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Analysis and Design of the institutional environment for deploying a green hydrogen value chain in the Netherlands

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Introduction

The increasing global temperatures and adverse effects that are experienced call for a dramatic change in the amount of greenhouse gas emitted with studies indicating a decrease of at least 90% by 2050. The decarbonization of the energy sector has therefore become a stringent topic in national and international efforts to combat climate change [8]. Green hydrogen has the potential to contribute to this decarbonization [29], because it can be produced from renewable energy and does not emit greenhouse gases. Consequently, this hydrogen type has received significant attention among academia, practitioners and policymakers [2]. The value chain of hydrogen can have different configurations since the energy vector can be produced, stored and converted in different ways and forms (e.g. gaseous, liquid [31], but typically consists of the nodes 'source of energy', 'production units', 'storage facilities', 'transportation modes' and 'end use' [1].

The potential of green hydrogen relates to the use of renewable energy sources for the production, rather than fossil fuels from which the currently used grey hydrogen is produced [18]. With green hydrogen the production process can therefore be decarbonized [2, 14]. Hydrogen also has the potential to replace fossil fuels in the process industry and to be used in mobility, built environment and commercial sectors [15, 35]. Thus, green hydrogen has the potential to enhance the sustainability and reliability of the energy system and play an important role in assuring flexibility of the energy system [19]. Accordingly, the European Commission has set a target of 40 GW of green hydrogen production by 2030 [6] and, following the Russian invasion of Ukraine, the production and import of 10 million tonnes of green hydrogen each by 2030 [7]. Also in the Netherlands the potential of green hydrogen has resulted in the goal of an electrolyser capacity of 3-4 GW by 2030 [16] and 15 - 20 GW around 2040 [24]. Besides plans for green hydrogen, several projects are taking place in the Netherlands. Examples are the execution of four pilots on hydrogen use in the built environment [30], the construction of a national hydrogen network [22] and the development of a large-scale hydrogen hub in the Port of Rotterdam [28].

Despite the potential of green hydrogen in decarbonizing the energy system and the formulation of targets on green hydrogen across the EU, the transition to green hydrogen has encountered several barriers, amongst which technical, economic and regulatory challenges. The policies and regulations relating to hydrogen form in many countries a barrier in their efforts to scale up the hydrogen energy system whilst the technologies are ready for implementation [17, 13]. These barriers are for instance regulatory uncertainty due to the lack of a harmonized legislative framework [3] or difficulties in regulatory frameworks from moving disruptive technologies from demonstration projects to large-scale deployment [31]. In other words, conventional 'one-size-fits-all' approaches to regulation might be outdated for sectors in transition, thereby making alternative approaches to regulation potentially more suitable [21].

The scale-up of the hydrogen market is faced with a 'chicken-and-egg' problem [25] where on the demand side businesses interested in using green hydrogen require insight about the expected quantity, price, network operators and tariffs, whereas in terms of supply potential investors require insight into the future demand [23]. Additionally, this impasse in transitioning to green hydrogen is exacerbated by the big cost gap between grey and green hydrogen, resulting decreased interest among producers and consumers [2]. Meanwhile, the expected demand and supply determines the development of infrastructure

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[23]. Overcoming these interdependencies require coordinated action across stakeholders to materialize the full benefit of hydrogen in the transition to green hydrogen systems [15].

Thus, barriers encountered in transitioning to green hydrogen relate to the formal rules of green hydrogen value chains (GHVCs) on the one hand and coordination amongst stakeholders on the other hand. Overcoming these barriers requires gaining an understanding of the institutional framework in which its activities take place [9] and the interaction between the political, techno-economic, market and social dimensions of the hydrogen transition [13]. An institutional framework consists of formal and informal institutions, actors and the governance of a sector [9]. Institutions are defined as widely understood rules, norms or strategies which create incentives for behaviour in repetitive situations [4]. These can either be public policies and laws (formal) or spoken or tacitly understood social norms (informal) [10] and can comprise a single statement or multiple statements [32]. Gaining an understanding of the institutional framework and its institutional framework in the hydrogen transition will provide insight into the sector and potential negative mechanisms [9], thereby contributing to the identification and implementation of adequate policy mechanisms, which are crucial for transparent procedures for national, renewable-based hydrogen plans that support hydrogen supply and demand as well as necessary infrastructure [14, 13].

