Hydrogen — market

Operation of Electrolysers in the Electricity Market considering the German National Hydrogen Strategy

MAON | umlaut

Contents

Background and goals	4
Electricity market model	6
Scenarios for 2030 and 2035	8
Revenues and costs	10
Utilisation, integration and green share	12
Summary	16
Bibliography	18

Background and goals

Maon and umlaut[1]

Both the EU commission and the German Federal Government have set the climate–policy goal of achieving greenhouse gas neutrality by 2050. According to the German Federal Government's "National Hydrogen Strategy"[2], hydrogen should gain in competitiveness and be deployed at greater volumes in energy conversion, industry and transport. This strategy should lead to a transformation in all relevant sectors. The relevance of hydrogen for the energy transition was shown in a prior study[3] by umlaut. Major results show that energy will still need to be imported in the future. Hydrogen can provide an ideal medium for this purpose, as it can be generated in a completely carbon–neutral fashion using renewable energy in comparison to fossil fuels. In addition, the usage of hydrogen presents the lowest possible transformation costs to the overall system, as components of existing infrastructure can be reused (e.g. gas transmission and distribution networks) and large areas of logistic infrastructure are already available. The importation of hydrogen also offers the current fossil fuel exporting nations a subsequent business opportunity.

The National Hydrogen Strategy foresees, alongside the exportation of energy facilities, the development of domestic generation capacities for so–called "green hydrogen" within Germany. Green hydrogen is hydrogen as that produced with the use of renewable generated electricity

in electrolysers. The current plans intend Germany's electrolysers to reach an installed electrical capacity of 5 GW in 2030 and 10 GW in 2035. Growth in this market depends – in addition to government incentives – crucially on economic viability and thus from the incentives of the electricity and hydrogen markets. At the latest in 2035 the electrolysers are expected to make a significant contribution to the electricity market. Against this background, future operators are asking in particular the following questions:

- How high will revenues, costs and contribution margins be for the operation of electrolysers on the electricity market?
- What annual operating durations (full load hours) should be considered for each usage scenario for the electrolysers?
- What amortisation periods can be expected for electrolysis facilities based on the usage strategies and concepts?

In this study, Maon and umlaut provide answers regarding the operation of electrolysers at the European electricity market.

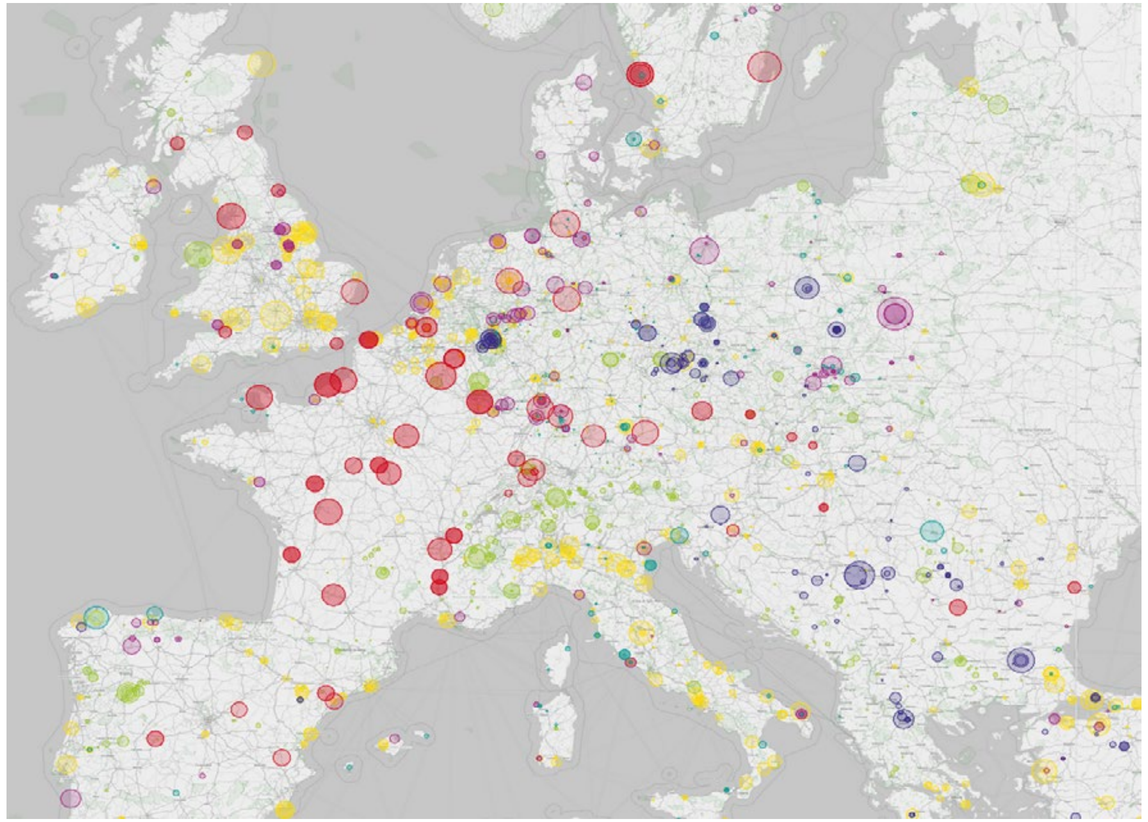
Electricity market model.

