# Identification of barriers and investment determinants for hydrogen infrastructure: Development of new business models

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***Abstract*: Reaching of the Pan-European decarbonisation targets requires radical steps (e.g., phase out of gas and coal) and the development of innovative business models to support the uptake of Renewable Energy Sources. Implementing new business models will be central to provide incentives for the advancement of and investments in new technologies. This study employs the *e3value* business modelling methodology for exploring hydrogen production from curtailed renewable electricity and identifies potential barriers, which may prevent investment into the Power-to-Gas infrastructure for utilising curtailed electricity from RES. Following the *e3value* methodology the study identifies the main involved actors, activities, and value exchanges between them. Based on the modelling the study identifies the critical barriers and suggests the next steps for resolving these.**

***Keywords: Hydrogen energy, Power-to-Gas, Business Modelling, Regulatory and Policy Barriers***

## I. Introduction

The EU has set the ambition to reduce greenhouse gas emissions to the point of becoming climate neutral by 2050 and minimize the negative and irreversible effects of climate change. Reaching this goal will require shifting the energy system to a renewable-based system and radical technological, behavioural, and organisational changes in the economy and society.

This paper presents results from the activity "Identification of investment determinants and barriers" in the H2020 project OpenENTRANCE (2019-2023).

### A. Objectives of the study

Achieving the Pan-European goals for decarbonisation of the energy sector requires several radical changes and raises the need for the development and implementation of new business models, which employ advanced technologies enabling innovative business ideas. Hence, it becomes necessary and increasingly important to explore and validate the feasibility of these models and identify potential barriers, which may prevent successful deployment or limit functionality of these. This necessity defines the main objective of the study – to identify the main barriers preventing investments and deployment of the hydrogen infrastructure at the present stage of the energy transition.

The secondary objective is to verify whether business modelling is a sufficient and viable methodology for this purpose. Accordingly, the main contribution of the study is to highlight the critical issues and suggest a practical way to make critical business assessments of new technologies prior to their deployment.

### B. Structure of the paper

Achieving the main objectives, the present paper includes several steps: (1) Overview of the main project, and the role of the present study in it (2) Introduction of green hydrogen, its main properties and its role in the Pan-European energy strategy (3) Presenting business modelling as a necessary tool for successful deployment of new technologies (4) Selection of appropriate modelling methodology i.e., *e3value* (5) Development of a new business model (6) Mapping of the barriers (7) Conclusions.

## II. Background

### A. OpenENTRANCE in a nutshell

The H2020 project OpenENTRANCE [1] aims at advancing energy systems modelling to support the transition to a net-zero European energy system by 2050. This is to be achieved by developing an open platform allowing modellers to share and link state-of-the-art open models. A wide range of datasets will be made openly available in a common data format, increasing their usability across different modelling frameworks. The platform is also intended to serve as a collaborative environment to facilitate and improve the dialog between researchers, modellers, policy makers, industry and other stakeholders. The core of the project is the development of four different pathways to a future net-zero energy system, focusing on different combinations of the policy, technical and social engagement sphere. The scenarios are analysed on a pan-European, national and, for a choice of countries, a

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regional level (for more details see [1]) Also, behavioural aspects of communities and individuals are studied, by incorporating them into the energy systems modelling framework with an innovative approach that allows for their comprehensive integration. The energy system analysis is further supported by macro-economic investigations to provide insights into economic effects, with focus on possible new business models and the aspect of a fair transition.

The present paper presents results from the activity related to development of innovative business models for the energy transition and maps potential barriers preventing deployment of these. The whole activity included creation of several models linked to new technologies, but due to space limitations, the present paper presents only one business model – generation of hydrogen from curtailed electricity.

*B. Green hydrogen as an example of enabling technologies*

Several new technologies act as key enablers for business processes or "game changers" leading to development and deployment of new business models in the power industry.

