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Usage of locally produced green hydrogen for peak load coverage in alpine regions and a local community – Simulation based on Austrian communities

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Hydrogen (H_2) technology offers promising opportunities since hydrogen is a medium for the long-term storage of energy, to address peak loads by reconverting hydrogen to electricity via fuel cells. This approach can also be used for the transport sector and could be applied to fuel-cell-powered commercial vehicles. Furthermore, fuel cells enable the provision of large amounts of energy in a timely manner, relieving local electricity bottlenecks by an energy source without carbon dioxide (CO_2) emissions. This paper shows how hydrogen technology can be used to power three fuel-cell-powered snow groomers to ensure a sufficient supply over the winter season and how the identified peak loads during the annual load analysis can be reduced by 25% and 50% compared to reference value by reconverting locally produced green hydrogen via a fuel cell. According to simulation results based on observed electricity consumption from real data, there is an electricity surplus in the target community (area Salzburg) during summer months. While this surplus does not meet the entire electricity demand on an annual balance sheet, the surplus could produce H_2 of 21,250 kg yearly for the fuel-cell-powered snow groomers. Regarding additional renewable energy generation, the use of wind power and photovoltaic (PV) systems to partially cover peak loads and produce additional green H_2 using the increased electricity surplus proved feasible. The existing peak loads are caused only by ski slope operations, which accounted for up to 19 MW during November compared to the separate peak load of about municipality at 7.7 MW. The simulations concluded that unrealistically oversized fuel cells and hydrogen components would be required. The analysis demonstrates that the full power of the fuel cell would only be needed for two months a year; hence, hydrogen seems to be unsuitable for this purpose. Nevertheless, the local production of green hydrogen has significant potential in terms of achieving a green tourism future in alpine regions. Alternative strategies of using H_2 to prevent higher loads and frequency variations are reasonable and need to be explored with regard to blackout prevention strategies.

Keywords: Power2X, green hydrogen, water electrolysis, sector coupling, heavy-duty vehicles, peak shaving, fuel cell powered snow groomer

INTRODUCTION

The shift to renewable energy sources is particularly important so that climate policy goals can be met [1]. The expansion of renewable energy producers in not only urban but also suburban areas, such as in tourism-intensive alpine regions, is indispensable to achieve a share of at least 32% of renewables in the European Union (EU) according to the [2]. The temporal discrepancy between electricity generation and consumption in a tourism community should be a focus for the further expansion of renewable energy and should at least cover peak loads; ideally, however, the energy production and energy consumption should be balanced over a longer period of time.

The issue of the year-round balance between production and consumption plays an essential role in connection with the volatility of renewable energy production. The value chain for locally produced green hydrogen starts with water electrolysis. Electrolysis is a process that involves splitting water into its components: hydrogen (H_2) and oxygen (O_2).

The hydrogen produced can be used within the electricity and transport sectors. For the electricity sector, the temporarily stored hydrogen is converted back into electricity via the fuel cell and can smooth out peak loads by supporting the local power grid. Among other applications, the hydrogen can be used for the transport sector. The transport sector in this paper includes only the supply of three fuel-cell-powered snow groomers (FC-PSG) over a winter season; this field is possibly to become subject to regulations similar to those that apply to heavy-duty vehicles in the EU, which require a reduction of CO_2 emissions [3].

This paper focuses on the suburban area and includes a tourism intensive community in Salzburg (for reasons of data protection law, the community may not be published) according to [4]. Other papers increasingly examined the use of hydrogen in conjunction with battery storage systems such as Fasihi & Breyer (2020) or Papadopoulos et al. (2020) or power-to-gas applications such as Weidner et al. (2018) [5-7]. Therefore, this is the first paper dealing with the integration of hydrogen in tourism

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regions and mountain railways with high peak loads in details.

In addition, this paper describes how mountain railways can responsibly invest millions of euros in reducing CO_2 emissions to preserve their livelihood while simultaneously promoting economic efficiency and climate protection. This research is conducted to enable communities and ski resorts to make the leap "into a green energy and tourism future" and secure "Austria's system leadership in the field of ecologically optimized winter tourism" [8].

OBJECTIVES

The Objectives cover the main two sectors. For the transport sector, the supply of the FC-PSG and for the electricity sector the peak load coverage will be investigated. Derived from this, various research questions arise:

- How do the monthly average peak loads behave in the community and the mountain railways?
- To what extent can green hydrogen be used efficiently and effectively in an alpine tourism region to supply three FC-PSG and to reduced identified peak loads by 25% and 50% by means of conversion back into electricity via the fuel cell?
- How are the adequate system components (electrolyzer, storage tank and fuel cell) to be designed for each scenario?

