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Identifying Sustainable Transformation Trajectories for a Low Carbon Economy Using a Multi-Stakeholder MCDA Approach – The Case of Germany

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ABSTRACT

Navigating the complex transformation process towards a sustainable energy system requires considering multiple stakeholders and various criteria within a multifaceted decision-making process. This work lays out a conceptual framework to identify holistic transformation trajectories for the implementation of a sustainable bioeconomy in Germany under consideration of stakeholder-specific perspectives and weighted decision criteria in the context of energy planning towards a low carbon economy.

Keywords: energy planning, low carbon economy, PROMETHEE, group decision-making, bioeconomy, FEW nexus

1. INTRODUCTION

As part of the aspiration to achieve the Sustainable Development Goals (SDGs), the current economic system, mainly based on fossil resources, needs to be transformed towards a sustainable economy [2]. Societal transformation processes and structural changes of that scale, such as the Energiewende in Germany, require long-term strategic decisions involving several public and private stakeholders with divergent opinions and preferences. This leads to a complex decision-making process determined by the stakeholders' dynamic interplay and needs to incorporate economic, social and environmental considerations – and thereby often conflicting objectives and uncertainties. Previous experiences in the context of the *Energiewende* illustrated that historically rooted, conflicting objectives influence decision-making and its outcome over time, including negative effects connected to lacking acceptance of involved stakeholders [3,4].

As a result of the policy-driven coal phase-out and as part of its climate action strategy Germany is currently striving towards a transformation following the concept of a sustainable bioeconomy [5,6]. The concept has received great attention in Germany and a growing number of countries globally adopted related bioeconomy strategies [7-9]. Within the German strategy, it is explicitly set in connection to the SDGs to address resource concerns linked to the transition towards a low carbon economy [8]. Further, resource substitution is considered a key element of the intended transition [8]. This will have a direct impact on the energy sector in Germany, which currently uses more than two-thirds of biogenic residues and waste [10]. While positive effects concerning the abatement of GHG are expected, it will also affect costs [11]. Thus, enhanced utilization for industrial purposes and changes with respect to the allocation of biomass increases pressure on existing resource conflicts, such as rivalry between the energetic usage of biomass and the production of foodstuffs, and raises competition within and between sectors and intended utilization approaches. Addressing related transformation processes thus requires considering multiple divergent objectives and stakeholders on various governance levels and accounting for related interdependencies among food, energy and water (FEW) nexus resources [12,13].

Generally, definitions of bioeconomy within policy strategies can be distinguished into a narrow and broader understanding [14]. The narrower definitions of the term highlight innovation potential and the application of modern biotechnology, whereas the broader understanding focuses on resource aspects and affected sectors, often including normative aspirations to support the transition to a bio-based economy [14]. The definitions within the German bioeconomy strategies relate to the broader understanding of bioeconomy and partly use the term bio-based economy synonymously for bioeconomy [6,8,14,15].

Identifying sustainable transformation trajectories (TT) for the intended transition is challenging since it entails dealing with a wicked problem and the properties of complex societal transformation processes. Wicked problems are characterized by certain key properties. These include that it is difficult to formulate a specific goal, which constitutes a central element of planning any possible policy solution for a given problem [16]. Further properties include that solutions to these problems are rather good or bad instead of true or false [16]. Moreover, every wicked problem is unique and can be considered a one-shot operation [16]. Overall, identifying a transformation pathway can thus be understood as aiming to find the best option possible instead of a non-existing optimal solution.

2. STAKEHOLDER VISIONS & PERCEPTIONS

Striving for sustainable development as agreed upon by the international community with the Paris agreement can be considered a guiding point for related activities in research and policy. Yet, the actual implications for an implementation of policy strategies in a national or regional context are often less obvious. While technological solutions are necessary, they cannot be considered sufficient since techno-economically optimal solutions are rarely ever realized in a real-world setting of societal transformation processes [3,4]. Stakeholder discourses and power constellation have severe influence on decision-making processes and involved stakeholders act upon their subjective perceptions and interests [3,4]. Thus, subjective stakeholder perceptions need to be considered in prospective transformations.

To categorize existing bioeconomy visions and perceptions among stakeholders, this paper follows the distinction into *bio-technology*, *bio-resource* and *bio-ecology* laid out by Bugge et al. that build upon general assumptions with respect to sustainability and the natural world [17]. The prevailing understanding of the *bio-technology* visons is to perceive the bioeconomy as strengthening research and development of biotechnology and bio-based products [17]. The *bio-resource* vision highlights the use of biomass instead of fossil resources in industry and production [17]. In delimitation to these, the *bio-ecology* vision acknowledges that bio-based products are not necessarily sustainable and further considers socio-economic aspects, such as justice and participation, as fundamental parts of a successful transition [17].

To gather first-hand information on potential lines of conflicts between stakeholders and their perceptions concerning the implementation of a sustainable bioeconomy, a focus group workshop among representatives of different stakeholder groups, including farmers, environmental organizations, industry, has been conducted. For the majority of the observed group, environmental aspects as well as a fair share of financial burdens (justice) were in the center of their concerns. Thus, the stakeholder perceptions in the observed group were close to what is comprised in the bio-ecology vision.

