Evaluating how green hydrogen supply chains affect society and energy justice

1. Introduction

The integration of renewable hydrogen into energy systems has the potential to enhance flexibility by balancing supply and demand, thereby promoting energy efficiency on a broad scale (1). The emergence of a global market for clean hydrogen is contingent on several factors, including the development of novel supply chains. The decision regarding the optimal approach to take is subject to extensive deliberation among stakeholders, comprising governments, renewable electricity suppliers, industrial gas producers, electric utilities, automobile manufacturers, oil and gas companies, and numerous other entities (2). As Lindner's (3) work indicates, the quality of democracy, human rights and government accountability seem to have only a marginal effect on policy-making in the majority of green hydrogen collaborations between countries of the Global North and Global South. In line with the findings of the relevant literature (4), the most significant impacts can be observed in the context of extra-UE long supply chains.

At present, research undertaken within the social sciences in relation to green hydrogen tends to focus on social acceptability and perceptions. However, further challenges can be identified (5,6,7). For example, the existing literature on the subject is lacking, particularly when considering the potential impact of hydrogen production on local communities and indigenous peoples. Additionally, further research is necessary to ascertain the impact on the current and future labour market, as well as the social implications of water consumption required by electrolysers. Finally, a balanced exploration of the opportunities and risks associated with energy independence is essential to inform policy and decision-making processes. As Blohm and Dettner (8) argued ~~(8)~~, the development of a theoretical framework by social scientists is of potential value in the identification of a hierarchy of priorities among the criteria. Such a framework could then serve as a guide to assist in assessing the sustainability of hydrogen projects. Indeed, the transition to a zero-carbon economy has the potential to result in social costs connected to the construction of new infrastructures, the raw materials required, the accessibility of energy services and the overall distribution of benefits and ills. However, without the implementation of socially just policies, there is a risk that this transition will lead to an increase in economic inequality rather than a reduction in it (9). The objective of this study is to develop a theoretical model that can be utilised to evaluate the potential social implications of the deployment of hydrogen-related technologies and projects in the context of a transition towards a hydrogen-based energy system.

3. The energy Justice and the capability approach

The implementation of green hydrogen has the potential to influence industry and society, while also addressing potential injustices within global supply chains. When the concept of energy justice is applied to the context of green hydrogen, it becomes imperative to address a range of concerns from the production stage through to the final utilisation stage. This incorporates social issues pertaining to the extraction of raw materials, the siting of infrastructure, pricing structures and levels of consumption.

Jenkins et al. (10) promoted a "whole systems" approach to identify potential externalities and unintended consequences, by shifting the focus to a global scale. A whole-systems approach involves identifying the characteristics of the system elements and examining the interactions between them. McCauley et al. propose three tenets of energy justice (11): *distributive justice*; *procedural justice*; *recognition justice.*

The capability approach is a comprehensive framework for analysing and measuring both individual well-being and societal structures. It serves as a basis for evaluating policies and proposing changes to improve social conditions (12). In particular, it can bridge the theories of energy justice with the more concrete aspects of policy-making and energy systems (13). Amartya Sen (14) and Martha Nussbaum (15) have developed a capability approach which considers a set of individual capabilities as an indispensable part of an evaluation of human development. Several studies have used the capability approach to examine the impact of energy projects in different contexts (16,17,18,19,20,21).

It is argued that human rights can provide a minimum core for a list of capabilities that can evolve to address different applications and purposes, and it would be justified by an international consensus-building process (22). Therefore, in the “Human Rights-Based Capability Framework”, the choice of core or basic capabilities is justified by human rights theories. Building on this, we develop a theoretical framework for assessing the impact of green hydrogen through a list of capabilities that find their foundation in the Universal Declaration of Human Rights (23) and in the European Union Charter of Fundamental Rights (24). We identified domains of capability that have general foundations and can thus guide the analysis of the potential implications of green hydrogen supply chains.

4. Theoretical assessment framework

The benefits and criticalities of the development of the green hydrogen socio-technical system may be relevant to different geographical and socio-cultural contexts, as may the effects of different stages of the green hydrogen life cycle. The objective of this framework is to consider the social implications of the following: (a) the extraction of raw materials; (b) the construction and operation of renewable energy facilities; (c) the construction and operation of

~~electrolyzers~~electrolysers; (d) hydrogen storage and transport facilities; and (e) final use. In this framework, the six domains that are considered to be the most involved in the development of the green hydrogen industry are presented. The aim is to cover the majority of its impacts. The domains in question cover fields such as *labour market, quality of life, health, ~~citizens~~citizens' rights, participative processes, knowledge transfer.* The capabilities associated with each of these domains are inspired by several articles of the Universal Declaration of Human Rights (23) and of the Charter of Fundamental Rights of the European Union (24). It is thus possible, through the application of the framework, to evaluate and assess the social impacts of green hydrogen in relation to fundamental human rights.

The framework follows the suggestion of Pellegrini-Masini (25) of moving away from a horizontal approach to capabilities and prioritising those most important for human well-being, drawing on Maslow's hierarchy of needs. The findings of empirical research on the factors influencing subjective well-being support the proposition that needs can be divided into two categories: 'maintenance' and 'growth'. It is possible to allocate certain capabilities domains to the 'maintenance' dimension. This is due to the fact that such domains can affect the possibility of life that is both decent and meaningful. It is therefore essential that they should never be negatively impacted. This is the case for domains such as l*abour market, quality of life, health,* and *citizen~~l~~ rights*. Capabilities domains such as *participative processes* and *knowledge tranfers* can be assigned to the "growth" category. It is considered that the impact on these capabilities does not call into question the possibility of life itself; rather, it is suggested that they can determine important aspects of social life quality. In light of the context-sensitivity intrinsic to the capabilities approach, the classification of capabilities domains into two categories may be subject to variation. The incorporation of an additional hierarchical dimension into the assessment framework can facilitate the identification of conditions that are most likely to engender positive or negative social impacts. A comparable approach was undertaken by Clark et al. (26).

6. Conclusions

The proposed framework has the potential to offer policymakers and relevant stakeholders a comprehensive overview of the social dimensions that may be impacted by the deployment of green hydrogen energy. These include, but are not limited to, employment and labour market implications, material well-being, health, justice, democratic participation, and socio-economic inequality in general. The approach advocated here is to encourage consideration of different social domains in order to address the multidimensional nature of social impacts. Furthermore, it is capable of promoting community engagement by recognising the importance of including local voices and concerns in the planning process. This, in turn, can help to design projects and/or policies that are more likely to promote inclusive economic growth, reduce undesirable impacts and, ultimately, be accepted by communities. The utilisation of this theoretical framework has

the potential to enable the development of policies and initiatives that are founded upon a robust theoretical basis. Consequently, this ensures that decisions are not solely driven by economic considerations, but that social sustainability is also given due consideration.

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