined. Within this paper, the first results of research question one are presented whereas the questions two and three are analysed from a conceptual, methodological perspective and not in practical terms.

1. Which factors do influence and/or trigger the developments of renewable self-supplying regions?
2. What are the effects of these regions on the energy system in terms of total system costs, the cost optimal technology mix, the security of supply, the necessary grid extensions and the unit commitment as well as the power flow?
3. What are the chances and risks of grid autarky from the perspectives of different stakeholders at the private, public and industrial level?

To answer the research questions an interdisciplinary approach is used. The fields of socio-scientific research, electricity grid and energy system analysis are joint to address the mentioned questions. Research question one is targeted by a qualitative and quantitative analysis, resulting in different renewable self-supply scenarios for Germany. First an analysis of the renewable energy regions (regarding their targets, potentials and their share of renewable energy generation) using geographical information system (GIS) is conducted. For the socio-scientific research the CIB (cross-impact-balance) method will be used [3]. The method is based on expert interviews and workshops in order to develop different consistent scenarios for the development of renewable self-suppling regions within Germany.

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Research question two will be addressed by further developing an existing energy system model ENTIGRIS. The objective of the model is to identify the required technology mix and infrastructure for the electricity supply in Germany and its neighbouring countries with the constraint of minimal system cost. The model optimizes the unit-commitment and the expansion of the power plants as well as the increase of the net transfer capacities according to [4] and [5]. In terms of the model expansion especially the electricity load flow and grid expansion will be targeted, by integrating new side constraints, which will be identified within an iterative process between the optimization model and a load flow simulation, as well as a separate grid optimization model (refer to Fig. 1). Research question three will be based on the model results, on a qualitative analysis based on literature research as well as on expert interviews.

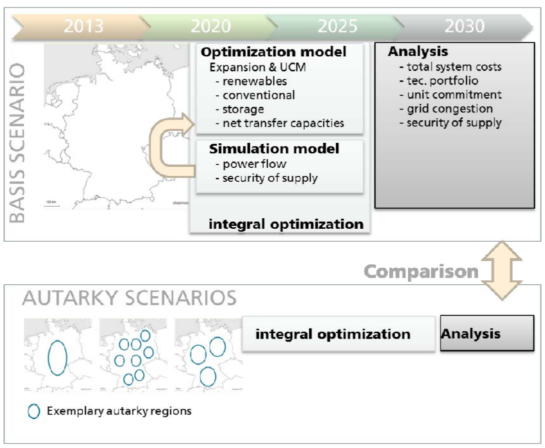

Figure 1: Concept of evaluating chances and risks of grid autarky

In this paper, research question one is partially answered through the pre-analysis. The qualitative system analysis will be conducted in order to completely address the question.

B. *Pre-Analysis of Renewable Energy Regions*

The pre-analysis of the renewable energy regions targets a knowledge development regarding the factors that influence and trigger the development of the renewable energy regions. The following questions are addressed:

- Where are the renewable regions located within Germany?
- To which extend is grid autarky targeted?
- What is the size of the renewable energy regions?

The analysis helps to cluster regions with similar targets or characteristics which are then mapped in an energy system model. Also it gives an overview of the motives for the ambitions to be a renewable energy region. The following parameters were collected within the analysis:

- Location (rural district, region, city etc.)
- Type of support scheme
- Which targets (renewable share or CO_2-emission reduction) are pursued?
- Degree of autarky
- Renewable potential
- Population

To answer the above mentioned questions an extensive literature review was done. The starting point for the overview is the project "100% Renewable Energy Regions" which is led by the Institute of decentralised Energy Technologies (IdE) in Kassel. The project identifies, accompanies and links regions, communes and cities which target to transfer their energy supply on the basis of renewable energies in the long-run. The regions can apply to be integrated in the network. Conditions for their admittance are, besides others targets regarding the renewable energy supply, CO_2-reduction targets and measures for the transformation. [6]

For each of the listed region the above mentioned parameters were collected. For the regions which set their renewable energy target in the long-run the year 2050 as the year of target fulfilment is assumed.

C. *Qualitative System Analysis*

In order to include elements in the analysis, that are not covered by the energy system model (e.g. societal or political developments), a qualitative system analysis using CIB [1] was conducted following the steps listed below [7]:

- Identification of the most crucial scenario factors by expert interviews, literature research and expert survey
- Definition of several realistic development paths for each factor (variants)
- Evaluation of all cross-impacts between the different variants by expert interviews and expert survey
- Analysis of the resulting CIB-matrix to identify the realistic combinations of the variants
- Storyline construction for the selected scenarios

The resulting CIB-matrix gives an overview of the interdependencies between the different scenario factors, as well as identifying all realistic combinations of the different variants: the consistent scenarios. In order to capture the effect on the degree of autarky of different types of regions, as many scenario factors concerning the degree of autarky as there are types of regions will be included as scenario factors. The typology of regions is determined by cluster analysis.