Hydrogen as an enabling technology has several unique properties, which may be pivotal for reaching the ambitious European decarbonisation goals. The major advantage of hydrogen as an energy carrier is that it can be produced and converted to energy (e.g., electricity and heat) with relatively high efficiency [5]. Hydrogen can be long-term stored and transported over long distances. Apart from energy generation, it can be used for other purposes e.g., transport (vehicles, trains and boats) or chemical processes, while the outcome of its combustion is pure water, which can be utilised for many other purposes. Generation of hydrogen or Power-to-Gas (PTG) by using curtailed renewable electricity from windpower and PV is often mentioned as one the most promising approaches, contributing to a more stable and flexible energy system, supporting further integration of variable RES and thus avoiding costly expansion of electricity grid infrastructure [2]. The EU's paper "A Hydrogen strategy for a climate-neutral Europe" [3] is a paramount document, explaining the necessity for deployment of hydrogen infrastructure. It also points out that the priority for the EU is to develop renewable hydrogen, produced using mainly wind and solar energy, also known as green hydrogen. Renewable hydrogen is the most compatible option with the EU's climate neutrality and zero pollution goal in the long term and the most coherent with an integrated energy system. Therefore, the present study focuses specifically on green hydrogen.

There are however several doubts related to the overall feasibility of the PTG model since the knowledge and experience, related to construction and operation of hydrogen infrastructure, are still very limited. The following business model explores this alternative and identifies the potential barriers, which may prevent investment into the PTG infrastructure for utilising curtailed electricity from RES.

*C. Business models for Power-to-Gas*

Business modelling is becoming recognised as a vital activity to ensure successful deployment of new technologies. The European Commission underlined the importance of this by the creation of a dedicated Working Group (WG) on Business Models [4] within the BRIDGE framework. This WG among other things aims at comparing the profitability of different business models applicable to smart grids and energy storage solutions.

As a new and promising technology PTG has received considerable attention during recent years, because despite several foreseen benefits it has been challenging to proceed from the demonstration phase of PTG to the commercialisation phase [6]. In order to address these issues, business modelling of hydrogen infrastructure comprising electricity generation assets as windpower and PV, electrolyser, hydrogen storage etc. has been done in several studies. In study [6] development of optimised business models, based on integrated value chain approach assessed most beneficial combinations of input and output parameters. The study concludes that it is necessary to utilise the whole value of the available products and services to establish sustainable business models. However, there may be a potential for PTG markets in transportation sector and chemical industry, rather than seasonal storage in electricity. Another comprehensive study [7] develops business models on the basis of various process chains considering different plant scales and operating scenarios. The study assesses the influence of the scale and the type of the integration of the technology into the existing energy network with emphasis on economic consequences. Due to the flexible nature of PTG providing numerous specific applications for different end-uses within the energy sector, possible business models are presented on the basis of various process chains considering different plant scales and operating scenarios. Furthermore, the European Association for Storage and Energy (EASE) developed a set of PTG business cases [2], including the electricity system, concluding with necessity for ensuring access to markets with a level-playing field.

Recognising the importance of feasibility aspects addressed in the above-mentioned studies, the present study intends to highlight the necessity for modification of the existing and creation of new roles and responsibilities. The European electricity sector is a well-established industry with several decades of deregulations, which is now undergoing a considerable transition process caused by the political goals. The hydrogen infrastructure on another hand is a new and innovative part of energy sector, where the regulatory framework is still under development. In order to explore the potential barriers, the study employs the *e3value* modelling methodology.

*D. e3value methodology*

The selected initial business ideas have been developed and formalised as business models by applying the *e3value* methodology. This is a well-established conceptual modelling approach with extensive documentation [8], including a variety of downloadable tools and tutorials. It was initially developed at the Free University of Amsterdam [9] in the early 2000s and has been further developed. *e3value* develops a formal representation of a business model to enable the analysis, map the barriers and further develop it into a business case. The methodology has been successfully applied in several R&D projects both in the energy domain, such as BUSMOD [10], EcoGrid EU and SmartNet [11] and other areas [12]. Several recent publications make comparative evaluation of *e3value* with similar methodologies (see [13] and [14]) and acknowledge its functionality.