The conducted research in this PhD seeks to contribute to overcoming these barriers in the hydrogen transition by taking a socio-technological perspective on the transition to GHVCs. It combines the disciplines of law, social sciences and engineering to perform a comprehensive analysis of the influence and design of the institutional framework in achieving a coherent technological and institutional transition to a GHVC. With a socio-technical perspective the green hydrogen value chain is considered as a combination of the social and technical systems involved in making, distributing and using green hydrogen [14]. Using this perspective allows for the analysis of the interactions between the institutional framework and the technical dimensions of the GHVC. As this doctoral research started in January 2023, research results or papers are not yet available. Up to the time of writing this research abstract, the doctoral research consisted of the identification of knowledge gaps and formulation of the approach to be taken to decrease these gaps. In the following sections, the formulated research approach, questions and methods are therefore described.

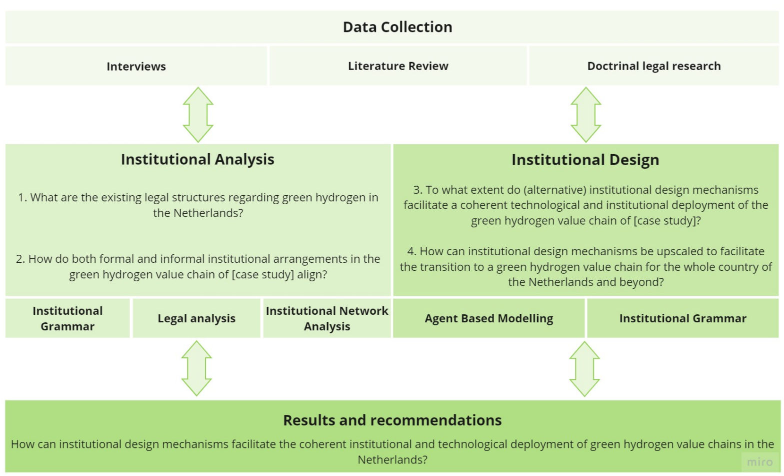

Figure 1: Research approach

Research methods

This research will be applied to a GHVC in the Netherlands that already exists or will be developed. The use of a case study will aid in maintaining a feasible and manageable research scope. Additionally, the research results will be valuable to stakeholders of the chosen GHVC application. In terms of methodology, a synergy between legal, qualitative and quantitative research is proposed. These research steps will build onto each other and will collectively provide insight about the effect and potential design of the institutional framework of a chosen GHVC in the Netherlands. The approach that will be taken in this research is depicted in Figure 1, along with the corresponding research questions and methodologies. This research is divided into two phases, the institutional analysis and institutional design phase, which will be discussed in the next subsections.

Institutional analysis

This doctoral research commences with gaining an understanding of the institutional framework of a GHVC in the Netherlands that already exists or will be developed. This phase identifies the space in which actions related to green hydrogen can be undertaken and the extent to which alternatives are possible by identifying and analysing (1) the formal institutions and (2) the stakeholders and their informal institutions on the other hand. Legal analysis will be employed to understand how the formal institutions shape and influence the development of the GHVC under analysis, thereby answering research question 1 shown in figure 1. Data will be collected with literature review and a doctrinal legal analysis which entails research into the law (legal acts, regulations, policy guidelines, case law, administrative decisions) and the legal concepts [5].

The stakeholder network of the GHVC and their informal institutions, such as their relationships, agreements and strategies, and the alignment of their formal and informal institutions, will be studied using Institutional Network Analysis (INA) which utilizes interviews for data collection. The approach aids analyzing and visualizing the complexity of the institutional framework of a subject where multiple stakeholders are involved and coordination is required [20].

To visualize the alignment of institutions, we use the Institutional Grammar (IG) which is an analytical tool for assessing the content and structure of institutions. A first step in applying IG is dissecting an institution into its constituting statement(s) [32], which are the shared linguistic constraints or opportunities that prescribe, permit or advise actions or outcomes for actors [4, 33]. The tool enables the analysis of the core elements of institutional statements in a structured manner with a syntax, which aids in identifying common components of institutional statements and establishes the set of components that comprise each type of institutional statement [4, 33]. By analyzing the elements of the institutions identified for the case study GHVC using IG and visualizing them using INA, the alignment of the institutions in the institutional framework will be identified as well as potential voids or overlaps.

Institutional design

In the second phase of the doctoral research the interaction between the institutional and technological dimensions of the GHVC under analysis will be studied by means of agent based modelling (ABM). The methodology is suited for comparing and illustrating before and after situations of a policy implementation [12, 27]. ABM will be used to simulate the future development of the GHVC under the existing and alternative institutional design, thereby providing insight about the extent by which the institutional framework plays a role in the transition to a GHVC and providing insight on potential mechanisms that can be employed to facilitate the coherent technological and institutional development of the GHVC. To integrate the institutions into the ABM, the meta-model “Modelling Agent systems based on Institutional Analysis” (MAIA) introduced by [11] will used as a basis. This framework helps understanding and analyzing social systems where interactions taken place under an institutional structure. It extends and formalizes the concepts of the Institutional Analysis and Development (IAD) framework of [26] and provides a template of concepts to model social systems, particularly focused on the institutional aspects of the system [34].