The original goal was a 100% supply of renewable energy and the use of hydrogen for the community and mountain railways. However, the analysis of the electrical data, based on real data in 15-minute timestamps from Salzburg Netz GmbH (local energy supply service provider), showed in Fig. 1 that the peak loads of the mountain railways produced enormous consumption by the snow cannons and therefore a 100% coverage was considered improbable. Since the community did not have such large peak loads, an approximation of 25% and 50% were chosen to smooth the peak loads of the mountain railways.

In Fig.1 the energy consumption reaches hourly peaks of over 19 MW in the months of November and December. In general, the load curve of the mountain railways behaves similarly over the entire underlying data set. Furthermore, the investigation showed that summer tourism and the accompanying use of the cable cars in this community requires significantly less electricity than in winter.

In comparison, the local community has a far less significant peak load of 7.7 MW, however has a vastly higher annual electrical consumption of about 34 GWh compared to the mountain railway's 10.5 GWh. This highlights the importance of handling peak loads for hydrogen energy systems to be viable.

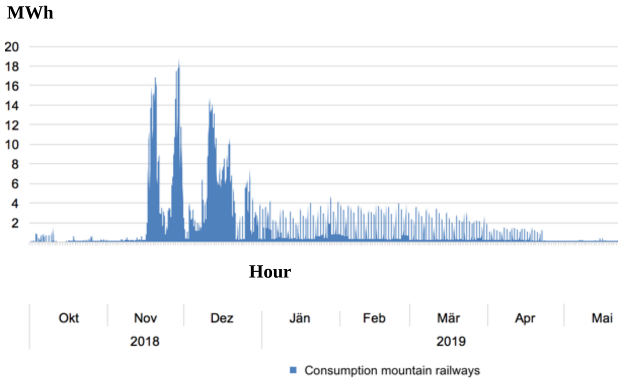

Fig.1. Consumption mountain railways from the season 2018/2019 (own figure)

Based on the whole dataset from community and mountain railways different scenarios are set up in section three. The results are presented in section four. Finally, in section six (discussion and conclusion), the research questions are divided and answered in paragraphs, whereby research question two and three are combined, because the system components of hydrogen electrolysis are connected to cover peak loads.

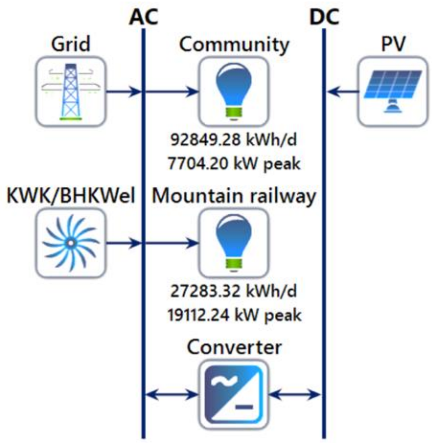

Fig.2. System configuration of base case

METHODOLOGY

Different scenarios are constructed and simulated using HOMER Pro (https://www.homerenergy.com; hereafter, HOMER). The provision of hydrogen for three FC-PSG in regular operation over a winter season is simulated; thereafter, further scenarios are built to meet peak demands with additional renewable sources. The hydrogen supply of the FC-PSG in scenarios 1, 2 and 3 is guaranteed with a maximum priority. In case of a peak load coverage, various combinations were used to attempt to contain the supply of hydrogen to the grid with the return of electricity via the fuel cell, especially at the end of the year. This results in a base case (Fig.2) presenting the current status in the whole area without using hydrogen electrolysis and three additional scenarios (Fig.3, Fig.4 and Fig.5) utilizing hydrogen electrolysis and peak load coverage:

The scenario cases have been adjusted for economically viable configurations of renewable energy production within the constraints of heavily alpine geography.

SCENARIOS SETTINGS

a) Base case: actual situation in the target community without hydrogen electrolysis
b) **Scenario 1**: H_2 production to supply three FC-PSG and max. peak load coverage, without additional renewables
c) **Scenario 2**: H_2 production to supply three FC-PSG and approx. 25% peak load coverage, with additional renewables (1 MWp PV plant and 2x wind turbines of 4.2 MW each)
d) **Scenario 3**: H_2 production to supply three FC-PSG and approx. 50% peak load coverage, with additional renewables (2 MWp PV plant and 4x wind turbines of 4.2 MW each)