The current scientific literature dealing with empirical studies that explore what stakeholders understand in the context of bioeconomy, however, focuses predominantly on stakeholders from policy, research and industry and the prevailing understanding is mainly in the sense of a bio-resource or bio-technology theme [18,19]. Actors from civil society have rarely been investigated and, overall, we found a noticeable underrepresentation of ecological and social concerns. This indicates a gap between the leitmotif of the bioeconomy as a sustainability concept and the way it is communicated compared to the perception of involved stakeholders, especially those in policy-making and industry that considerably shape the transformation process. To identify holistic TT that are feasible, desirable and acceptable under consideration of stakeholder-specific perspectives, however, it is necessary to ensure a broad social consensus.

3. MCDA AND SUSTAINABILITY DEVELOPMENT

To approach that, methods based on Multiple-criteria decision analysis (MCDA) illustrated their potential in coping with problems connected to sustainable development from a micro and macro perspective [20,21].

Decisions based on MCDA approaches, depending on the specific method applied, are not exclusively meant to deduct an optimal solution in the context of energy planning but can help to rank alternatives ranging from best to worst. Decision analysis can support decision-makers and stakeholders by providing a scientific basis under consideration of the applied working hypothesis and assumptions made during the structuring of the decision problem at hand [3]. It can contribute substantially in circumstances with several actors involved. That is also due to the fact that most decisions we take are not based upon a single objective but usually concern multiple aspects to varying degrees. The importance of considering more than a single criteria increases even more in cases where several actors are involved. Only focusing on a single aspect (monocriterion) could, depending on the decision-making context a given decision takes place, result in neglecting crucial aspects and illustrate features of only a specific belief and value system as overall goal [3]. Applying a multicriteria approach can impede such problems from arising through fostering a debate on the significance of an individual criterion and including several perspectives [3,4].

In this connection, Multi-attribute decision making (MADM) methods have proven to be useful in supporting decision-makers faced with complex problems in the context of sustainability transformations in real-world group decision-making settings [20]. In particular, PROMETHEE outranking approaches allow for considering subjective stakeholder assessments expressed as weighted decision criteria while avoiding complete compensation. These properties are of particular importance in the context of the transformation towards a sustainable bioeconomy as intended in Germany.

4. METHODOLOGICAL APPROACH

The group of PROMETHEE outranking methods was initially popularized in the early 1980s as a partial-ranking approach (PROMETHEE I) and was subsequently further developed to achieve a complete ranking of a finite set of alternatives (PROMETHEE II) while considering multiple conflicting objectives [1,22,23]. Since then, it has been successfully applied in various environmental decision-making contexts worldwide [20]. It offers several benefits for the intended application in Germany. Those include that qualitative and quantitative indicators can be integrated, which allows for flexible integration of subjective stakeholder perspectives. Other reasons include that it is only partial compensatory, which is closer to the actual decision problem. Further, it can be extended to the PROMETHEE Group Decision Support System (GDSS) and thereby support the search for a compromise solution [24,25].

For this approach, the PROMETHEE II with the GDSS extension will be utilized. PROMETHEE II is intended to address the following problem with an absent optimal solution [1]:

$$\max \{g_1(a); g_2(a), \ldots (g_j(a), \ldots g_k(a) \mid a \in A\} \quad (1)$$

where A stands for a finite set of potential alternatives $\{a_1, a_2, \ldots a_i, \ldots, a_n\}$ while $\{g_1(\cdot), g_2(\cdot), \ldots, g_j(\cdot), \ldots g_k(\cdot)\}$ illustrates a set of evaluation criteria [1]. To approach this, a generalized preference function for each criterion is determined. The authors identify six types of preference functions sufficient for most use cases [1]. The applied preference function can be chosen based on the respective evaluation criteria.

PROMETHEE II further requires a set of criterion weights. To integrate the divergent value-systems into the PROMETHEE II, we can utilize the three bioeconomy visions laid out above (see section 2) representing involved stakeholders. Given the conflicting perspectives concerning the importance of core elements and goals illustrated through the bioeconomy visions, each model stakeholder can be depicted by a set of weights that highlights the relative importance of indicators linked to the respective bioeconomy visions (see section 2).

Based on that, the PROMETHEE method calculates the outranking relation π for all alternatives [1]:

