Business Models of Hydrogen Production: Status Quo, Trends and Design

Masterarbeit

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1 Introduction

"The atmosphere is warming and the climate is changing with each passing year. One million of the eight million species on the planet are at risk of being lost. Forests and oceans are being polluted and destroyed." (European Commission, 2019, p. 2)

The first paragraph of the European Green Deal contains this statement. Global warming and its repercussions are the reason the European Commission agreed on a mutual roadmap and a strategy to tackle the challenge of stopping climate change. A consolidated economic area commits to invest in research and development and measures to shift economical acting and change their policies (European Commission, 2019). One key measure is the expansion of renewable energy production. The generation of electricity by solar, wind, hydro, biomass or geothermal power does not emit any greenhouse gas. If harvested, the annual worldwide solar radiation could account for 7,400 times as much as the currently needed amount of energy per year. The sun is able to originate all forms of renewable energy sources (Mertens, 2018). To employ and utilize this huge potential proves to be difficult. One emerging problem is the volatility of renewable energy sources. Especially in the production of wind and solar energy, a lot of energy is lost during the production process. Low conversion efficiency and forced curtailment and even shutdowns of production plants due to feed-in management lead to inefficiency and high costs (Bundesnetzagentur, 2018; Pflug et al., 2019).

The solution to this is *Power-to-X*, i.e. converting the otherwise lost energy into another energy carrier and using it as a battery (Lehmann et al., 2018). Hydrogen is the lightest and most abundant element in the world and at the same time the most suitable option for energy storage (van de Graaf et al., 2020). With Power-to-X, surplus energy can be used to produce pure hydrogen, hydrogen-based fuel or hydrogen-based feedstock (Lehmann et al., 2018). Hydrogen is a secondary energy carrier that can be used in various areas due to its aggregate state and chemical properties. The only by-product of combustion is oxygen (van de Graaf et al., 2020) so greenhouse gas emissions are zero. When produced by electrolysis powered by renewably generated electricity, the whole production process of hydrogen as an energy carrier is completely decarbonised (Amoretti, 2011).

Conclusively, the so-called green hydrogen is considered one of the key solutions for the energy transition from fossil fuels to renewable energy sources. Nevertheless, only 1-2 % of total hydrogen production is currently generated by electrolysis, 98 % by fossil fuels releasing large amounts of carbon (IEA, 2019; van de Graaf et al., 2020). This fact implies that the production of green hydrogen must be expanded.

For private and public players who want to invest and be involved in the hydrogen economy, financial and economic incentives are crucial. The production of hydrogen must be possible through a business model, that ensures financial stability, success and competitiveness. Consequently, the structuring and design of business models are an important factor in assessing the future viability of hydrogen production. This research paper aims to follow this path and analyse the business models of hydrogen production. In order to know the current situation and build on it, the status quo is researched and presented, followed by trends to depict ongoing developments and future potentials. Finally, the design and blueprint of how a successful business model needs to be structured and aligned is elaborated to complete the full assessment and economic approach on hydrogen production.

For this reason, chapter 2 presents the theoretical background to hydrogen and explains the basics of business models. Understanding the technology and peculiarities is of great importance to determine a valid business model for hydrogen and Power-to-X. Hydrogens characteristics and features influence the status quo, the trends and design and must therefore be taken into account in the analysis. In addition, it is important to understand how business models are generally designed, how a successful business model is to be evaluated and which evaluation tools are to be used in the further process. As a result, Chapter 2 mainly covers the status quo and implies some of the trends.

The analysis of the initial situation of hydrogen production and its trends will be deepened in Chapter 3. A systematic literature review is performed to further investigate the status quo and identify trends and relevant elements for the future of hydrogen production. For the review, a systematic approach and keyword search is conducted to capture the literature landscape. This also allows further research on the findings to ensure reproducibility and the entire search process.

Chapter 4 aims to design a business model that represents successful and competitive green hydrogen production. Therefore, a *Business Model Canvas* analysis for green hydrogen is first performed to identify the core elements of the business model. Subsequently, the design is applied to a case study. The transfer to real practical examples concludes the chapter.

In Chapter 5, a detailed discussion brings all aspects together and completes the assessment of the status quo, trends and design of business models of hydrogen production, before chapter 6 briefly summarises all results and provides an outlook for the hydrogen economy.

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6 Conclusion and outlook

This paper aimed to analyse and survey the status quo, trends and design of business models of hydrogen production. One of the trends, a clear focus on sustainable acting business models, was integrated as the focal point throughout the process of the paper. Green hydrogen and its production with renewable energy were considered and incorporated in every chapter. The paper achieved to illustrate the status quo and trends in form of a theoretical presentation of the hydrogen economy and its business models and a conducted literature review. The design of business models of green hydrogen economy could be elaborated by the method of a Business Model Canvas and a case study. Conclusively, the results and interpretations were resumed and discussed, alongside with limitations and implications of the procedure.