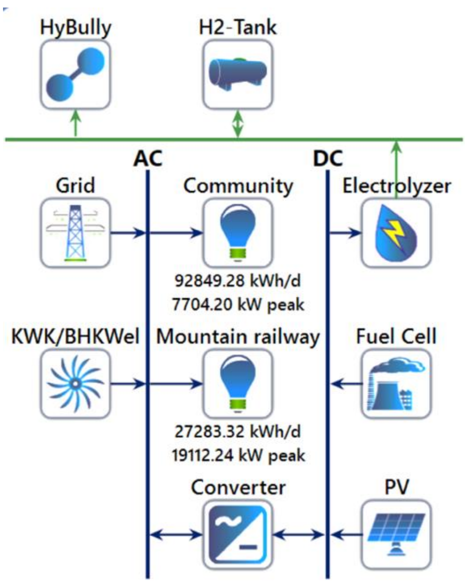

Fig.3. System configuration of Scenario 1

For the simulation of the hydrogen quantity for the three FC-PSGs, a master's thesis which deals with a fuel-cell-powered snow groomer is used [9]. Since there are different applications and requirements for a snow groomer, the required hydrogen quantity varies, so a reference vehicle was assumed in this paper. This representative vehicle has a service time of 9.3 h, an idle rate of 8.95%, and covers a distance of 69.4 km per day and for this vehicle, the required hydrogen consumption is around 47 kg. This results in the following amount of hydrogen for three FC-PSGs assuming that these vehicles are used for 150 days:

$$47kg\ H_2 * 3\ HyBullys * 150\ Operating\ days = 21{,}150\ kg \quad (1)$$

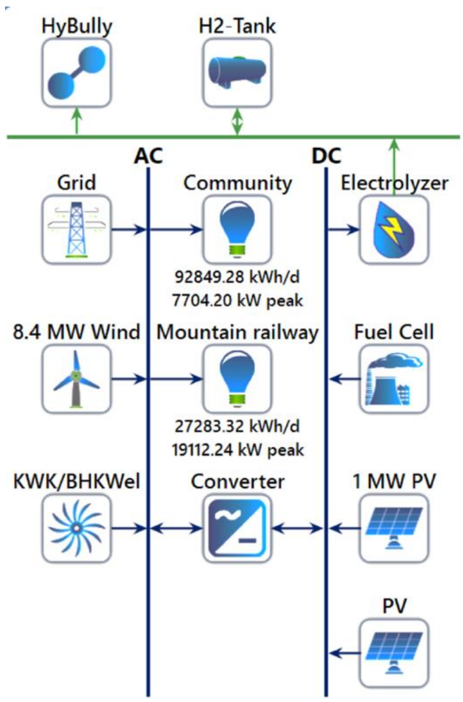

Fig.4. System configuration of Scenario 2

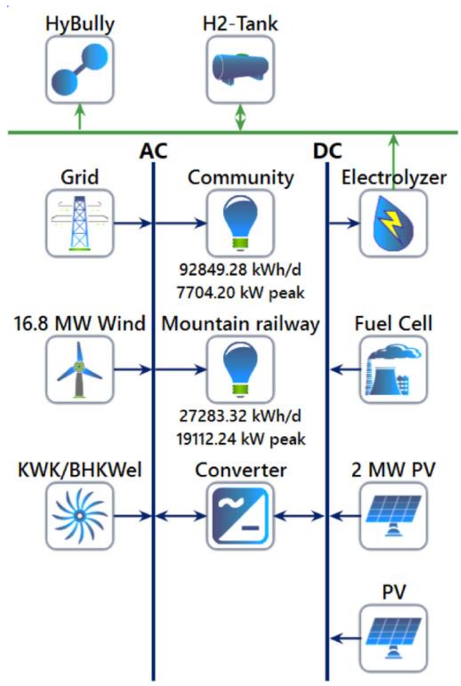

Fig.5. System configuration of Scenario 3

This amount of hydrogen is defined as a fixed parameter for the hydrogen supply of the three FC-PSGs in the ski area. Within HOMER, this quantity must be available by 31st of October to supply the groomers during the winter period.

DATA

The electrical data set refers to the balance area (community and mountain railways) and is implemented separately in HOMER. The values for the year 2018/2019 were chosen with the help of the inventory analysis, which corresponds approximately to the average of the existing data. The analysis results show that 33.97 GWh/a are consumed by the community and 9.95 GWh/a by the mountain railways. The total production in the from installed PV plants in the community amounts to 16.34 GWh/a. For the hydrogen components, the parameters in Tab.1 apply, while, for the additional installed renewable energy sources, the parameters in Tab.2 apply.