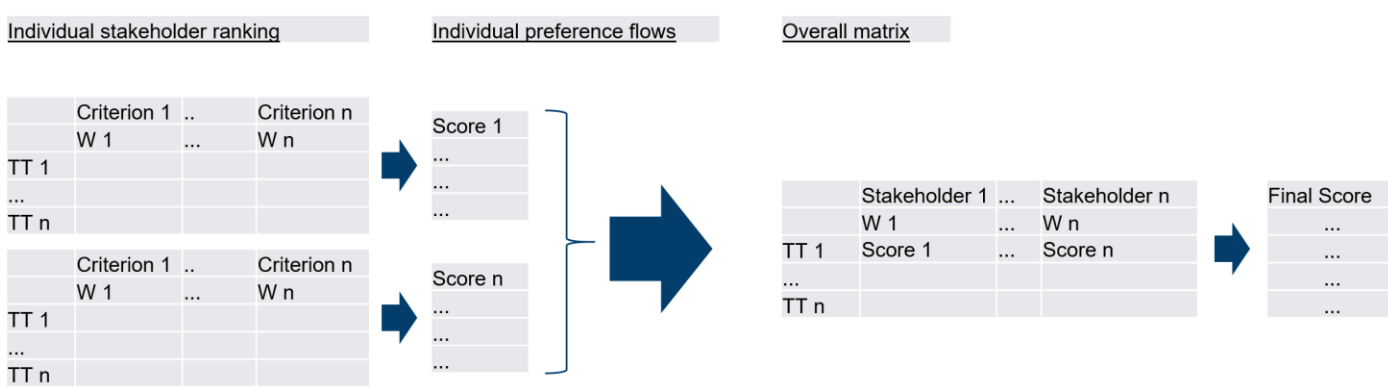

Fig. 1. Conceptual approach for the applied GDSS, *Source:* Authors, based on Brans and De Smet [1]

$$\pi(a,b) = \sum_{i=1}^{k} w_l \cdot P(a,b) \quad (2)$$

The preference index π(a,b) is a measuring unit for the preference strength for an alternative a over an alternative b while simultaneously considering all criteria. Next, the leaving flow as a measurement for the strength of all alternatives is determined [1]:

$$\Phi^+(a_j) = \frac{1}{n-1} \cdot \sum_{j=1}^{n} \pi\ (a_j,a_j) \quad (3)$$

Subsequently, the entering flow as a measurement for the weakness of all alternatives is defined as [1]:

$$\Phi^-(a_j) = \frac{1}{n-1} \cdot \sum_{j=1}^{n} \pi\ (a_j,a_j) \quad (4)$$

Using this strength and weakness index, the net flows of all alternatives $a_1, \ldots, a_n$ can be calculated [1]:

$$\Phi(a_j) = \Phi^+(a_j) - \Phi^-(a_j) \quad (5)$$

Following the PROMETHEE II complete ranking, a outranks b (aPb) if $\Phi(a) > \Phi(b)$ and a is indifferent to b(aIb) if $\Phi(a) = \Phi(b)$.

Using the resulting net flow, it is possible to rank the alternatives according to PROMETHEE II, which allows for identifying which alternative is preferred for one individual stakeholder. The resulting individual preference net flows illustrate the basis for the following step within the PROMETHEE GDSS [1]. Here, the net flows of all assessed stakeholders are combined in a new evaluation matrix on which the PROMETHEE II calculation will be performed anew. Following this procedure, as illustrated in Fig. 1, allows generating a complete ranking of the respective TT for the group of stakeholders.

5. PATHWAYS & EVALUATION FRAMEWORK

The conceptual foundation for the TT can be identified in the Shared Socioeconomic Pathways that have been used for the IPCC Sixth Assessment Report on climate change [26,27]. Based on that, TT developed, quantified and described along with three narratives for potential transformation pathways for the future development of the bioeconomy in Germany can be utilized [28-30]. These can serve as the base for the set of alternatives for the assessment within the PROMETHEE II method and PROMETHEE GDSS.

At present, however, existing indicators are not able to monitor the transformation towards a bioeconomy comprehensively [31]. A possibility to address this limitation temporarily can be identified in the integration of existing, diverse data sources [32]. For the case of Germany, this can be done by connecting indicators laid out in the German Sustainability Strategy based on their relevance to the concept of the bioeconomy. This allows the utilization of a robust data set including information concerning the current state as well as related target values for each indicator. To assess related SDG indicators with regard to their importance to the bioeconomy, ongoing works and preliminary monitoring approaches developed for various governance levels can be analyzed and can serve as a foundation (see, e.g. [31-37]). Subsequently, the identified indicators can be categorized according to three dimensions based on the bioeconomy visions (see section 2).

Using the national dataset along with weights based on the modeled stakeholder perceptions illustrates a fruitful approach to identify a TT in relation to the national goals as stated in German sustainability policy under consideration of involved stakeholders.

6. DISCUSSION & CONCLUSIONS

In this paper, a conceptual framework in the context of group decision-making was developed to lay out the foundation for the strategic implementation of desirable, feasible and acceptable TT of the bioeconomy in Germany. The application to a wicked problem highlights the opportunities enabled by the possibility to use MCDA and, in particular, the PROMETHEE outranking approach to account for the importance of divergent stakeholder perspectives in the context of societal transformation processes.

The framework developed in this connection is not meant as a universal approach to every societal transition since several parts of this framework can be considered as context-depended. At the same time, however, it can be regarded as flexible, in a sense that MCDA approaches allow incorporating fundamental knowledge needed to ensure profound social decisions in situations involving complex decision-making and multiple conflicts of interest lacking optimal solutions. The modeling approach pursued with this framework further allows excluding real side effects and thus calibrating it meaningfully so that improved model rates can be expected in future applications.

Beyond that, by applying the developed concept and generate an improved understanding of how the transformation in Germany works, valuable insights that can be beneficial for other regions facing similar transitions can be extracted.

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