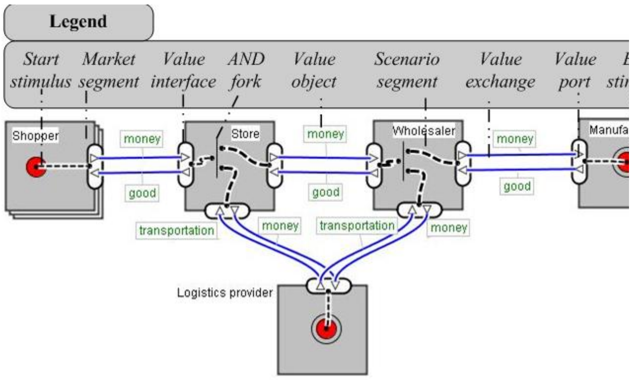


Figure 1. Key elements for *e3value* methodology

Creation of a business model in *e3value* includes several sequential steps, allowing formal representation of a business idea. This allows to define specific value exchanges between the actors, corresponding scenario path and herewith uncover potential barriers and shortcomings.

## III. Development of the Business Model for Hydrogen

### *A. Reference case and assumptions for the business model*

The present model is inspired by a real-life test case at Varanger Kraft (Northern Norway). The company received a concession for construction of 200 MW of wind power, but in practice cannot install more than 45 MW due to limited hosting capacity of the existing network. Today the company operates 2,5 MW Polymer Electrolyte Membrane (PEM)

