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Research article

Managing the resilience space of the German energy system - A vector analysis

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ABSTRACT

The UN Sustainable Development Goals formulated in 2016 confirmed the sustainability concept of the Earth Summit of 1992 and supported UNEP's green economy transition concept. The transformation of the energy system (Energiewende) is the keystone of Germany's sustainability strategy and of the German green economy concept. We use ten updated energy-related indicators of the German sustainability strategy to analyse the German energy system. The development of the sustainable indicators is examined in the monitoring process by a vector analysis performed in two-dimensional Euclidean space (Euclidean plane).

The aim of the novel vector analysis is to measure the current status of the Energiewende in Germany and thereby provide decision makers with information about the strains for the specific remaining pathway of the single indicators and of the total system in order to meet the sustainability targets of the Energiewende.

Within this vector model, three vectors (the normative sustainable development vector, the real development vector, and the green economy vector) define the resilience space of our analysis. The resilience space encloses a number of vectors representing different pathways with different technological and socio-economic strains to achieve a sustainable development of the green economy. In this space, the decision will be made as to whether the government measures will lead to a resilient energy system or whether a readjustment of indicator targets or political measures is necessary.

The vector analysis enables us to analyse both the government's ambitiousness, which is expressed in the sustainability target for the indicators at the start of the sustainability strategy representing the starting preference order of the German government (SPO) and, secondly, the current preference order of German society in order to bridge the remaining distance to reach the specific sustainability goals of the strategy summarized in the current preference order (CPO).

1. Introduction

1.1. Literature review

Sustainable development goal 7 of the UN agenda for sustainable development urges the global community to enable access to affordable, reliable, sustainable and modern energy for all (United Nations, 2015). This transformation process (Fischedick, 2015), the nature and design (Henning et al., 2015) of a sustainable energy system (ForschungsVerbunds Erneuerbare Energien, 2015), has been discussed in Germany for more than 30 years (Hake et al., 2015) and in this discussion (Renn, 2015) a distinction is made between the process towards sustainable development, which is termed green economy (Mundaca et al., 2016; Pahle et al., 2016), and the goal of this transformation process, sustainable development itself (United Nations, 2012a,b). The German Institute for International and Security Affairs (SWP) interprets the green economy as a global concept that "has the potential to function as a central implementation strategy of the guiding principle of sustainable development (Simon and Dröge, 2011)" and a new institutional framework of sustainable development (United Nations, 2012b). For the United Nations Environment Programme (UNEP), the green economy is a strategy to replace the current unsustainable energy technologies by new green technologies (UNEP, 2011).

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Hence, the energy sector is at the centre of this technological transition process (Rifkin, 2012), because as the International Energy Agency (IEA) stated in the World Energy Outlook 2008 "the world's energy system is at a crossroads. Current global trends in energy supply and consumption are patently unsustainable — environmentally, economically, socially. But that can — and must — be altered (IEA, 2008)." One method to analyse this energy transformation process is the vector analysis.

The vector analysis is already used in energy research in various ways. Liu et al. analysis multi-vector energy systems by taking into account synergies between different energy vectors (cooling/heat/electricity/gas) to facilitate the penetration of renewable energy in the energy system (Liu et al., 2017). This method is also used by Devlin et al. for scrutinizing with a multi vector analysis the energy system of Britain and Ireland (Devlin et al., 2017). The vector analysis is not only used for energy system research but also for specific renewables such as photo voltaics. Cabezas et al. using a hydrogen vector to avoid seasonal or climate discontinuities Esperanza Base, Antarctica (Cabezas et al., 2017). However, Lu et al. developed an interactive game vector for a stochastic operation-based pricing mechanism for smart energy systems with coupled-microgrids (Lu et al., 2018). Owen et al. enlarge the methodology of vector analysis to consider different energy policy questions by using energy-use and energy-extracted vectors (Owen et al., 2017). A multi-vector energy network was developed by Samsatli et al. for strategic design & tactical operation in energy research. This approach was also used by Abeysekera et al. to develop a method for simultaneous power flow analysis in coupled multi-vector Energy Networks (Abeysekera and Wu, 2015). Hence the review has shown that the vector analysis is already used for engineering and socio-economic research issues.