For the derivation of electricity purchasing costs and potential revenues of electrolysers, a fundamental electricity market model[4] has been used. It simulates the unit commitment of the power stations and electricity demand in Europe and takes all technical and economic restrictions of the facilities into account. Thereby, it includes the merit order procedure on the basis of the existing power stations, electricity demand as well as resulting electricity imports and exports.

Figure 1 visualizes the power stations used to determine the status quo. All future developments with regard to the commissioning and decommissioning of conventional power stations, extension of generation capacities based on renewable energy or flexible demand behaviours e.g. caused by electro–mobility or photovoltaic battery systems are modelled.

Locations of European thermal and hydro power stations in 2020

Fig. 01



Hydro · Other · Lignite · Hard coal · Nuclear · Gas · ~ 1 GW

Scenarios for 2030 and 2035.

For the forecast, the electricity market in Europe is modelled in an hourly resolution, taking the hydrogen market for the scenarios in 2030 and 2035 into account. The following Table 1 depicts the assumed capacity of the coupling facilities and the hydrogen storage capacity.

Scenario	2030	2035	Sensitivity
Electrolysers	5GW	10GW	10GW
H_2 storage	5GWh	10GWh	15GWh
H_2 turbines	5GW	10GW	10GW

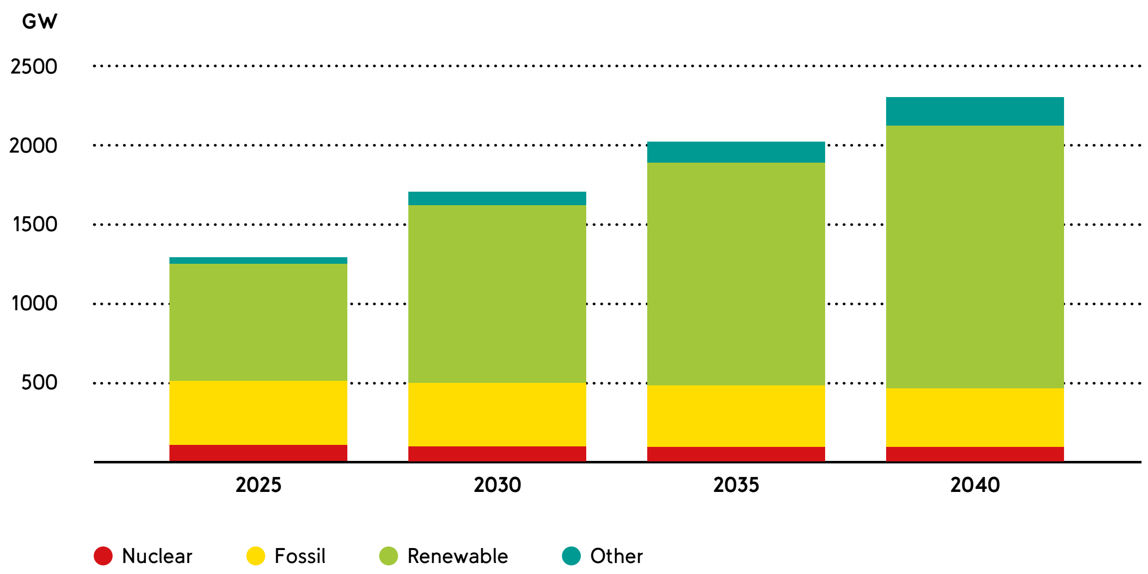
Table 1: Scenarios for 2030 and 2035 including the installed capacity of new facilities in Germany

In all scenarios, the decision on the operation of the electrolysers is reflected without consideration of network charges and the EEG levy. On the one hand, this is intended to focus solely on the electricity market. On the other hand, it is intended to determine whether an economically viable operation of such facilities can be achieved in Germany at all. The electricity costs for the operation of the electrolysers thus always reflect the wholesale prices and can be considered as the "best case".

