POWER-TO-X MODELLING WITH IDENTIFICATION OF ECONOMIC KEY FACTORS USING A BUS FLEET SENSITIVITY ANALYSIS

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Overview

Climate change and the associated need to reduce carbon dioxide emissions (CO_2-emissions) are increasingly coming into focus of society and politics [1]. The use of electrolysers can play a central role not only for the decarbonisation of regional infrastructures, but also for the offer of flexibilities in the electricity market [2]. Electrolysis of water is the process of using electrical energy from renewable energy sources to decompose water into oxygen and “green hydrogen” [3]. One kilogram of hydrogen contains about as much energy as 3.3 litres of diesel, so hydrogen has a high energy density by mass [4]. This and the fact that hydrogen in mobility usually competes with very expensive energy sources such as diesel and petrol make the use of hydrogen from electrolysis in mobility a promising path of use. Particularly, due to the shorter charging time and the potentially longer range than a battery electric vehicle (BEV), the focus of local public transport providers is on the use of hydrogen in the heavy-duty sector [5]. Additionally, electrolysers can use hydrogen storage to offer adjustable options in the electricity market of the future, so that they contribute to the stability of electricity grids. In addition, the hydrogen storage system offers the option of taking advantage of favourable electricity prices on the spot market by operating the electrolyser flexibly [6].

This paper identifies and quantifies key factors influencing the results of an economic analysis of a 1 MW PEM (Proton Exchange Membrane)-electrolyser with a hydrogen storage on the german energy market by using the example of a bus fleet with ten fuel cell electric buses (FCEBs), and then evaluates them with the aid of sensitivity analyses. Furthermore, a solver for linear programming problems is used to investigate the optimisation potential of the hydrogen storage system from an economic point of view. For the transferability of the results the unit electrolyser full load hours is introduced to be able to describe the storage size.

Methods

The net present value (NPV) was used to assess the profitability. For this purpose, the following formula was used, taking into account the residual values:

$$\mathrm{NPV}_0 = -\mathrm{I}_0 + \sum_{\mathrm{t}=1}^{\mathrm{n}} \frac{\mathrm{C_t}}{(1+\mathrm{i})^{\mathrm{t}}} + \frac{\mathrm{R_n}}{(1+\mathrm{i})^{\mathrm{n}}}$$

I_0: Investment — n: Investment period
C: Cashflow — i: Calculation interest rate
t: Time interval — R: Residual value

The period under consideration is twenty years and a depreciation period of 25 years is assumed for the electrolyser and the hydrogen storage. In this business case, the stack replacement costs were taken into account as operation an maintenance costs.

In order to identify the adjustable potentials resulting from the use of different sized storage systems and fluctuating electricity prices, it is assumed that an ideal electricity price forecast is possible. The best result is expected with optimal market timing, therefore the objective (function) is formulated as a mixed integer linear programm with

$$J = \max_x \; c^T x, \qquad A \in [-1{,}0{,}1]^{m \times n}, b \in \mathbb{R}^{m}, c \in \mathbb{R}^n, x \in [0 \dots 1]^n,$$
$$\text{subject to } A \cdot x \leq b,$$

whereby n represents the number of single hour contracts on the power exchange and m represents the number of constraints. Decision vector is noted as x with length $|x| = n$, and c contains the electricity prices for all single hour contracts. Inequality constraints of this linear program can be passed to the solver used as A and b.

Results

For the assumptions made, the NPV shown in Figure 1 result with the key factors and sensitivities. The result shows that despite high subsidy rates (55% for electrolyser and H_2-storage and 60% for FCEBs on the innovative share) the NPV results clearly in negative values. The electricity price components such as levies, grid fees and taxes have a huge influence on the NPV-result. With an increase of the electricity price for the first GWh of a year by 99.96 €/MWh and for the second GWh of a year by 60.33 €/MWh, which roughly corresponds to the grid fees, the levies based on the renewable energy law in Germany (second GWh only 40%) and the electricity tax in Germany, the NPV is reduced by 3.09 mio. € from -3.51 mio. € to -6.60 mio. €. Furthermore, Figure 1 shows that the operating costs of FCEBs, the diesel price (fuelling of the diesel buses as a comparison scenario), the kilometer-specific hydrogen demand of FCEBs as well as the funding rate on the innovative share of FCEBs have a significant influence on NPV-results. In addition, the price increase for CO_2-emissions does not have a major impact.