D. *Modelling*

For addressing the second research question the energy system model ENTIGRIS expansion planning is used. The model is a linear optimization problem realized in GAMS. It optimizes the unit-commitment and the expansion of energy technologies, electrical storages and the electrical grid between the investigated regions. The target function minimises the total system cost. The general model setup is pictured in Fig. 2. The methodology is based on [4] and [5].

The model covers Germany (in different regional clusters) and the neighbouring countries as one node for each country. The time horizon of the model for the calculations for this concept is the year 2050. The unit-commitment of the power plants is optimized hourly. The ENTIGRIS expansion planning model allows therefore the system analysis of the German energy system, for different scenarios.

A special focus will be the expanding of the model by integrating side constraints that allows the reproduction of load flow as well as grid extension combined with the technology portfolio expansion within one optimization model. This approach is used to secure the analysis of the influence of renewable self-suppling regions on the whole energy system.

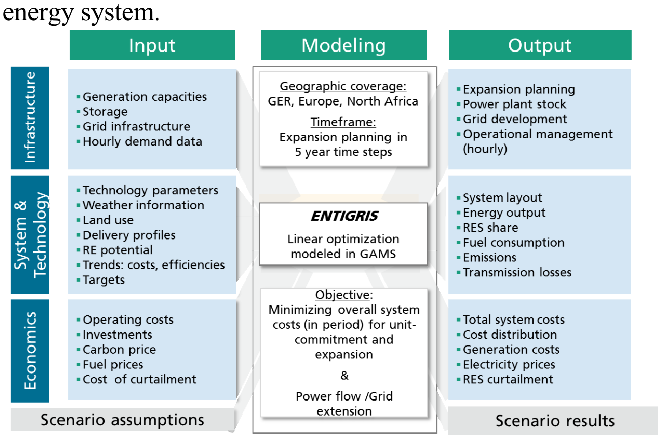

Figure 2: Scheme of ENTIGRIS expansion optimization model

E. *Combination*

The combination of qualitative analysis and quantitative modelling is inspired by the Story and Simulation (SAS) approach to scenario construction [8]. Including qualitative as well as quantitative factors – which also serve as input for the simulation model - in the CIB, each set of factor variants (or scenario) is also defined by a specific input to the energy system model. Thus the final scenarios will consist of the numerical output of the simulation model, as well as of the according combination of qualitative factors, which can be summarized in a storyline.

The scenarios that are defined in table 1will serve as the basis to answer research question two. The reference scenario represents a development, in which no renewable or CO_2-reduction targets are set in each regions. It shall represent the case of an economic optimization – the least cost case. The actual ten year network development plan (TYNDP) of the European network of transmission grid operators (ENTSO-E) [9], which contain the regional investment plans of electricity grids will be considered in each scenario. The realistic scenarios shall take into account, that there are already regions that have set targets and that there is an increasing trend of these regions. It attempts to represent realistic developments regarding the number and size of autarkic regions, their degree of self-supply of electricity and their year of fulfilment. In order to do so, the regions will be clustered before the CIB analysis and result in different factors, representing specific types of regions. Thus, other factors can have a different effect on specific types of regions.

The clustering of the regions for the realistic scenario uses the results of the pre-analysis of the renewable energy regions and additionally a data evaluation of the current and past energy system on NUTS 3 level, referring to [10]. The clustering will combine the targets of the renewable energy regions, their renewable potential and the current status of renewable self-supply.

The potential of photovoltaics and biogas are collected on NUTS 3 level. But the used methodology showing the results within this paper covers only the wind potential on NUTS 2 level (basic regions), which made it necessary to disaggregate the wind potential on NUTS 3 level by the area size of each NUTS 3 region.

TABLE I. SCENARIO DEFINITIONS

Parameter	**Autarkic scenarios**			
	Reference scenario	***Realistic scenario(s)***	***Extreme scenario 100% autarkic regional***	***Extreme scenario 100% large autarkic regions***
Grid	Optimized expansion (incl. TYNDP)	Optimized expansion (incl. TYNDP) – for autarkic regions no additional extension	Optimized expansion (incl. TYNDP) – for autarkic regions no additional extension	Optimized expansion (incl. TYNDP) – for autarkic regions no additional extension
Degree of autarky	No autarkic trends	Defined by expert estimations	Based on status quo with a linear increase to 100% self-supply (hourly)	Based on status quo with a linear increase to 100% self-supply (hourly)
Size of autarcic region	No autarkic regions	Defined by expert estimations	Defined by expert estimations	In size category of a federal state

For this paper the renewable generated electricity self-suppling share on NUTS 3 level is on the basis of the year 2013. The self-supply rate is identified by disaggregating the hourly load profile for Germany (published by the transmission grid operators) with the normalized GDP for the related year. The renewable electricity generation for wind and PV is calculated by multiplying normalized generation-profiles, accounting to the weather information and the power plant portfolio (according to [11]) with the installed capacity within that year. The full load hours of running water and biogas is assumed to be the same for all plants resulting from the annual generation of the technology type and the installed capacity. The annual sum of the renewable generation by the annual demand is resulting in the annual self-supply rate.