In addition to the electrolysers, hydrogen storage facilities (H_2 storages) and gas power stations with hydrogen turbines (H_2 turbines) are also taken into consideration in the future scenarios in order to reflect their interactions. The installed capacity in Germany and the 70% efficiency of the electrolysers correspond to the information given in the National Hydrogen Strategy.

Development of the generation capacity in the Distributed Energy scenario in the ENTSO–E region[6]

Fig. 02



The electricity price, consumption and hydrogen generation rate of the electrolysers represent the results of the simulation, whereas the hydrogen price of €1 to €4/kg is predefined in order to simulate a market for hydrogen incl. a mid–range price. For 2035, a sensitivity scenario (Sensi) with a hydrogen storage increase in Germany of around 5 GWh will also be considered. Other input data such as facility operation cost and power, electricity consumption, electricity import capacities and CO^2 prices are based on the information for the "Distributed Energy" development path from the TYNDP 2020[5]. Figure 2 shows in this regard the installed electricity generation capacity in the region in question.

Revenues and costs.

The costs, revenues and contribution margins of German electrolysers resulting from the simula–tions are displayed in Figure 3. The contribution margins related to the installed capacity increase remarkably with the rising sale price of hydrogen. This is on the one hand due to the proportional influence of the hydrogen price on revenues and on the other because of the flat curve of the merit order or additional costs caused by higher electricity purchasing. A comparison of the 2035 and Sensi scenarios shows that additional storage capacities can only marginally increase the revenues and thus the economic viability of electrolysers. The amortisation period of interest–free investment in an electrolyser turns out at, for example, eleven years if the price of hydrogen is at €2/kg, the annual contribution margin at €72/kWa and the investment costs[7] at €800/kW in 2030. The costs given in the simulation for electricity purchasing reflect the wholesale price on the electricity market, meaning taxes and du–ties are not included. Higher costs would arise if electrolysers were defined as end consumers, as in the current market design. Consequently, the results show only a theoretical revenue potential. The market design and incentives such as tax breaks and benefits are options for reaching this theoretical result and making investment incen–tives sufficient to realise the National Hydrogen Strategy.

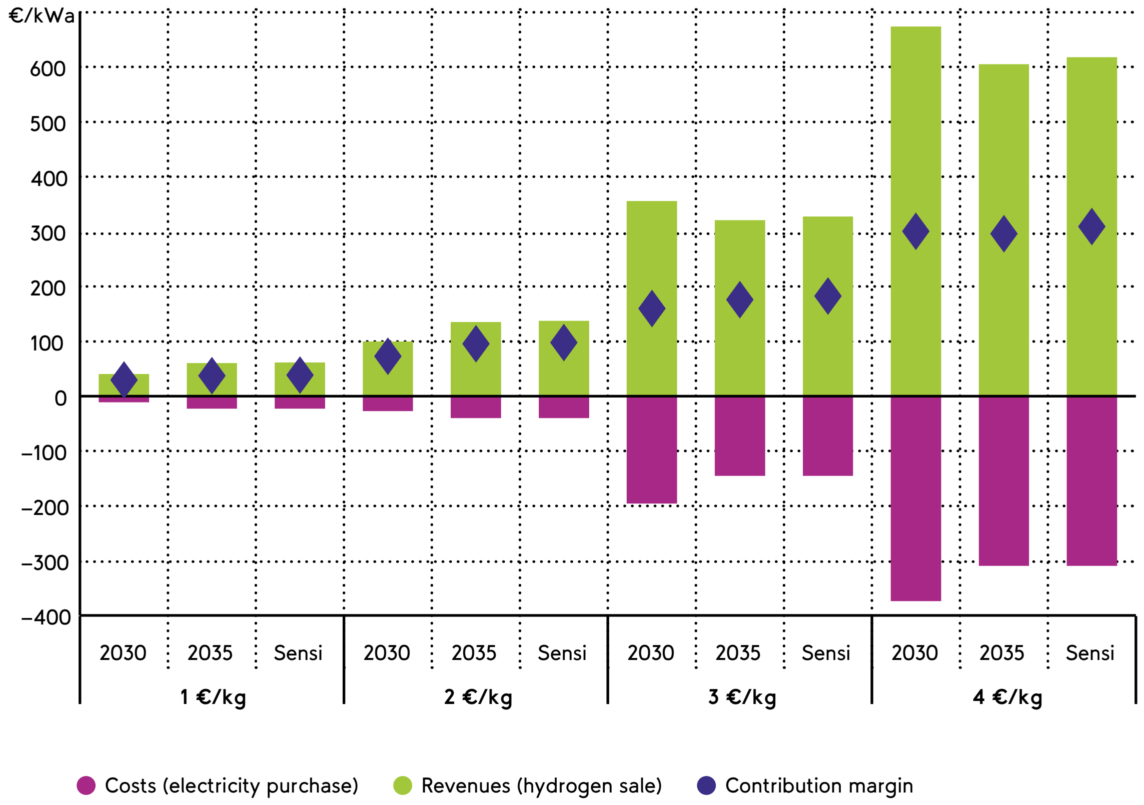
The economical operation of electrolysers in an identical tax and duty landscape to that in which today's end consumers exist is expected to be possible only from a hydrogen price of more than €7/kg.

