environments

MDPI

Article

Usage of Methanol Fuel Cells to Reduce Power Outages in the Etelä-Savo Region, Finland

Pedro Gomez Hernandez [1], Thomas Leopold Berg [2] and George Xydis [1,*]

[1] Department of Business Development and Technology, Aarhus University, Birk Centerpark 15, 7400 Herning, Denmark
[2] Blue World Technologies, Langerak 15A, 9220 Aalborg, Denmark
* Correspondence: gxydis@btech.au.dk; Tel.: +45-9350-8006

Abstract: The operation of the electricity grid can be heavily affected by unexpected meteorological phenomena which generate emergency situations that cause extensive outages. This often has to do with weather-related events. In several places in the world, an electricity network operator is responsible for fairly compensating end-users. In Finland, there are areas where these weather-related impacts are significantly harsher than those in other areas. Based on this and historic data, the applicability and viability of a high-temperature proton-exchange membrane fuel cell (HT-PEMFC) backup power system was studied in order to assess the opportunity for its installation in the affected municipalities and regions. When implemented on a larger scale, from both technoeconomic and social perspectives, such systems have the potential to yield significant benefits. Compared to a diesel generator, the HT-PEMFC produced nearly half of the volume of CO_2 and its fuel costs were six times smaller; however, it remains inapplicable to individual detached households.

Keywords: power system; fuel cells; municipalities; compensation

check for updates

Citation: Hernandez, P.G.; Berg, T.L.; Xydis, G. Usage of Methanol Fuel Cells to Reduce Power Outages in the Etelä-Savo Region, Finland. *Environments* **2023**, *10*, 96. https://doi.org/10.3390/environments10060096

Academic Editors: Shu-Yuan Pan, Daeseung Kyung and Cheng-Hsiu Yu

Received: 30 March 2023
Revised: 18 May 2023
Accepted: 31 May 2023
Published: 5 June 2023

1. Introduction

Power systems in Finland have been undergoing significant changes since the early 1980s due to privatization [1]. With increases in adverse weather events that have produced long outages [2], the electricity grid has taken severe damage and blackouts have affected large numbers of the population, and to improve this situation, the Finnish government has issued legislation that makes the Distribute System Operators (DSO) compensate end-users if the outages-per-year reach certain thresholds. Electricity companies in Finland have contingency power plans in place for failures and outages in order to minimize their impacts; however, they still occur and often take a significant amount of time to be resolved. The compensatory pay from energy companies has increased, with nearly EUR 7,000,000 being paid to end-users by companies in 2017 [1]. In addition to the financial cost, the humanitarian cost for individuals is high, with power outages leaving people in vulnerable positions without power [3], and DSOs are being reproached by their customers for not providing good services. Such systems are intended to provide power, and resolving these outage scenarios could reduce the social impacts of these outages.

Finland experiences weather events ranging from heavy snowfall in the winter to thunderstorms in the summer. These events can result in major failures and power outages, especially when the events cause catastrophic damage to power lines. In addition, prolonged periods of cold weather can also lead to increased demands for heating, which can strain the power grid. The adverse weather events in Finland, especially in the region of the lakes [4], have hit the country particularly hard, with resultant increases in maintenance costs and an expansion of the current network [1]. Lowering the customer interruption cost (CIC) is an important goal for DSOs. Houses and essential services have been affected by these outages as well, leaving thousands of homes without access to electricity for long periods of time [5], and there have been previous instances where vulnerable individuals have required relocation to protect them from harsh cold temperatures [6].

To find a solution that aligns with the goals of the Finnish government's goals for sustainability [7], this research investigated the use of a high-temperature proton-exchange membrane (HT-PEM) fuel cell as a possible technology to reduce the impacts of power outages [8]. The objective of this research was to examine the cases where an HT-PEM system could reduce the impacts of power outages, and more specifically:

- the objective of this research was to investigate if an HT-PEM system would be able to provide a cost-effective measure for providing basic electricity needs and lower compensation costs for DSOs; and
- this research intended to gain insight into the reasons why a similar solution to the proposed one has not been implemented yet.

Fuel cells are used to generate clean energy via electrochemical conversion based on a chemical reaction between a fuel and an oxidant. Fuel cells work by converting chemical energy, i.e., hydrogen or natural gas, to electrical energy. The known types of such fuel cells include:

- Proton-exchange membrane (PEM) fuel cells: PEMs are considered the most promising type of fuel cell for transportation applications due to their quick response time and their high-power density. They typically require a source of hydrogen as fuel and use a proton-conducting polymer membrane as the electrolyte.
- Phosphoric acid fuel cells (PAFCs): PAFCs have a high tolerance for impurities in the fuel (much higher compared to PEMs) and can use several different fuels, such as natural gas or methanol. One of their disadvantages is that they are relatively heavy and occupy a lot of space, making them not suitable for transportation.
- Solid oxide fuel cells (SOFCs): SOFCs are high-efficiency and can operate even at very high temperatures, making them well-suited for power generation.
- Molten carbonate fuel cells (MCFCs): MCFCs are high-efficiency and can operate at very high temperatures, similar to SOFCs. Furthermore, they can use a variety of different fuels, including natural gas or even biomass.