Additionally two extreme scenarios will be addressed. The first extreme scenario represents the case that the regions that are identified within the realistic scenario reach the status of grid autarky at least until 2050. Within the second extreme scenario the regions that reach grid autarky until 2050 are regions with the area size of a federal state. These scenarios are especially developed to have the ability to draw concrete recommendations regarding the support of renewable energy regions, because they give an insight on the arising costs (the cost of realizing the self-supply within the region will be included in the total system costs) as well as the changing infrastructure.

F. *Chances and Risks of Grid-Autarky*

The chances and risks of grid autarky itself will be analysed with different instruments. First the model results, as described above, are used to evaluate the chances and risks on the level of the energy system. Second an evaluation will be made that carries out which kind of technical equipment is necessary to realize grid autarky. Also energy economic factors, like the effects on the grid utilization charges will be assessed. Third the single stakeholders will be interviewed if they see direct chances and risks for themselves.

III. RESULTS

A. *Current Situation in Germany*

1) Targets: The pre-analysis reveals that 72 regions on the NUTS 3 level have targeted 100% annual electricity self-supply by renewable energies latest by 2050. The rest of the analyzed regions have set themselves either a CO_2 emission reduction target or a certain degree of annual electricity self-supply target. As of 2015, 9 regions can completely supply themselves within one year with another 28 regions aim to achieve this by 2030. The development of the renewable energy regions in Germany until 2050 is shown in Fig 3. The entire population of these regions is approximately 12.4 million, with the average population of each regions being 171,000. Frankfurt and Hannover are the two largest regions with population exceeding 500,000 each.

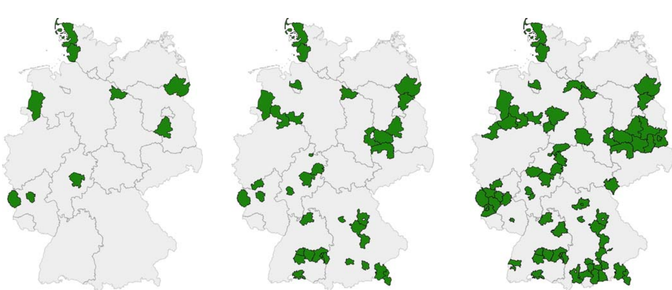

Figure 3: Regions with 100% renewable energy target by the year 2015 (left), 2030 (middle) and 2050 (right)

At present most implementation of such renewable energy target depends strongly on public interventions such as support schemes due to the high financial requirements. Therefore, in order to understand the motivation that drives these regions in targeting annual electricity self-supply, they were first characterized according to their respective support schemes and the providers. From the results shown in Fig. 4 it can be seen that national support programs provide incentives to most regions. The largest support program is the "Nationale Klimaschutzinitiative", which was initiated in 2008 by the Federal Ministry for the Environment, Nature Conversation, Building and Nuclear Safety in order to encourage projects that contribute to reducing greenhouse gas emissions. Succeeding the national support schemes are the support programs from local governments, often realized with the cooperation with banks, research institutes or industrial firms. Apart from that, some regions benefit from support schemes provided by the EU. "Intelligent Energy Europe" and "EU LEADER Gateway" are programs that support local actors to develop a region using renewable energies.

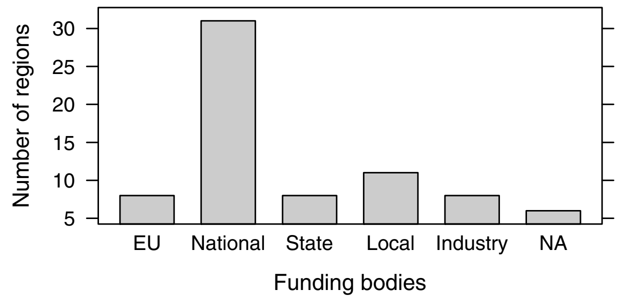

Figure 4: Support schemes in regions with renewable energy targets

Another possible motivation for a region to set renewable energy targets is the abundance of renewable energy sources. However, no significant relationship was observed between the available solar and wind energy potential and the renewable energy regions. This could be observed in Fig. 3, as the renewable energy regions are randomly spread across the country regardless of the high renewable potentials in the north (wind) and south (solar). However, the achievement of a sustainable energy system by means of annual renewable electricity self-supply rests, among others, on the use of endogenous potentials for renewable energy resources rather than energy imports. Therefore the degree of autarky of the region, largely contributed by renewable energies, are analysed and discussed in the following section.