Electrolysers/H_2 turbines/H_2 storages			
[GW]/[GW]/[GWh]	2030	2035	Sensi
Germany (DE)	5/5/5	10/10/10	10/10/15
ENTSO–E (excl. DE)	0/0/0	162/162/24	162/162/24

Table 2: Scenarios and assumptions for the modelled ENTSO–E region

Revenues, costs and contribution margins of electrolysers in Germany

Fig. 03



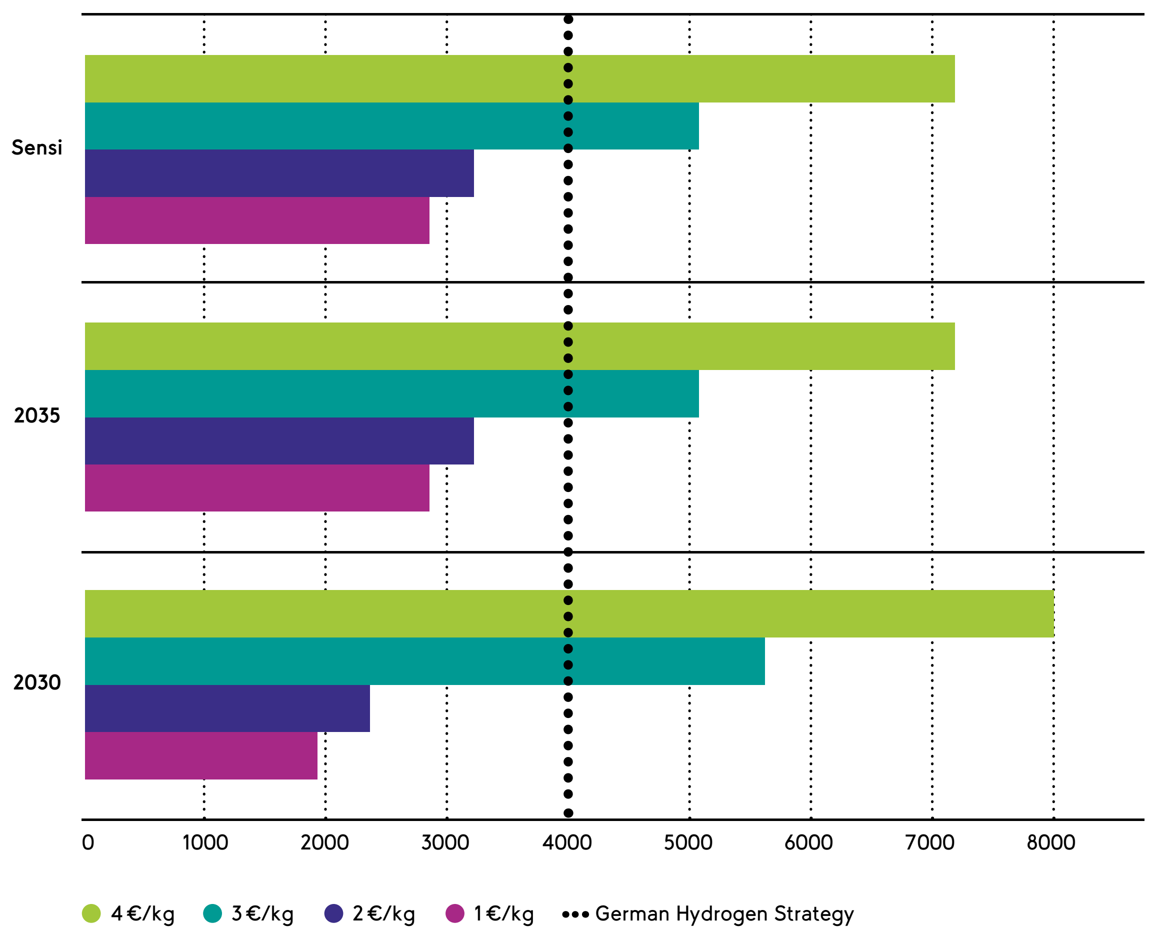
Utilisation, integration and green share.