In recent years, significant progress has been made in reducing the cost of fuel cells and optimizing their overall performance. For instance, researchers have been working with focus on new materials in order to improve the efficiency of fuel cells [9].

There are many options for providing auxiliary power during outages, but the technology to be further explored must be in line with Finland's green objectives while also being capable of meeting the energy requirements that are essential for minimizing the impacts of outages [9]. Of the presented different fuel cell types, proton-exchange membrane fuel cells (PEMFC) provide the amount of power needed to cover housing and small company power outages, and they have the flexibility needed for a system that needs to be deployed in the field. Such systems have already been widely used worldwide [10,11]. PEMFCs have several advantages over other types of fuel cells. PEMFCs are relatively lightweight and compact, making them well-suited for transportation applications. They also have a relatively fast response time and can operate at relatively low temperatures, which makes them more efficient and easier to control than other types of fuel cells. A high-temperature PEMFC (HT-PEMFC) is a PEMFC variation that is capable of operating at temperatures between 120 °C and 180 °C, without external humidification, and HT-PEMFCs provide significant benefits over other low-temperature PEMFCs [12]. This technology has been further improved in the Blue World Technologies version of a system that included a methanol reformer that allowed for the use of renewable methanol as a fuel source, which, when utilized, provided for a carbon-neutral operation, from a well-to-wheel perspective. There are many different types of auxiliary power systems that can assist during power outages. Different types of batteries are used for this reason, especially in isolated areas, including intelligent energy systems and smart loads. Other times, these solutions may come from connections with different power systems, such as wind farms or solar parks with hydropower. However, little is known about HT-PEMFCs and how they can be used as a basis for a back-up system during a power outage.

The objective of this study was to determine the financial viability of using HT-PEMFCs as auxiliary power systems to minimize the costs resulting from power outages. The study area used in this case was the Etelä-Savo region in Finland.

2. Materials and Methods

For a calculations-based analysis that would follow a Distribution System Operator (DSO), a private company, a detached house, and a care center were examined in order to evaluate if such a system could be improved with respect to CO_2 emissions and to determine if the proposed system would be a viable investment. The cases were carefully described, including the methods used to perform the calculations, assumptions, and approximations. The analysis was based on the existing legislation, extracting specific numbers from both the literature and the legislative framework in place, and providing the necessary background information to allow readers to understand the context and the significance of this work.

We performed a quantitative-based research analysis since it would include data related to compensation, costs, and CO_2 emissions. Regarding the data collection methods, these included literature-collected data and data from the Electricity Market act records in Finland. We note that since these are publicly accessible websites and databases, there were no ethical considerations related to the case studies.

3. Analysis and Results

3.1. The Case for DSOs in Etelä-Savo, Finland

The residents of Southern Savonia (Etelä-Savo), which is also part of the lake district area, have been experiencing more adverse weather phenomena over recent years. Storms have occurred in this region, with at least two resultant severe clusters of power outages, as illustrated in Figure 1.

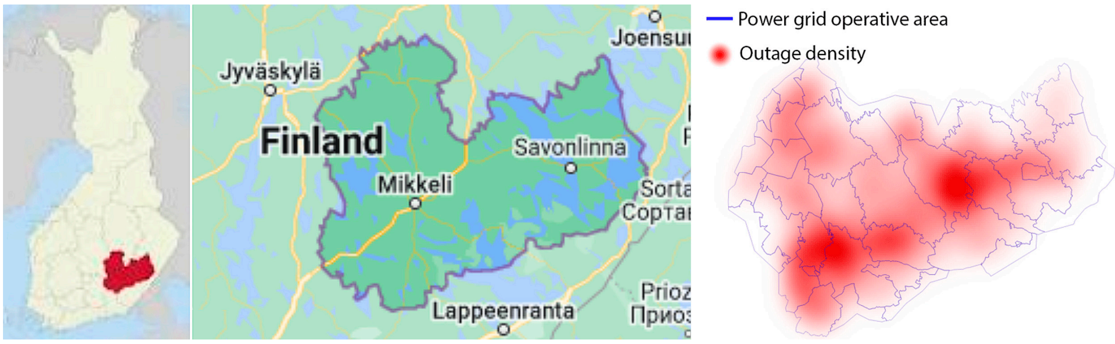

Figure 1. Power outage map for the Etelä-Savo region's municipalities [4].