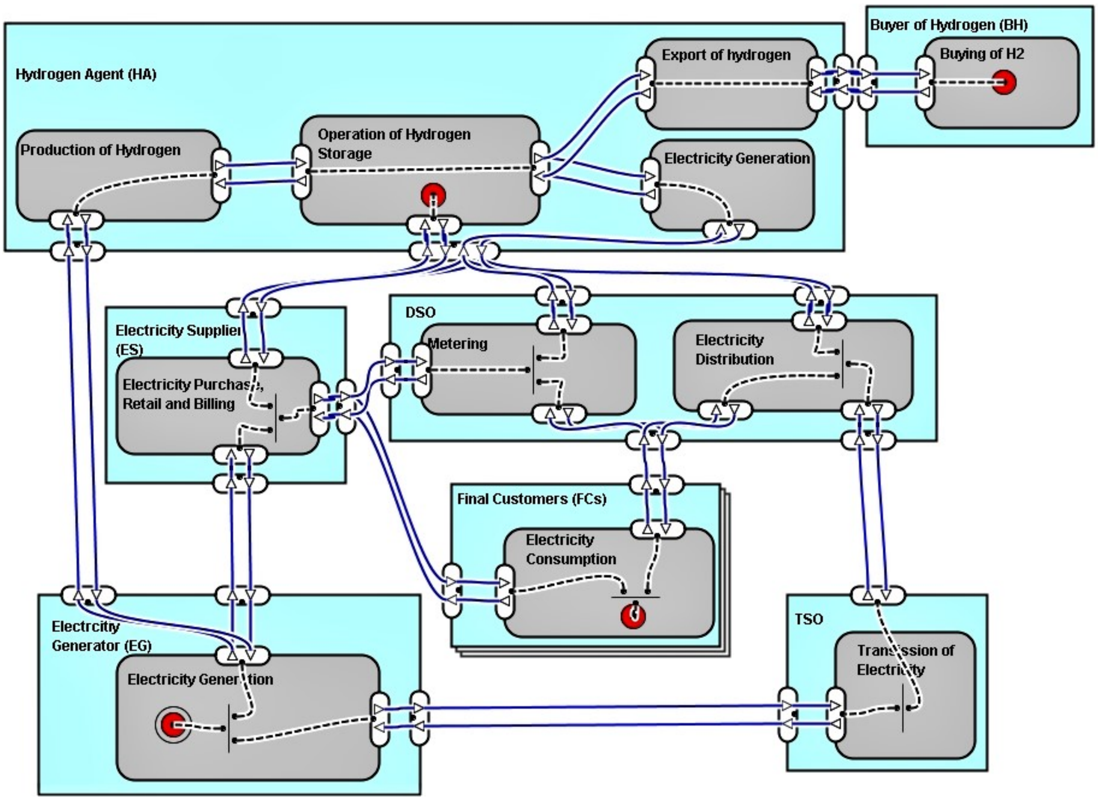


Figure 2. Business model Generation of Hydrogen from curtailed electricity

The approach is unique because it focuses on the concept of economic value as a central modelling construct. The *e3value* offers a number of interrelated core elements, also called an ontology, which are used to build a semi-formal abstract e-business model. Fig. 1 presents the key elements of *e3value* ontology, based on the example of manufacturing and retail of a simple good.

A business model is a set of value activities and value objects, which are exchanged between these value activities. More specifically, in the electricity sector there is a number of value activities that are common for the electricity business, namely: generation, transmission, distribution, supply, coordination of sales, etc. Actors in the electricity business are generators, distribution system operators, transmission system operator, suppliers, etc. Each actor can perform one or more of such value activities. The ultimate goal of the business modelling is to evaluate the business idea and discover a business scenario, feasible for every stakeholder.

electrolyser, which produces up to 1 metric ton hydrogen to be used domestically for transport and heating of dwellings (see [15] for details).

A set of assumption has been made:

- It is assumed that the whole area is self-sufficient with energy at any time and is a net exporter of energy in form of electricity or hydrogen. This means that no external electricity generator needs to be included in the model.
- There is no local network i.e., all actors are connected to the conventional distribution network, which is used for both feeding in and consumption of electricity.
- The installation cannot function in island operation mode; therefore, it needs system services and frequency support. This brings the Transmission System Operator (TSO) into the model.

- Heat generated by the process and the fuel cells is not utilised in this version of the model.

- In Norway metered data are exchanged through a dedicated date hub - Elhub [16], operated by the TSO, but in the business model, for the sake of simplicity, the Elhub is not shown.

- Assignment of responsibilities for electricity metering and billing is done according to the existing legislation in Norway.

To make the model functional it is necessary to set reasonable boundaries and make corresponding simplifications. The model does not consider local voltage management, electricity losses, operational costs related to maintenance. In this version of the model, produced hydrogen will have unspecified export to a hydrogen buyer, who does not have any specific connections to the model otherwise.

*B. Actors and value activites selection*

The model is presented in Fig. 2.

*1) Hydrogen Agent (HA)*

HA is a new actor, who is principal for deployment of this business model. The HA is responsible for activity Production of Hydrogen from curtailed electricity and the following activity Operation of Hydrogen Storage, including compression of hydrogen. The same actor also runs Electricity Generation from hydrogen, by using the fuel cells. The electricity is further sold to the Electricity Supplier and delivered physically to the DSO. In addition to this, the HA runs Export of Hydrogen to an external Buyer of Hydrogen (BH) through a dedicated value port.

The HA has two interfaces for electricity: one value port is a physical delivery of excess electricity from the EG, and the second value port is related to exchange of electricity (purchase or sell) with the Electricity Supplier and associated use of Electricity Distribution Services and Metering. To ensure reliable operation of hydrogen storage at any time, the HA purchases electricity from the Electricity Supplier.

*2) Electricity Supplier (ES)*

The ES is responsible for Electricity Purchase, Retail and Billing activities. For the retail: the ES has two different interfaces or value ports for retail i.e., the one towards HA as an industrial end-use customer and the second for the regular Final Customers.