The costs and revenues result from the electrolyser commitment. Therefore, Figure 4 shows the full load hours derived by the market model. The assumed 4,000 h/a of the National Hydrogen Strategy is achieved at a hydrogen price between €2 and €3/kg, if today's tax burden on end consumers is not maintained. Additional hydrogen storage in combination with later reconversion has a comparatively low influence on utilisation ("battery storage" application). Its usage only results in a minor change in the schedule of the electrolyser in times of high contribution margins. From a hydrogen price of €2/kg upwards, the full load hours increase significantly, because in these cases the profitable price differences between hydrogen and electricity multiply. A deeper analysis has demonstrated that electrolysers will only contribute on a secondary level to the integration of renewable energy sources in 2030 and 2035, as other flexible facilities such as battery storage systems and hydroelectric power stations will be available at the same time. In addition, reconversion will not achieve a significant contribution margin. Thus, the use of electrolysers will be decisively influenced by the provision of hydrogen to the local market.

It is to be considered positive that, discounting the current tax burden on end users, full load hours of up to 8,000 hours per year can be achieved if the local price of hydrogen rises to €4/kg. On the other side, it must be noted that an increase in the full load hours to over 4,000 hours per year will bring the electricity mix during

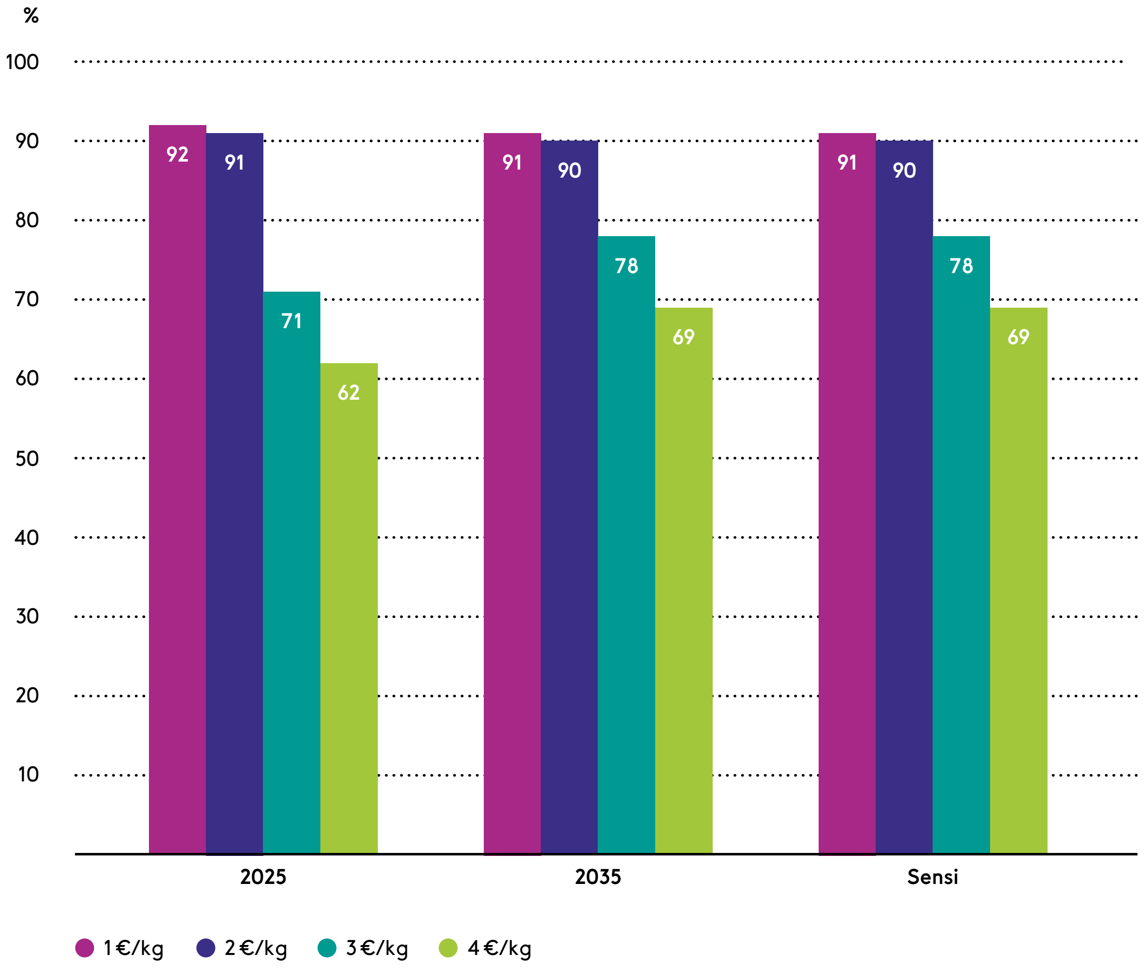
Full load hours of electrolysers in Germany depending on the market price of hydrogen