Both businesses and residential customers were equally affected by these storms, and the consequences of these outages were substantial. As a result, the government had to enact legislation that increased the accountability of DSOs regarding network reliability [13]. More frequent and severe storms can increase the risk of power outages. Extreme temperatures, rising sea levels, and decreasing water availability can further impact the ability of the electric grid to supply power consistently. It is important for power companies to take steps to prepare for storms and other potential threats to the grid, as a widespread outage could have significant consequences for communities and individuals.

According to the Electricity Market Act of 2003, costs are imposed on Distribution System Operators (DSOs) [14] based on the total duration of a power supply interruption experienced by individual customers. The corresponding rates can be found in Table 1. After the Market Act of 2013, the table of compensation was expanded to include power cuts beyond 192 h, with a maximum fine of EUR 2000 [15].

Table 1. Standard customer compensation rates in Finland according to the Electricity Market Act of 2013 [15].

Standard Customer Compensation	
Outage Time (h)	**Compensation (%)**
12–24	10
24–72	25
72–120	50
120–192	100
192–288	150
>288	200

In order to calculate the overall compensation-related expenses and assess the potential for a company to mitigate costs for specific private customers, the total cost of ownership for a system could be balanced by reducing the compensatory costs incurred by DSOs. We determined that the annual consumption of a detached household in this area ranged, on average, from approximately 5000 kWh (without electric heating) to 19,000 kWh (including electric heating) [16]. The average cost of electricity in Finland was taken as EUR 0.23 per kWh [17]. Based on these estimations, the cost of electricity ranged between EUR 1150 and EUR 4370 for rural residential houses; however, a maximum of EUR 2000 [15] was maintained in our calculations. Table 2 illustrates the fines (compensation) that would be imposed on a DSO in the event of an outage, and they are categorized according to different fine brackets. These totals were calculated using Equation (1):

$$Fine = Annual\ custommer\ electricity\ price\ (€)\ *Percentage\ of\ compensation\ (\%). \quad (1)$$

Table 2. Compensation paid by a DSO in the case of an outage.

Type of Household Compensation	Total Annual Energy Cost (€)	Compensation Cost at 10% Compensation Bracket (€)	Compensation Cost at 25% Compensation Bracket (€)	Compensation Cost at 50% Compensation Bracket (€)	Compensation Cost at 100% Compensation Bracket (€)	Compensation Cost at 150% Compensation Bracket (€)	Compensation Cost at 200% Compensation Bracket (€)
Compensation to a detached household without electric heating	1150	115	288	575	1150	1725	2000
Compensation to a household with electric heating	4370	437	1093	2000	2000	2000	2000

With most outages lasting between 12 and 72 h, the payback time would depend on the number of outages a company is able to minimize, which we calculated using Equation (2):

$$Payback\ time\ in\ years = \frac{Total\ cost\ of\ the\ system}{(average\ fine\ per\ customer\ yearly\ *\ number\ customers\ covered\ yearly)} \quad (2)$$

3.2. Case for Private Companies

The private sector in the Etelä-Savo region, which is focused on forestry and manufacturing, is heavily affected by the power instability in the region. The specific losses incurred have varied depending on the nature of the outage (whether it was a planned outage or one resulting from faults). Table 3 presents the estimated customer interruption costs for peak power (in €/kW) for a planned outage scenario, with the paper and construction industries experiencing the highest losses.

Table 3. Typical CIC values for industry sectors (in €/kW) for peak power for a planned outage scenario [18].

	Planned Outage		
	1 h	**4 h**	**8 h**
Metal	18.33	56.05	95.34
Food	9.64	21.70	71.81
Chemical	16.77	20.28	39.69
Glass	7.30	27.07	45.09
Paper	24.40	102.04	160.97
Timber	7.29	26.56	86.04
Construction	40.89	124.35	260.86
Electrical	9.07	22.76	49.57

This case revolved around minimizing losses during planned outages by focusing on loss reduction. Companies facing these outages must modify their operations to account for power losses. To mitigate these losses, the utilization of a fuel cell (FC) system as an alternative power source during scheduled power outages can be considered. In order to determine the advantages of implementing an FC system in a private company, a comparison was made between the cost of a system and the losses incurred during a planned outage. Additionally, other potential benefits were explored, such as utilizing such a system during periods of high energy prices or participating in demand-response projects [19,20].

3.2.1. Cost Estimation

The total amount of yearly hours was largely within the 12 or 24 h cuts category [1], and therefore, this was the area in which most companies would find themselves when these cuts occurred. Table 4 represents the power cut costs, or CICs, for planned outages for the timber and construction industries, which were measured in €/kW.

