Sustainability analyses of the German energy transition using TOPSIS

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Overview

The German energy transition is considered as major shift towards a green and sustainable energy system. Overall, it strives for the superior objectives of a secure, economic and environmentally friendly energy system until 2050. The comprehensive target system covers indicators regarding energy infrastructure and supply, e.g. the phase out of nuclear, the increase of renewable energies, the reduction of primary energy demand, and additional transmission capacities. (BMWi 2010) Several research institutes calculated scenarios for different entities to further define and describe the pathway of the energy system transition (e.g. cf (Lutz et al. 2018; dena 2018; Pfluger et al. 2017)). Even though the main assumptions of the different studies are similar, the results differ strongly in terms of final energy demand of the sectors, storage needs and utilisation of individual technologies.

(Rösch et al. 2017) provide a comprehensive indicator system consisting of 45 indicators to assess the sustainability of the German energy system and its transition. In addition to the commonly applied environmental, economic and technological indicators they include socio-technical aspects (such as acceptance, affordability and participation). Further indicator sets applied by scientists to assess the sustainability of energy systems are described e.g. by (Liu 2014) and (Maxim 2014).

These proposed comprehensive sustainability indicator sets allow for a thorough assessment of energy systems and can provide detailed information on the advantages and disadvantages of different pathways towards a decarbonised energy system. Interdependencies and conflicting targets can be derived yet it remains open to politics to solve these conflicts. As the sustainability indicators are measured in different units, a comparison of the pathways is difficult. Thus, applying comprehensive indicator sets the question remains, which pathway of the energy transition is better than another from a holistic sustainability perspective. In order to contribute to this question we apply the multi attribute decisions method Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to selected pathways. The application results in a ranking of the pathways allowing the derivation of policy implications.

Methods

Multi-criteria decision making describes approaches to assess a number of alternatives like different policy measures, technologies or projects. It takes into account that applying a number of different criteria involves conflicting targets. Applying multi-criteria decision techniques, the performance of the alternatives for each individual criterion is evaluated and then aggregated to derive conclusions. (Dias et al. 2019) Numerous methods have been developed to serve for this purposes, TOPSIS is one well-known and broadly applied method thereof (Behzadian et al. 2012). TOPSIS was originally introduced by (Hwang and Yoon 1981) and assesses the alternatives in comparison to the best and worst performance within each criterion. It consists of the following steps: (1) normalizing the initial decision matrix, (2) weighting the normalized decision matrix, (3) determining the ideal solutions (positive and negative), and (4) calculating the relative closeness coefficient. Finally, the alternatives can be ranked according to the closeness coefficient and thus, the method suits well the problem at hand.

Our selection of indicators is based on the specific requirements for indicators to measure sustainability described by (dos Santos Bernardes et al. 2002) and on the ability of the applied models[1] to calculate appropriate indicator values: Besides GDP, total employment, changes in jobs, regional disparity, total system costs, and diversity of the generation technology, we take the full set of indicators recommended for the Environmental Footprint Life Cycle Impact Assessment into account. These 19 Environmental Footprint indicators provide for a holistic environmental perspective and comprise e.g. climate change, land use, acidification potential, eutrophication, and human toxicity (cf (Fazio et al. 2018)). We use the weighting factors provided by the European

[1] Indicator values are calculated by DLR - Institute of Engineering Thermodynamic applying the model REMix, by GWS – Institute of Economic Structures Research applying the model PANTHA RHEI, and by INATECH – Department of Sustainable Systems Engineering applying the model flexABLE.

Commission's Joint Research Centre (JRC) to the Environmental footprint indicators (cf (Huppes and van Oers 2011), for the other indicators the weights are based on an experts workshop.

Results & Conclusions

Our ongoing research analyses different pathways towards a decarbonised German energy system holistically. With regard to the derived ranking of the pathways we will analyse the impact of the different indicators and provide insights into conflicts of targets. First results show, that these conflicts not only occur between different sustainability dimensions (e.g. economic versus ecological indicators) but also and especially between the ecological indicators themselves.

Overall, our preliminary results indicate that TOPSIS supports well the identification of a clear rank regarding the sustainability performance of the different pathways. Whereas the calculations of the TOPSIS ranks are rather simple, the understanding of the impacts of indicator choice and applied weights require attention and will also be discussed. Furthermore, questions of rank reversal due to a reduction of indicators will be analysed in the presentation as well as policy implications derived.

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