The goal of this paper is to develop a vector analysis approach for sustainability research to describe and analyse the transition process of the German energy system using the sustainable indicator system of the German sustainability concept. The vector analysis in the two-dimensional Euclidean space (Euclidean plane) inspired by the compromise programming methodology (Ringuest, 1992) and the conception of an ideal vector (Ringuest, 1992; Yu, 1973) enables us to measure and to sort the indicators in order to create a sustainable preference order (Wichman, 2016) for the Energiewende.

The aim of this novel vector analysis is to measure the current status of the Energiewende in Germany and thereby provide decision makers with information about the strains for the specific remaining pathway of the single indicators and of the total system in order to meet the German sustainability targets for the Energiewende.

The vector analysis enables us thereby to analyse the preference order of both the government and of German society. We identified the starting preference order of the German government (SPO) representing the ambitiousness of the German government and, secondly, the current preference order (CPO) of German society, the remaining distance to reach the specific sustainability goals of the German sustainability strategy.

1.2. Sustainability - the context of the German energy system

1.2.1. The system boundaries

The German Federal Government took up the UN sustainability model in 2001 (United Nations, 2001) and defined a quantitative sustainable development strategy for Germany in 2002 in preparation for the Johannesburg Summit of 2002 (German Federal Government, 2002a,b), which was updated in 2012 and 2014 (German Federal Statistical Office, 2012, 2014) and revised in 2017 (German Federal Government, 2017; Statistisches Bundesamt, 2017).

The government has defined two boundaries in its sustainability strategy which have to be considered in the administrative processes (German Federal Government, 2012): relative and absolute boundaries of sustainability. These boundaries summarize the ethical values of the German government in the sense of Kant "What should I do (Kant, 1781)" describing the ethically responsible social praxis of politics (Rawls, 2000):

- The government has determined an **absolute global boundary** of sustainability which may not be crossed to protect the basis of human existence (German Federal Government, 2012).
- The **relative boundaries** of the social-economic-ecological system (SEES) have more degrees of freedom to react to changes than the absolute boundaries (Schlör et al., 2015). The German government is looking for a resilient socio-economic system design for Germany to defend German society against the turbulences of the globalized world (German Federal Government, 2012) within the relative boundaries. I.e. the government makes society more robust "to security threats (Bale et al., 2015)" caused by developments of the world economy, such as Lehman Brothers collapse (Dumontaux and Pop, 2013).

For the Federal Government, sustainability means bringing together economic efficiency, environmental protection and social responsibility in the administrative decision to protect the absolute boundaries and to manage the relative boundaries (German Federal Government, 2012). The German sustainability strategy will be the backbone of the reflexive sustainable government approach for the German Energiewende concept as part of the green economy process. The German government is attempting to manage the energy-related social system in the green economy process (German Federal Ministry of Economics and Technology (BMWi), 2012; German Federal Ministry of Education and Research, 2012).

1.2.2. The German Energiewende - a green economy project

At the Rio+20 Conference in 2012, the United Nations defined the green economy as the institutional framework for the energy system (United Nations, 2012b) and regards the green economy as "an approach to achieving sustainable development (United Nations, 2011)." After the Rio+20 Conference, the German government took up the ideas of the conference and also regards the concept of the green economy as a tool for the implementation of sustainable development in Germany. For the German government, the green economy concept is a model for an internationally competitive, ecological and socially minded German society (BMBF (Federal Ministry of Education and Research), 2014) and a process to enhance the resilience of the German energy system and the Germany economy in a globalized world. According to Dennis Meadows resilience is defined as "the capacity of a system to absorb shocks and to continue functioning (Meadows, 2012)." The green economy tries to develop measures enhancing resilience (Kishita et al., 2017) in order to enable the system to absorb the shocks set by a globalized economy. It is thus an alteration process for the whole of society, where the complex interdependences between the subsystems and its actors have to be analysed and considered (BMBF (Federal Ministry of Education and Research), 2014). A central aspect of the German green economy transition project is the realization of a sustainable energy system (German Federal Ministry of Economics and Technology (BMWi), 2012). The German government sees its current energy transition programme (German Energiewende) as an instrument that "boosts green innovations,