Table 4. Power cut costs measured in €/kW for planned outages for the timber and construction industries [18].

	1 h	**4 h**	**8 h**	**12 h**
Timber	7.29	26.56	86.04	115.56
Construction	40.89	124.35	260.86	292.48

Most planned outages do not last longer than 12 consecutive hours [21], and with the initial cost of the system, the loss in production would take a long time to pay back. This is the main reason why a DSO could benefit more from such a system—they would be able to meet the demands of many customers with one system. As an alternative approach, companies have the option to employ such systems as the primary means of power generation. Typically, diesel generators are widely used for power generation at construction sites. However, an FC system can serve as a sustainable alternative, effectively replacing conventional diesel generators.

Compared to other fuel sources and power obtained from the grid [22,23], the use of an HT-PEM with a methanol reformer can provide reductions in CO_2 emissions compared to a diesel generator. In terms of emissions, the main greenhouse gas associated with the production of green methanol is carbon dioxide (CO_2), which is absorbed by plants and used as feedstock during growth. The CO_2 emissions from green methanol production are considered to be "carbon neutral" [24] because the CO_2 that is released during the production process is offset by the CO_2 that is absorbed by plants during growth. Hence, if the type of methanol acquired is classified as green methanol, this indicates that it was sourced from renewable resources, and therefore, the system can provide negative emissions.

3.2.2. Power Generation for Mobile Applications

As Finland is becoming a more environmentally friendly country [25], utilizing an FC system may lower fuel costs as renewable fuels are not taxed in Finland [26]. Due to this, the company Veolia is investing in a plant that will produce bio-methanol, and it will begin production in 2023 [27]. This will establish a timeline for companies in Finland to shift towards renewable methods of electricity generation. Moreover, the legislation guarantees tax exemptions for biofuels, further encouraging their utilization [28].

One of the main obstacles to new power generation methods is their high initial investment cost [29]. To understand the difference, a cost analysis was conducted to capitalize on the affordability of renewable fuel. The cost of diesel fuel in Finland as of 9 September 2022 was EUR 2.152 per L [17], with an energy density of 9.7 kWh/L, and the cost of renewable methanol was EUR 0.48 per L, with an energy density of 4.4 kWh/L. A 5 kWh power generator consumes 3.25 L of diesel per hour, and an HT-PEMFC consumes 2.5 L of methanol per hour [30,31]. With this, we could calculate the cost comparison and the reductions in CO_2 emissions (Table 5).

Table 5. Comparison between diesel generator and methanol FC fuel costs and emissions.

	Initial Investment (€)	Fuel Cost (€/L)	Fuel Consumption (L/kwh)	Operating Cost (€/h)	Fuel Emissions (gCO_2/L)	Total CO_2 Emissions (g)
Diesel Generator	3000	2.152	0.650	1.399	2984	1939.6
Methanol FC	14,000	0.480	0.550	0.264	1083	595.65

Assuming that there are no price changes in the market for both fuel types, the FC system would require an operational duration of 2450 h to recover its initial investment. This assumed no reduction in cost when purchased and that the technology had not lowered its price by 2023. This case is unlikely as Finland subsidizes innovative energy generation methods that reduce emissions [32] and, at the same time, lower the initial cost of the system. The Finnish government provides not only financial support for the development and deployment of "traditional" solar panels and wind turbines but also offers funding for the research and development of new and innovative energy generation methods. Additionally, Finland has set a goal to achieve carbon-neutral energy production by 2035. The fuel cost of methanol could drop even lower as the fuel sold in the region would have a tax exemption, and the total cost of production would be lowered as more and more companies invest in the market.

Seeing that there is potential for cost reductions once the production of the fuel and the technology are further optimized, a case scenario for the adoption of a system such as this in 2023 has been drafted (Table 6). With the recent events that have increased the cost of energy all over Europe, the last quarter of 2022 was expected to see the largest peak in energy cost [33], with an average three-month price of EUR 0.50 per kWh. This could expedite the development of other energy technologies such as biofuel to reduce energy costs.

Table 6. Comparison of the estimated 2023 diesel generator and methanol FC fuel costs and emissions.

	Initial Investment (€)	Fuel Cost (€/L)	Fuel Consumption (L/kwh)	Operating Cost (€/h)	Fuel Emissions (gCO_2/L)	Total CO_2 Emissions (g)
Diesel Generator	3000	2.152	0.650	1.399	2984	1939.6
Methanol FC	7000	0.236	0.550	0.130	1083	595.65

These cost reductions could potentially reduce the payback time to 1100 h or less than 1 year, assuming a work rate of 2500 h/year, with a reduction in emissions of 12 T of TTW CO_2 emissions, which could be reduced even further depending on the production method of the methanol.