Table 1. Implemented hydrogen electrolysis parameters for the simulation

Electrolyzer [10-11]	
Efficiency	85%
Minimum load ratio	5%
Electrical bus	DC
Size	iterative dimensioning
Schedule	HOMER optimized
Fuel Cell [12-13]	
Efficiency	50%
Minimum load ratio	5%
Electrical bus	DC
H_2 characteristics	lower heating value 120 MJ/kg
H_2 characteristics	density 0,090 kg/m^3
Size	iterative dimensioning
Schedule	focused on Nov, Dec due to the identified peak loads, other months HOMER optimized
gaseous H_2 Tank	
Initial tank level	0 kg
Require year-end tank level	No
Tank Size	iterative dimensioning
Converter AC	
Efficiency	98%
Parallel with AC generator	Yes
Converter DC	
Efficiency	95%
Relative capacity	100%

In HOMER, the "cycle load strategy" is selected for the simulation. This strategy is a dispatch strategy where all power sources (grid, wind, PV, fuel cell) operate at full output power whenever the power sources must serve the primary load. In this case the community and the mountain railways are the consumers. The simulation software distributes the controllable power sources (grid, wind, PV, fuel cell) in a two-stage process observing a 15-minute time step for the simulation. HOMER selects the optimum combination of power sources (which consists primarily of renewable sources) to serve the electrical load (community and mountain railways).

Table 2. Implemented parameters of additionally installed renewable energy sources

	Scenario 2	Scenario 3
Photovoltaics [14]		
Power output	1 MWp	2 MWp
Efficiency	19,01%	
Electrical bus	DC	
Operating temp.	+85°C to -40°C	
Derating factor	90%	
Relative capacity	100%	
Solar radiation	3.25 kWh/m^2/day [15]	
Wind turbine [16]		
Power output	2 units [8.4 MW]	2 units [16.8 MW]
Hub height	135 m	
Rotor diameter	127 m	
Electrical bus	AC	
Ambient temp.	5.34°C [17]	
Wind speed	6,5 m/s [18]	

RESULTS

The results of the simulation refer to the reference year, 2018/2019. As the primary load or consumer, the community and the mountain railways were initially simulated separately but were subsequently combined as presented in Tab.3, Tab.4 and Tab.5. The total electricity generated from renewables are also subsequently combined. In Tab.4, the peak load coverage refers to the month of November. According to the inventory analysis, considerable peaks occur during November due to the snow-making systems of the mountain railways, which can be partially covered by the production of the fuel cell. The base case and the three scenarios are divided into electrical data, peak load coverage and hydrogen electrolysis.

Table 3. Results of electrical data

Base case	Scenario 1	Scenario 2	Scenario 3
Primary load [kWh/a]			
43,848,399	43,848,399	43,848,399	43,848,399
Renewables [kWh/a]			
16,339,251	16,339,251	46,642,059	76,944,867
Grid purchased [kWh/a]			
28,875,455	28,825,665	8,053,184	615,977
Grid sold [kWh/a]			
1,283,350	135,267	545,185	15,950,372

Table 4. Results of peak load coverage

Base case	Scenario 1	Scenario 2	Scenario 3
Max. peak load Nov. [kW]			
23,105	23,105	17,296	11,293
Peak load coverage [%]			
-	-	25.14	51.12
Fuel cell [kWh/a]			
-	51,467	4,829,761	8,206,272

Table 5. Results of hydrogen electrolysis

Base case	Scenario 1	Scenario 2	Scenario 3
Electrolyzer [kW]			
-	1,200	7,000	10,000
Fuel cell [kW]			
-	300	4,000	10,000
Tank [kg]			
-	75	150,000	200,000
Converter [kW]			
3,136	2,986	6,719	10,228
H_2 for 3x FC-PSG [kg]			
-	21,150	21,152	21,152
H_2 for fuel cell [kg]			
-	3,088	289,786	492,376

Scenario 1 is not suitable for peak sheaving, as only a small peak load coverage is possible due to the fact that the fuel cell size of 300 kW is not sufficient for peak load coverage. In contrast, scenario 2 (see Tab. 4) smooths the peaks by 25.14% in November, there is no need to purchase any electricity from the grid from May to October. Scenario 3 (see Tab. 4) covers peaks of 51% in November and 53% in December.

Scenario 3 covers the burden of the entire balance area from February to October but only half in the winter months of November and December. The results examined according to the inventory analysis related to the short-term peak loads of the mountain railways, occurring within minutes, so the additionally installed capacity of the fluctuating renewables should be able to provide the energy within a few minutes. In contrast, the fuel cell produces about 4.8 GWh of electricity in scenario 2 and about 8.2 GWh/a in scenario 3.