For the purchase: ES purchases electricity produced by the EG, which is physically delivered to the transmission network. The ES participates in Day-Ahead market, but this is not included into the model for the sake of simplicity. The ES receives metering data from Metering activity at the DSO. Billing as services is embedded into value exchanges showing electricity sell.

*3) Transmission System Operation (TSO)*

For the scope of the present model, the TSO runs the conventional activity Transmission of Electricity. For the sake of simplicity other TSOs activities are excluded from the model.

*4) Distribution System Operator (DSO)*

The DSO's main activity is Distribution of Electricity, i.e. physical delivery of electric energy. The DSO in this model is also responsible for Metering.

*5) Electricity Generator (EG)*

The EG in this model is a local wind power generator, and normally it feeds electricity into the Transmission Network of the TSO.

However, as it was mentioned in Section III (A), the available capacity of the transmission network is quite limited. To avoid curtailing and thus maximise the share of RES-based generation, the EG delivers the excess electricity to the HA, so it can be used for production of hydrogen. According to the reference case, since the Electrolysers are located in the vicinity of generation, it delivers physical electricity directly to the HA agent i.e., without use of the distribution network as such. In monetary terms the excess electricity is sold to the ES, which ensures economic balancing and retails the electricity to the Final Customers.

*6) Final Customers (FCs)*

The FCs in the model are conventional passive end-users, buying electricity from the ES and get it delivered physically by the DSO. The FCs are metered by the DSO and billed by the ES.

*7) Buyer of Hydrogen (BH)*

The BH buys hydrogen from the HA and sells it elsewhere outside the model's boundaries.

*C. The scenario path*

According to the *e3value* methodology the scenario path starts at a point indicating demand for goods or services, shown as *Start Stimulus.* In our case the scenario starts at two actor segments showing demand for electricity and one for hydrogen:

(i) FCs purchase electricity from the ES, the electricity is delivered and metered by the DSO. The DSO receives physical electricity through TSO, where it has been delivered by the EG. FCs are billed by the ES. The ES retails electricity purchased from the EG. The *AND* fork at the EG leads to termination of this scenario path, the *End Stimulus.*

(ii) For activity Operation of Hydrogen Storage, the HA purchases electricity necessary for maintaining reliable and safe operation from the ES, which is also delivered and metered by the DSO. The HA is billed by the ES. The DSO receives physical electricity through the transmission network from the TSO. This terminates the scenario path through *AND* fork at the same *End Stimulus* as the previous path.

(iii) The External Buyer of Hydrogen purchases compressed hydrogen from the Export of Hydrogen activity of the HA. The hydrogen was kept into Hydrogen storage. The storage received hydrogen from Production of Hydrogen activity of HA. Electricity, necessary for production of hydrogen was received directly from the EG (wind power). The *AND* fork shows that the generated electricity is delivered both to the transmission network at the TSO and for Production of Hydrogen at HA. The *AND* fork terminates this scenario path at the same point as the previous two.

## IV. MAPPING OF BARRIERS

The evaluation of business models in this paper is focused on the detection of possible barriers to investments deployment of the new technology directed towards the transition of the energy system towards a decarbonized structure. In this light the *e3value* methodology has been used to highpoint important interactions between actors via value exchange links connecting the different value ports. The following issues were identified during the modelling exercise.

*A. Regulatory status of PTG facilities: roles, responsibilities and ownership*

The immediate issue, which was noticed during the development of the business model, was the necessity to establish a new business role – the Hydrogen Agent having a very complex nature due to combining several business activities and linking together hydrogen and electricity. In the reference project, this role was actually assigned to a newly established company within the Varanger Kraft concern.

The main challenge is that responsibilities for this new role are still very unclear, especially when it comes ownership and operation of the following:

- PTG facilities as electrolysers
- Supporting facilities such as compressor stations and pipelines
- Other supporting facilities such as hydrogen storage
- Any peripherals for retail of hydrogen (e.g., vehicle charging stations and export terminals)

In the power industry there is a very clear picture of roles and responsibilities for the main actors, including limitations as for example ownership and operation of energy storage [17]. The picture is not static, but modifications happen in well-structured public discussions/consultations and are formalised in different regulatory acts.