3.3. Case for Residential Use

Private households in the area could benefit from an alternative method for powering their houses as power outages, in these cases, can have dangerous consequences where some households utilize alternative methods to provide heat. With areas that, in the past, have experienced "normal" outages lasting over 17 h [34], the proposed HT-PEM could be a way to reduce the risk of freezing in rural areas. The frequency of power outages is increasing in the rural areas of the region, and as a result of these outages, such as the one that happened on 12 December 2021 (Figure 2) [24], many households in remote areas are at risk of temperatures becoming too cold and may need to be evacuated.

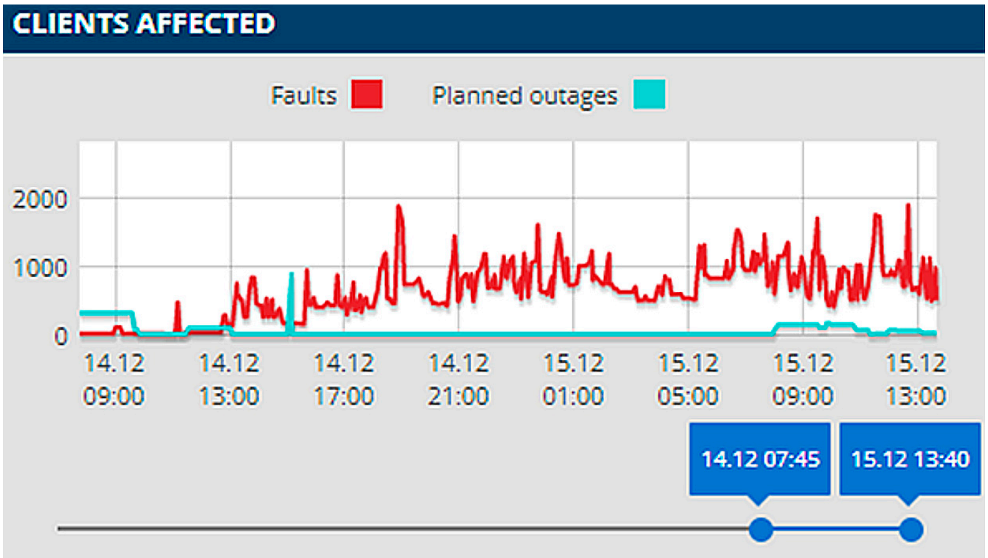

Figure 2. Power outages from 14 to 15 December 2021 [21].

Cases such as the one above will be minimized once the grid becomes more reliable as companies invest in infrastructure [35]; however, an investment in a such a system for a single household may not be worth the investment risk. This is why a cost comparison between a fuel cell system and the energy grid cost was made (Table 7). Table 7 compares the cost per hour of utilizing energy from the grid (FI) [36] to the cost per hour of using an HT-PEMFC system (FC).

Table 7. Cost comparison in relation to Finnish grid costs.

	FC Opex 5 kW		
	FC vs. FI 2020	**FC vs. FI 2019**	**FC vs. FI 2018**
Hours where the FC cost is lower	1 h	26 h	35 h

The combination of the energy prices in Finland and the low annual usage of such a system creates a general obstacle for these systems to be financially advantageous investments for individual detached households. This is despite the social benefit of maintaining an uninterrupted power supply during unfavorable weather conditions.

The Energy Independence Case for Rural Residential Customers

The previously mentioned incentives for private customers are based on what the cost of energy and outages have been until now. While the latter is expected to be reduced with infrastructure investment, there are regions and houses where the infrastructure will take many years to become resilient and reliable enough for it to be completely stable year-round.

> "In Finland, the most challenging situation in terms of the supply norm set in the Regulation would be a situation in which the procurement of gas from Russia to Finland is completely interrupted for a longer period of time" [37].

Hence, a more economically stable and reliable energy source can fulfill the energy requirements of remote areas. This would also greatly increase the energy independence of these customers and communities, making them more resilient to external factors that could affect the general energy supply and price. Achieving general energy independence via diversifying energy sources would mean relying less on external factors that could affect the general energy supply and price, and it would make a residential end-user more resilient to potential disruptions. The use of autonomous systems in this context would need to be implemented carefully to ensure their safety, security, and reliability.

3.4. Case for Use by Social Services

The final selected case focused on social services or "essential" services provided by government or private institutions. These services aim to deliver social services that are deemed vital to their communities. This case focused on the value that an emergency FC system could offer. The case examined two different scenarios: assisted living facilities and hospitals.