CONCLUSIONS

In terms of the monthly average energy needed, the use of snow-making systems and their infrastructure causes the peak loads of the mountain railways to increase to 465% (max. ~ 19.1 MW) in November, while simultaneously energy demand in the community increases to 155% (max. ~ 6.1 MW) to their respective reference values. It should be noted, that this is not highest annual demand peak of the community, which takes place outside of November.

According to predefined parameters for hydrogen technology from the literature, the simulation results (scenario 1) suggest that currently, without additional renewable energy sources, a 1.2 MW electrolyzer would be the optimal design to produce the hydrogen supply of 21,150 kg for three FC-PSG. In addition, to ensure the operation of the FC-PSG during a winter season, a surplus of 3,088 kg H_2 can be produced. In this scenario, 90% of the locally produced annual surplus is used for electrolysis. For the months of November and December, an attempt was made to use this surplus hydrogen by converting it back into electricity in a fuel cell, resulting in a design of 300 kW. However, this design can only cover 1.6% of the consumption peaks. In terms of the balance sheet, there is little change in this scenario within the municipal area in relation to the electricity self-supply.

To shave the peak loads at 25% and 50% each (scenarios 2 and 3), the use of additional renewable energy sources is required. Taking realistic local data into account, average wind speed and solar irradiation and their complementarity to local hydropower, a combination of wind power and PV systems proved reasonable. For these scenarios, PV systems with 1 or 2 MWp and two or four wind turbines with a capacity of 4.2 MW in total seems to be a comprehensible approximation. These results were put into the respective simulation models. In both scenarios, the primary load in the balance area (community and mountain railways) would be completely supplied by local power plants. According to the simulation software, however, some peak loads would continue to exist because of the volatile load profiles of the renewables. In principle, a power surplus is used for a 7 or 10 MW electrolyzer. Despite twice the installed capacity of the renewables in scenario 3, a maximum electrolyzer capacity of 10 MW is required because the amount of hydrogen produced is already sufficient for the designed fuel cell to cover 50% of the peak load in November and December. An even larger quantity of H_2 could be produced from the resulting electricity surplus. Subtracting the H_2 quantity for three FC-PSGs according to the predefined parameters of the electrolyzer, this results in quantities of 289,786 kg H_2 (scenario 2) and 492,376 kg H_2 (scenario 3), respectively, which are available to the fuel cell with an output of 4 MW and 10 MW. Thus, the peak loads in November can be covered by exactly 25.24% and 51.12%, and the electricity from the local grid can be limited.

DISCUSSIONS

The results regarding the optimal design of the fuel cell for H_2-regenerating into electrical power demonstrate that the fuel cell capacity is only fully utilized in November and December; hence, the fuel cell is only in partial load operation during the other months. Among other factors, the volatility of the renewables influences the result, so the peak loads can be covered more effectively by additional renewables. According to the results of the simulation, a fuel cell for peak load coverage is questionable under the predefined conditions, and the hydrogen components would require high power capacities.

The specific use-case of supplying FC-PSGs such as snow groomers with locally produced hydrogen is shown to be viable already with small expenditure. Scenarios 2 and 3 give insights on how hydrogen interacts with heavy peak load management on a local level in an alpine tourism environment. This knowledge can be further expanded by applying it to a more suitable energy community in additional studies.

CONCISE CONCLUSIONS

Specifically, further study by the authors will be concluded in the municipality of Obertrum within the project "*H2 Village*". A less seasonally focussed yet still pronounced peak load profile allows more flexibility with hydrogen usage around the year. Additionally, using hydrogen for a local beverage industry's energy and logistics demands applies further understandings of this paper in a widely replicable manner. Particularly the usage of hydrogen in adapted lorries is expected to decrease emissions significantly.

Since several topics were not considered in this research paper for strategic reasons and due to the system limits of the simulation, further investigations are necessary to establish the use of hydrogen electrolysis in alpine regions *(e.g.* energy communities). For example, in order to analyze the economic efficiency, the costs for the achieved peak load coverage would have to be compared with the current energy price of the mountain railways. Another aspect is the investigation and further use of oxygen, which is a by-product of hydrogen electrolysis. Its use would have a positive effect on the calculation of the economic efficiency of hydrogen electrolysis. Regarding the extension of the system boundaries, this could include the thermal energy utilization that is generated during the conversion of electricity from the fuel cell - for example, by feeding the resulting thermal energy into a district heating network.

If the system boundaries are extended, electrochemical storage systems can create synergies between the electricity, transport and heating sectors. Thus, from a holistic perspective, both the economic efficiency and the system design as well as the energy balance of the resulting system can be significantly influenced.

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