When it comes to hydrogen, several issues remain unclear. Further investigation shows that for the time being the European Forum of Gas Regulators (the Madrid Forum) still considers two variants:

- PTG as "conversion service", not energy production, and thus can be considered as natural monopoly
- PTG as commercial activity, which cannot be done by regulated parties

The difference between a regulated natural monopoly and commercial activity is essential when it comes to investment decisions since it defines the future revenues. This issue was pointed out by the WindEurope association, which is one of the key RES stakeholders in Europe [18].

*B. Third Party Access to hydrogen infrastructure*

In addition to the ownership and operation of electrolysers, there are several interlinked issues including Third Party Access (TPA) to pipelines and storage facilities from possible competing producers and suppliers of hydrogen. Introduction of TPA and its type (negotiated vs. regulated) is essential for both recovering of the initial investments into the pipeline networks as well as development of competing hydrogen-producing infrastructure i.e., electrolysers.

*C. Cross-sector involvement of actors*

The above-mentioned issue has an additional dimension, related to sector coupling: it is unclear whether TSOs and DSOs can involve themselves into hydrogen production, transportation and storage or not. It is natural to draw parallels to the existing regulation of Electricity System Operators' involvement into ownership and operation of energy storage [17], where despite the limitations, considerable exemptions can be still granted to System Operators.

*D. Origins of hydrogen: is it really green?*

This issue has previously been raised by WindEurope (see [18]. Introduction of an electrolyser will inevitably bring the necessity of its optimal operation and utilisation of the electrolysers' capacity, which can be obviously improved by using electricity from the conventional grid, when there is no wind generation available. Since the conventional grid may have different energy mixes, this raises the question whether the produced hydrogen is carbon-free or not. This is especially relevant in case any RES-supporting schemes are applied to a certain PTG unit.

## V. Conclusions

Two main conclusions can be drawn from the present study. Firstly, modelling of hydrogen infrastructure with a specific reference to a real-life implementation, as a concept for future grid architecture supports its viability from a business perspective. The modelling however identified several barriers, and in particular the unclear status of PTG facilities and their interactions to the electricity sector, which may be effective "show-stoppers" for implementation of the model. The identified potential barriers and consequences for the investment decision are summarised in Table 1.

TABLE 1 SUMMARY OF THE IDENTIFIED BARRIERS

| Title | Description | Importance | Consequences for investment |
|---|---|---|---|
| Regulatory status of PTG facilities (electrolysers) | Undefined status for H2 electrolysers: natural monopolies vs commercial activities | Uncertain future revenues from electrolysers | This will limit and delay the initial investment |
| TPA to H2 infrastructure | TPA for PTG facilities (pipelines) has not been introduced yet | TPA will reduce entry barriers for PTG actors and increase the competition. | TPA may result in competitive H2 prices and reduced rate of return on infrastructure investments |
| Cross-sector involvement of actors | It is unclear whether electricity SOs can own and operate PTG assets | Unclear (for the time being) | Possible cross-subsidising |
| Tracing the origin of produced H2 | No methods for proving origins of H2 produced by electricity from the grid with varied energy mix | The issue influences eligibility of support schemes including taxation. | Reduced returns / longer investment payback period |

Secondly, *e3value* appears to be an appropriate methodology for evaluation of innovative business models in the energy sector. The methodology allows to identify potential structure, key actors and corresponding business activities with value exchanges, which comprise a business model and scenario path i.e., a complete business scenario.

Uncertainty and especially the absence of clear regulatory provisions are possibly two of the most significant barriers to establishing new services since this uncertainty could strongly discourage potential investors from developing the necessary infrastructure assets. Furthermore, to establish an operational environment, it can be equally important to indicate roles and responsibilities as well as any possible limitations of these in order to draw unambiguous legal borders.

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