3.4.1. Assisted Living Facilities

Power interruptions to assisted living facilities in the municipalities in the Etelä-Savo region can have devastating effects on the residents. In 2020, a total of 60,000 households experienced prolonged electricity outages for several days, placing vulnerable individuals residing in assisted living facilities at risk due to severe cold temperatures. Additionally, there was a potential threat where medical devices, such as ventilators or medicine refrigerators, could have been compromised. Nursing homes that lost power in the area of Florida after a natural disaster found a higher rate of mortality [38]. During a previous power outage incident in 2015, there was a need to evacuate homes, particularly for individuals with special needs [6]. This situation also posed a potential risk to other essential services, including larger healthcare facilities, which could have been impacted by the same power outage. Implementing power outage measures and infrastructure upgrades can provide benefits to people in need of special care [39]. Taking into account that Finland will require more healthcare workers in the near future [40], the importance of securing electricity without power cuts is clearly understood. These impacts and reductions on the effects of outages on people in need raise the following questions: why is an outage system not in place already, or why aren't outage systems mandatory in nursing homes? There is no legislation that enforces this, and despite that some may have their own small UPS for computers and other essential medical equipment such as respirators, limited information is accessible regarding the reasons why safety systems of this nature are not invested in by these facilities.

3.4.2. Hospitals or Health Clinics

Nowadays, hospitals provide critical medical services to patients, including life support, emergency incidents handling, operating rooms, etc. To this end, it is essential to be able to deliver these services constantly, meaning that possible electric power outages should be drastically countered. There are cases where hospital and medical center units still use diesel generators as backup power systems, which presents several disadvantages, including hazardous emissions, operational noise, high maintenance costs, and failure incidents. FCs have no moving parts, and thus, maintenance services are minimal. The generation of electrical energy is based on an electrochemical reaction, and compared to conventional generators, for FCs, operating emissions, which are comprised of air pollutants and greenhouse gases (GHG), are minimized or even eliminated depending on the fuel used (i.e., natural gas or hydrogen).

One of the primary challenges lies in the fact that hospitals have substantial energy requirements, necessitating appropriately sized and well-maintained backup generation methods. Moreover, these systems require trained staff to operate them effectively [41]. Given the aforementioned priority placed on acquiring healthcare personnel, hospitals tend to prioritize securing the necessary healthcare staff over operational staff, further complicating the implementation of backup generation systems. An FC system could present an advantage in comparison to standard alternative power generation methods, but the system requirements for hospitals are much higher than the current system can provide.

4. Discussion and Conclusions

The adoption of alternative solutions based on renewable energy sources in modern grids is crucial and more profound than ever before [42]. The research shows that despite power outages being a clear threat to many Finnish lives in the form of a loss of power to their houses or businesses, there is still very low interest from DSOs in making rapid changes, despite the fact that compared to diesel generators, HT-PEMFCs produce approximately half the CO_2 emissions, and their fuel costs are six times smaller. DSOs could utilize a system to reduce power outage times, but the low penalty costs and inequalities the system could create do not create a business emergency for DSOs, despite that doing so would make financial sense. Private companies could take advantage of such a system, but with many customers' compensatory pay and insurance covering the cost of losses, the financial incentive is not great enough to entice the investment, although there is reason to believe that as the technology develops, it could become even more cost-effective. Private households in rural areas could reduce their risk of planned and unplanned power outages, but with the energy costs being eventually lower and the comparatively low amount of hours this system would need to be utilized, the financial investment for it would have no business meaning, aside from the human benefit it could provide. If the system could provide lower energy costs, the transition to using these systems as the main form of energy production could be made [43]. In our study, the social impact was mentioned, but externalities were not calculated, and these could be part of a future study. Therefore, such investments have not been made since the current policy does not require them. With energy prices growing, and with the energy insecurities of the 2022–2023 winter season [44], a system that can provide stable power functionality could become a valuable alternative for businesses and residential customers alike, especially in remote areas where energy access is already affected during the winter months, with their severe weather.

5. Insight into Future Applications

The research suggests that despite the benefits of utilizing an HT-PEMFC as a source of energy to reduce power outages, there is low interest from DSOs to introduce such systems on a large scale and make drastic changes. However, there is room for private companies. Private companies could take advantage of this technology to reduce power outage times and offer services to the grid, with compensation pay and insurance covering the losses, despite the fact that the financial incentives may not be enough to an entice investment. This would include the option for enterprises to join efforts and support networking with relevant public players, such as DSOs or general grid service providers, with a view to fostering public–private partnerships (PPPs) in the energy sector [45]. Fostering PPPs within the electricity transmission ecosystem by promoting encounters between public bodies and participating SMEs, considering territorial needs, could remove the burden from the (often) state-owned DSOs.