Abb. 04



Share of hydrogen produced exclusively with "green electricity" in German

Fig. 05



the operational hours of the electrolysers closer to the "average electricity mix" in the year in question. In this way, at any rate, electricity from conventional power stations will be used to ope–rate the electrolysers in a "real" sense, and not just "on balance". The proportion of "green elect–ricity" in the electricity mix by annual comparison during the operational hours of the electrolysers is shown in Figure 5.

A deeper analysis reveals that the pure opera–tion of the electrolyser with "excess electricity" –respectively the exclusive usage in periods of negative electricity prices on the exchange – will only lead to full load hours of 300–700 per year. In the model the increased generation capaci–ty on the basis of renewable energies and the simultaneous reduced generation capacity of conventional power stations is not accompanied by longer periods of negative electricity prices.

From the above points, on the one hand, it is clear that the much closer coupling of the elec–tricity and gas (here: hydrogen) markets in the future must be considered in strategic decisions. On the other hand, these circumstances also il–lustrates the requirement for logical CO^2 charges as a regulatory element in the system and the need for proof of origin certifications for rene–wably generated products. This latter appears in connection with the growth of the hydrogen market particularly important, since the usage of "blue" or "turquoise" hydrogen must also be considered in order to cover short–term peaks in demand or high price differences. "Blue" hydrogen is produced in a non–renewable way, whereby CO^2 from the corresponding electrici–ty generation is separated and stored (carbon capture and storage). "Turquoise" hydrogen is hydrogen produced by the cracking of methane (methane pyrolysis).

Summary

The goals described in the German National Hydrogen Strategy of generating green hydro–gen require the installation of 5–10 electrical GW of electrolyser capacity. This electrical demand can also be considered relevant to the electricity market, for which reason their commitment in this market has been investigated in this paper.

Taking as a premise the exemption from the EEG levy and network charges, it can be assumed that sufficient full load hours for economical operation of the electrolysers can be achieved from a price of approx. €2.7/kg. Considering the current tax burden on end consumers, however, it appears unlikely that an economical operation of electrolysers is possible with a hydrogen price of less than €6/kg.

In the scenarios considered, the reconversion of hydrogen has no significant impact on the revenues of operators of the electrolysers if the hydrogen used for this purpose was previously generated domestically and in a green manner. It is always the better option to sell the produ–ced hydrogen on the future emerging hydrogen market.

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It should be noted that higher full load hours of electrolysers are always accompanied by electricity consumption which pushes for higher electricity prices due to the merit order effect. During the development of renewable energy facilities, which is currently still ongoing, these circumstances also imply that the entire electrici–ty mix will be used, and thus also electricity from conventional power plants will be used for the production of hydrogen.

The national generation of green hydrogen must therefore be accompanied by an enhanced de–velopment of facilities based on renewable ener–gies and increased CO^2 charges. The nascent hydrogen market also demands the introduction of proof of origin certifications. This allows, on the one hand, the use of ″blue″ or ″turquoise″ hydrogen in the start–up phase to balance the variable demand. On the other hand, a suitable market design must be conceived and imple–mented in order to ensure system stability and the CO^2 balance with the stronger interplay of the electricity and gas markets in the future.

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