First results of the expert interviews carried out in the scope of this project also show the importance of the project "100 % renewable energy regions", which started out as a scientific as well as networking project, providing a platform for exchange between regions interested in raising the share of renewables in their region. A yearly conference enabled the communication about best practise examples, as well as about the judicial problems connected with new forms of ownership of renewable power plants and electrical grids. The concurrence of this project with the "Nationale Klimaschutzinitiative" increased the momentum of the project, as regions interested in joining the network were now provided with the means to develop detailed development plans about their goals regarding the share of renewables in the region. This enables the project to make such a plan a prerequisite for joining the network, without excluding regions with less financial means.

2) Self-supply: Fig. 5 shows the annual renewable self-supply rate in Germany in the year 2013. Additionally the overlay grid and the grid knots are displayed, as well as the borders of the national states. The NUTS 3 regions are categorized related to their degree of self supply from lower than 30% to more than 100%. Especially the north east of Germany (all of Mecklenburg-Western Pomerania, Saxony and Brandenburg) has already a very high rate of annual electricity self-supply. A high density of self-supply can also be observed at the west-cost of Schleswig-Holstein and in parts of Lower Saxony.

In comparison to that large cities (Berlin, Hamburg, Bremen, Munic) and also larger urban areas (like in North-Rhine-Westphalia) have a low rate of annual renewable generated self-supply, which is related to the high demand of the regions. The middle of Germany has a rather low rate of self-supply.

3) Potential: The third criteria for clustering the German regions is the potential rate of renewable self-supply, which is illustrated in Fig. 6. The categories vary from a low rate (lower than 30%) to a very high rate (higher than 500%). Overall, Germany has the potential to supply itself with renewable energies annually with a factor of 1.2. The evaluation also shows that numerous regions especially in North-Rhine-Westphalia do not have the potential to supply themselves with renewable generated electricity. Also in many regions of Baden-Württemberg a self-supply can not be achieved. Apart from that many rural districts in Germany that are rather small have not the potential to supply temselves.

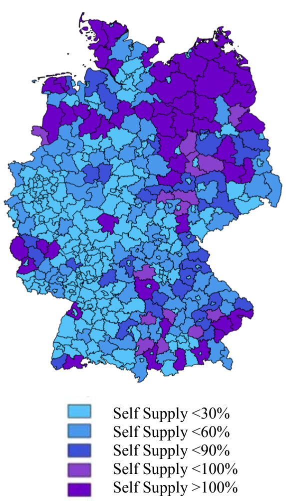

Figure 5: Annual degree of renewable self-supply in 2013

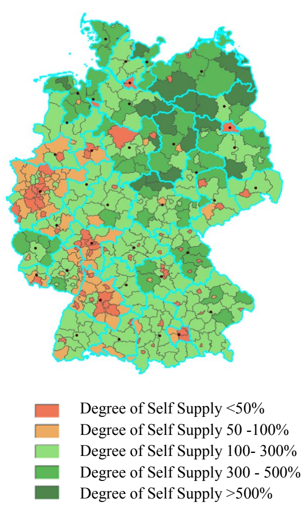

Figure 6: Potential degree of renewable self-supply in 2050

IV. Summary and Outlook

The pre-analysis of the regions shows that there are already numerous regions that attempt renewable electricity self-supply. Some regions have already successfully achieved these while others have set either 2030 or 2050 as the target year to achieve this goal. Most of these regions are of considerable size, such that electricity self-supply by them would require a significant change in the power supply system. Different support instruments, from governmental to industrial are fundamental to the target setting and developing of master plans. Out of the investigated regions most were supported mainly or party by national institutions. The „100% Renewable Energy Region“ project of the IdE [6] serves as a good basis of the developing of self-suppling regions. However not all regions that have set targets are part of the network. The emerging picture is therefore incomplete and assumptions for the remaining regions need to be done in order to substantiate the model analysis.

The potential of self-supply is not equally distributed over Germany especially small regions seem not to be able to supply themselves. Whereas the North East of Germany has already a very high rate of self-supply and the potential is accordingly very high.

Further steps include the implementation of the presented approach of coupling the socio-economic analysis with energy system modelling. This would enable the question of the chances and risks of grid autarky to be answered more profoundly. With the help of the defined scenarios, the influences on the system can be evaluated according to model results in addition to a quantitative analysis

V. Acknowledgement

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