As the technology develops, it could become even more cost-effective, which may change the situation. Such applications can operate in parallel to projects such as the German storage-as-transmission project, the 250 MW Grid Booster (Netzbooster), which will improve energy security and support the country's green transition commitment (Figure 3).

Figure 3. The 250 MW Grid Booster (Netzbooster) project in Germany.

Similar to the Grid Booster project and at a large scale, in the future, HT-PEMFCs can operate beyond being simply sources of energy to reduce power outages, but rather, they can operate as peer-to-peer storage-as-transmission solutions.

Future studies on this subject could include calculating externalities, which could be part of future investments. Therefore, the impact of the use of HT-PEMFC systems on electricity grids and energy infrastructure could be significant in reducing power outage times and costs, but further incentives may be necessary to encourage rapid adoption by both DSOs and private companies and partnerships.

Author Contributions: Conceptualization, P.G.H. and T.L.B.; methodology, P.G.H.; formal analysis and investigation, P.G.H.; writing—original draft preparation, P.G.H.; writing—review and editing, T.L.B. and G.X.; visualization, P.G.H.; supervision, G.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The data are available on request.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gündüz, N.; Küfeoğlu, S.; Lehtonen, M. Customer interruption cost estimations for distribution system operators in finland. In Proceedings of the 2018 IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT-Europe), Sarajevo, Bosnia and Herzegovina, 21–25 October 2018; pp. 1–5.
2. Gregow, H.; Peltola, H.; Laapas, M.; Saku, S.; Venäläinen, A. Combined occurrence of wind, snow loading and soil frost with implications for risks to forestry in Finland under the current and changing climatic conditions. *Silva Fenn.* **2011**, *45*, 35–54. [CrossRef]
3. Mango, M.; Casey, J.A.; Hernández, D. Resilient Power: A home-based electricity generation and storage solution for the medically vulnerable during climate-induced power outages. *Futures* **2021**, *128*, 102707. [CrossRef]
4. Tervo, R.; Láng, I.; Jung, A.; Mäkelä, A. Predicting power outages caused by extratropical storms. *Nat. Hazards Earth Syst. Sci.* **2021**, *21*, 607–627. [CrossRef]
5. Yle. Nearly 60,000 Homes Left without Power Following Päivö's Stormy Winds News. 1 July 2020. Available online: https://yle.fi/news/3-11427297 (accessed on 12 December 2021).