The climate change and its impact on the environment are one of societies biggest challenges of modern times (European Commission, 2019; IEA, 2019). Innovations in technology and changes in the way to act and economise are keys to reach the 2-degree target of the Paris Agreement. The energy industry needs to shift to renewable energy sources in combination with the Power-to-X technology. Excess energy during the renewable generation of electricity is stored by producing hydrogen (Lehmann et al., 2018). Green hydrogen ensures a complete decarbonised energy production without any greenhouse gas emissions (van de Graaf et al., 2020). This makes green hydrogen a promising and key technology for the future of the energy industry, which depicts the first aspect of the status quo. The hydrogen economy and therefore its business models are still in the initial stage. This leads to a rather technological research focus. In the literature review, only 6.7 % of the articles specifically researched in the area of business economics, the rest having a technological research background and supplementing business implications. This comes from no surprise; the technological fundamentals are one of the major requirements to design a financially successful and stable business model. The assumption of the initial stage being the status quo of the hydrogen economy is supported by the aspect of an either macro- than micro-economic approach of the majority of the reviewed literature. Some articles try to take on both positions and views, but almost 80 % partly or completely study hydrogen business models from a macro-economic perspective in relation to a micro-economic one from slightly more than half.

With regard to the business fields inside the value chain of hydrogen, the early phase is reflected as well. The value chain of hydrogen consists of the parts production, infrastructure and application. 76 % of all reviewed articles analysed business models of hydrogen production, whereas only 52 % on infrastructure and 36 % on application, with some publications examining a

combination of more than one. This presumes the current research focus in the hydrogen economy being on a successful and especially competitively viable production. As the first step in the value chain, an economical feasible production process of green hydrogen displays a precondition for the following business fields infrastructure and application.

Moreover, the executed literature review achieved to show a rising relevance and importance of the technology Power-to-X and its deployment with hydrogen. The literature review integrated 75 articles, published within the last 15 years. The created measure citation quote describes how often in average one paper was cited per year. With reference to all papers, the citation quote grew strongly in the last years. Whereas in 2017 every already published paper out of the literature review got cited by other literature in average 2.07 times, the citation quote increased to 7.08 in 2021. Looking to the total number of publications per year, the same effect occurs. The trend shows a constant grow of published articles discussing business models of hydrogen resulting in a count of 14 last year accounting for almost 20 % of the entire literature landscape of the review. This numerical analysis presumes a rising awareness and stronger research focus on hydrogen.

Especially Europe takes on a pioneer role in the hydrogen economy targeting to become a leading expert in technology, expertise, application and production location. This can be observed by clear roadmaps, investment commitments and strategies for the future elaborated and published by the European Commission (European Commission, 2019, 2020a, 2020b, 2020c) and the fact, that with a share of around two-third, the majority of articles out of the literature review are European.

As mentioned, 76 % of all articles examined in the literature review researched on hydrogen production business models. For these articles, a deeper analysis on specific parameters, including the production costs, the price and demand, the integration of environmental externalities, carbon tax and governmental funding, was performed. The production costs can be seen as the most crucial parameter. 14 % incorporated environmental externalities, 17,5 % governmental funding, 31,6 % carbon tax, 38,6 % the price and demand and with great distance, 82,5 % of the articles analysed the parameter of the production costs. All in all, the production costs of green hydrogen still exceeds the ones from coal or natural gas (IEA, 2019). This comes mainly due to the high costs for renewable energy, the capital expenditures and insufficient efficiency factors. Lowering the production costs will be essential for the future feasibility of green hydrogen (van de Graaf et al., 2020).

In summary, the status quo is determined by a fast-growing hydrogen economy that is still situated in the initial stage. Ongoing trends show a rising awareness, relevance and promising future prospects due to commitments to investments and business strategies from governments around the world.

The Business Model Canvas created a design for a stable, successful and competitively viable business model of green hydrogen production. The centre-piece is determined by the value proposition. Customers expect from hydrogen to be a green and sustainable but affordable energy alternative. The case study showed, that the capital expenditures and the employment of renewable energy sources are the biggest cost point. As of today, production facilities rely on governmental funding and support to finance the business model. In the future, this dependency could change, if the levelised costs of electricity of renewable energy sources will further drop. The technological benchmark to reach for the LCOE is 0.05 USD/kWh (Fuhs, 2017). Presuming the application in the mobility sector, this would lead to a consumer price of 7 USD/kWh (Fuhs, 2017). Under perfect conditions in regard to the best technology in conversion efficiency and climate conditions for the production of renewable energy, it could be demonstrated, that this is already possible to achieve today (IEA, 2019).

In reality, the production of green hydrogen still depends on the support of the government, as the SALCOS initiative or the H2V-Project show (Benzinger, 2021; Salzgitter AG, 2021). A change in policies will be in general a central point for green business models to prosper in the future. (Beltramello et al., 2013)

The number of application fields and market value of hydrogen is expected to grow in the future. If technology advancements and policy changes succeed, grid parity can be reached by the year 2040 (Brinner et al., 2018). By the year 2050, more than 425 million hydrogen powered cars, trucks and buses can be running and accounting for 25 % of the overall mobility volume. In addition to that, hydrogen is estimated to generate a revenue capacity of 2,500 billion Euro and 30 million employees working in the sector. Green hydrogen is taking on the role of a key player and solution, now and in the future, to couple all energy sectors and decarbonise the entire industry and reach the targets of the Paris Agreement to realise a successful energy transition.