As Figure 1 shows, Institutional Grammar will also be used in the institutional design phase of the doctoral research. IG will be used to decompose and integrate the institutions of the case study that are identified in the preceding research phase into the Agent Based Model. For exemplary purposes, the concepts of the MAIA framework, which correspond to the structures of the IAD-framework, have been applied to the green hydrogen value chain system in this research and is shown in Figure 2. In the IAD framework ”rules-in-use” and ”rules-in-form” are used, which in this research respectively refer to informal and formal institutions.

Discussion

The aim of this doctoral research is to show to what extent an institutional framework plays a role in the development of the value chain of hydrogen. Additionally, this research aims to show how the design of the institutional framework can facilitate the coherent technological and institutional development. The research questions will be answered by means of differing methodologies from various disciplines,

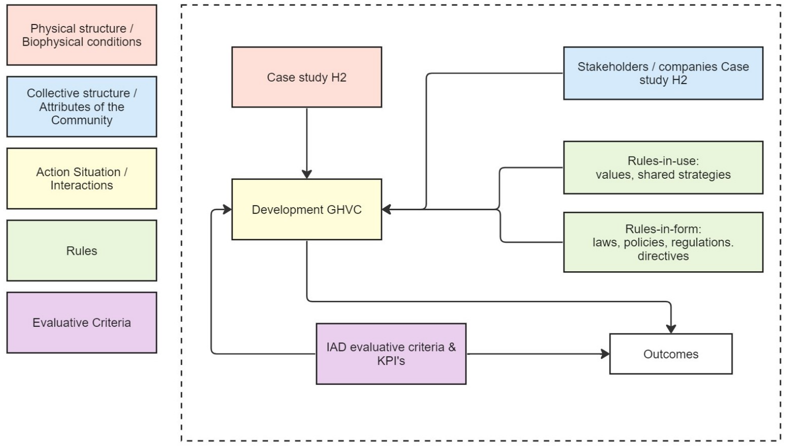

Figure 2: Draft structure of the ABM on the GHVC

thereby analysing the socio-technological system from various perspectives and allowing a comprehensive multi-dimensional understanding. The results are expected to demonstrate that a transition such as that of green hydrogen is not only determined by technological advancements, but that research into this topic should include the social and institutional dimensions. Moreover, this doctoral research seeks to provide insight into potentially effective institutional design mechanisms which can contribute to formulating effective regulatory and legislative approaches prior to the actual materialization of the GHVC. This can decrease the timeline of policy-making and avoid potential ineffective or harmful institutional design mechanisms to be implemented.

Limitations of this doctoral research relate to its focus on the coherence between the institutional and technological system of the GHVC, which infers less attention to the technical specificities related to hydrogen. Moreover, the socio-technical perspective taken in this research is limited to formal and informal institutions and stakeholders within the chosen GHVC whereas the social dimension could also include topics such as public acceptance or ethics. Even though these debates are of great importance, these fall outside of the scope of this doctoral research. As the research is interdisciplinary, it is limited in the depth attributed to each discipline whilst these all could encompass a doctoral research in itself. Lastly, the use of a case study does provide valuable results, also for other GHVCs, but does limit the generalizability of the research results.

Conclusions

Green hydrogen has received significant attention among academia, practitioners and policymakers since the energy carrier has the potential to replace grey hydrogen as well as fossil fuels. Despite the various national plans for the production and use of green hydrogen, both the unsupportive legislative and / or regulatory frameworks and lack of coordination among stakeholders form barriers in the materialization of green hydrogen value chains. Analysis of the institutional framework, which involves the formal rules, the stakeholders and their agreements, norms and behaviour, of a sector aids in understanding potential negative mechanisms for the advancement of that sector. This research therefore adopts an institutional analysis and design approach to analyze the development of a green hydrogen value chain in the Netherlands under the current and alternative institutional frameworks. In the institutional analysis phase will gain an understanding of the institutional framework and the alignment of the institutions applicable to the green hydrogen value chain of the case study. The design phase will identify how the GHVC will develop in the future and how design mechanisms can facilitate the transition the a green hydrogen value chain in the Netherlands. The obtained insights from the proposed research are expected to contribute to the development of robust and supportive regulatory approaches that facilitate the coherent technological and institutional deployment of GHVCs in the Netherlands. This can consequently contribute to achieving a more sustainable energy system, the decrease of greenhouse gas emissions and mitigating climate change.

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