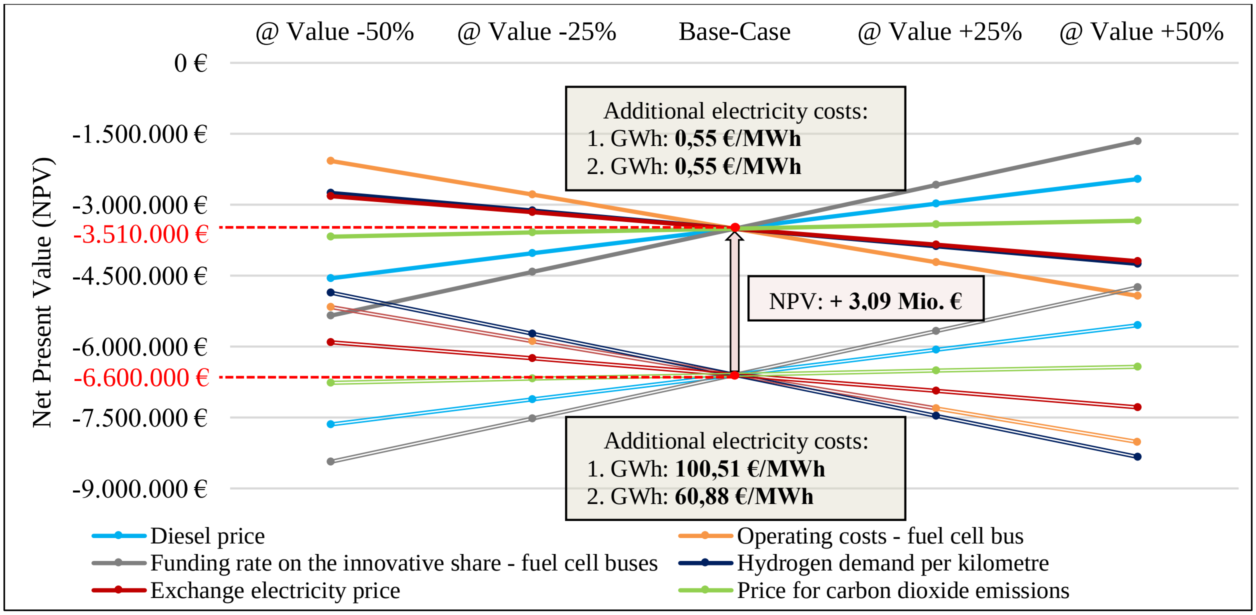

Figure 1: Sensitivity Analysis - Significant Factors Influencing the Net Present Value (NPV)

Figure 2 shows that larger storage capacity have a limited influence on the resulting average electricity exchange price.

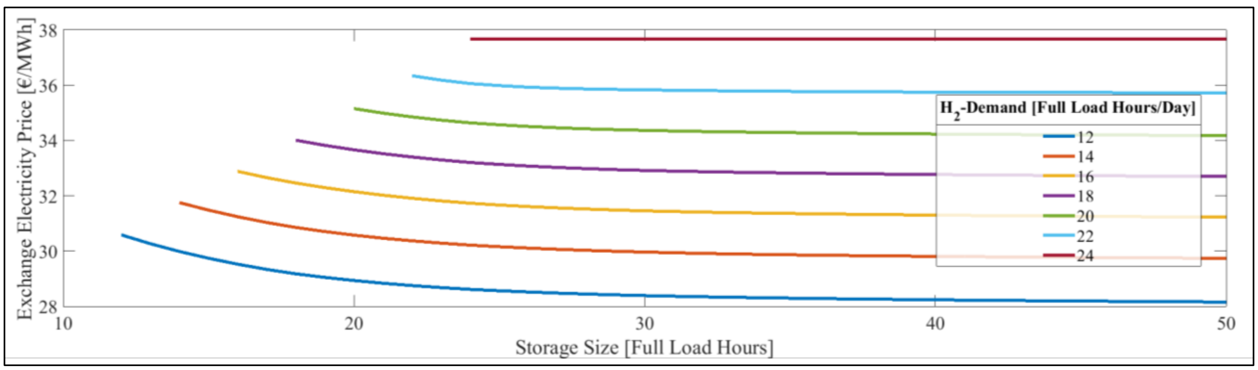

Figure 2: Average Elektricity Price Depending on the Design of the Electrolyser and Hydrogen Storage System

Conclusions

This paper illustrates that, above all, the price of CO_2-emissions must rise in order to increase the economic viability of the technology of water electrolysis. At the same time, the electrical power used in electrolysis must be largely exempt from grid fees, taxes and levies in order to be able to increase NPV significantly. Other factors with a positive influence on NPV are price reductions for electrolyser, storage system and FCEBs. Furthermore, modelling of the hydrogen storage shows that at current prices for the hydrogen storage system, it is not reasonable under the assumptions made to build a large storage facility in order to use flexibleness on the power exchange. This does not yet take into account a possible participation in the balancing energy market, which could be considered in further investigations.

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