6. Yle. Pensioners, Handicapped Evacuated from Cold Apartments without Power in Savo. 11 January 2015. Available online: http://yle.fi/uutiset/pensioners_handicapped_evacuated_from_cold_apartments_without_power_in_savo/7730788 (accessed on 12 December 2021).
7. Valtioneuvosto. Finland Ranks First in International Sustainable Development Comparison. 2021. Available online: https://valtioneuvosto.fi/en/-/10616/finland-ranks-first-in-international-sustainable-development-comparison (accessed on 18 December 2021).
8. Tzelepis, S.; Kavadias, K.A.; Marnellos, G.E.; Xydis, G. A review study on proton exchange membrane fuel cell electrochemical performance focusing on anode and cathode catalyst layer modelling at macroscopic level. *Renew. Sustain. Energy Rev.* **2021**, *151*, 111543. [CrossRef]
9. Raza, R.; Akram, N.; Javed, M.S.; Rafique, A.; Ullah, K.; Ali, A.; Saleem, M.; Ahmed, R. Fuel cell technology for sustainable development in Pakistan—An over-view. *Renew. Sustain. Energy Rev.* **2016**, *53*, 450–461. [CrossRef]
10. Chang, H.; Xu, X.; Shen, J.; Shu, S.; Tu, Z. Performance analysis of a micro-combined heating and power system with PEM fuel cell as a prime mover for a typical household in North China. *Int. J. Hydrogen Energy* **2019**, *44*, 24965–24976. [CrossRef]
11. Jannelli, E.; Minutillo, M.; Perna, A. Analyzing microcogeneration systems based on LT-PEMFC and HT-PEMFC by energy balances. *Appl. Energy* **2013**, *108*, 82–91. [CrossRef]
12. Martin, S.; Garcia-Ybarra, P.; Castillo, J. Long-term operation of a proton exchange membrane fuel cell without external humidification. *Appl. Energy* **2017**, *205*, 1012–1020. [CrossRef]
13. Ramos, A.; Tuovinen, M.; Ala-Juusela, M. Battery Energy Storage System (BESS) as a service in Finland: Business model and regulatory challenges. *J. Energy Storage* **2021**, *40*, 102720. [CrossRef]
14. Electricity Market Act, 2005, 'en19950386_20041172.pdf'. Available online: https://finlex.fi/fi/laki/kaannokset/1995/en19950386_20041172.pdf (accessed on 15 December 2021).
15. Electricity Market Act 588/2013. 2013. Available online: https://www.edilex.fi/smur/20130588 (accessed on 14 November 2022).
16. Hintaesimerkit. Järvi-Suomen Energia. 2022. Available online: https://www.jseoy.fi/palvelut-ja-hinnat/verkkopalvelumaksut/hintaesimerkit/ (accessed on 26 September 2022).
17. Global Petrol Prices. Finland Electricity Prices. 2022. Available online: https://www.globalpetrolprices.com/Finland/electricity_prices/ (accessed on 15 November 2022).
18. Küfeoğlu, S.; Lehtonen, M. Evaluation of power outage costs for industrial sectors in Finland. In Proceedings of the 22nd International Conference and Exhibition on Electricity Distribution (CIRED 2013), Stockholm, Sweden, 10–13 June 2013; pp. 1–4.
19. Roungkvist, J.S.; Enevoldsen, P.; Xydis, G. High-Resolution Electricity Spot Price Forecast for the Danish Power Market. *Sustainability* **2020**, *12*, 4267. [CrossRef]
20. Avgoustaki, D.D.; Xydis, G. Energy cost reduction by shifting electricity demand in indoor vertical farms with artificial lighting. *Biosyst. Eng.* **2021**, *211*, 219–229. [CrossRef]
21. Järvi-Suomen Energia. Power Cuts. 2022. Available online: https://www.jseoy.fi/en/power-cuts/ (accessed on 15 November 2022).
22. Engineering ToolBox. Combustion of Fuels—Carbon Dioxide Emission. 2009. Available online: https://www.engineeringtoolbox.com/co2-emission-fuels-d_1085.html (accessed on 27 April 2022).
23. Fingrid. Real-Time CO2 Emissions Estimate. 16 December 2019. Available online: https://www.fingrid.fi/en/electricity-market/electricity-market-information/real-time-co2-emissions-estimate/ (accessed on 13 December 2021).
24. IRENA. Renewable Methanol. Available online: https://www.methanol.org/wp-content/uploads/2020/04/IRENA_Innovation_Renewable_Methanol_2021.pdf (accessed on 8 March 2023).
25. This Is Finland. Finland Moves towards a Sustainable Future. 2016. Available online: https://finland.fi/life-society/finland-moves-towards-a-sustainable-future/ (accessed on 18 December 2021).
26. Finnish Energy. Energy-Related Subsidies and Taxes. 2022. Available online: https://energia.fi/en/advocacy/energy_policy/subsidies_and_taxes (accessed on 15 November 2022).
27. Veolia. Veolia Prepared to Invest in a Biomethanol Production Plant at the Metsä Fibre's Äänekoski Mill in Finland. 1 December 2020. Available online: https://www.paperfirst.info/veolia-prepared-to-invest-in-a-biomethanol-production-plant-at-the-metsa-fibres-aanekoski-mill-in-finland/ (accessed on 12 December 2021).
28. RES Legal. Tax Regulation Mechanism (Excise Duty on Liquid Fuels). 2019. Available online: https://www.res-legal.eu/search-by-country/finland/single/ (accessed on 13 December 2021).
29. Bujok, P.; Bjørn-Thygesen, F.; Xydis, G. Developing a sustainable energy strategy for Midtjyllands Airport, Denmark. *Int. J. Sustain. Transp.* **2022**, *17*, 273–297. [CrossRef]
30. Blue World Technologies. CellPack Stationary. Available online: https://www.blue.world/wp-content/uploads/2023/02/202301_CellPack-Stationary_data-sheet.pdf (accessed on 9 March 2023).
31. Jakhrani, A.Q.; Rigit, A.R.H.; Othman, A.K.; Samo, S.R.; Kamboh, S.A. Estimation of carbon footprints from diesel generator emissions. In Proceedings of the 2012 International Conference on Green and Ubiquitous Technology, Bandung, Indonesia, 7–8 July 2012; pp. 78–81.
32. Montel. Finland Aims to Drop Subsidies after 2020—Official. 2017. Available online: https://www.montelnews.com/news/843941/finland-aims-to-drop-subsidies-after-2020{-}{-}official (accessed on 12 December 2021).

33. Yle. Electricity Market Forecast: Price Will Triple by Winter, but Crash Next Spring. 7 August 2022. Available online: https://yle.fi/news/3-12566509 (accessed on 6 October 2022).
34. Yle. Maaseudulla ei Eino Hätkäytä—Jopa 17 Tunnin Sähkökatkoihin on Totuttu. 17 November 2013. Available online: http://yle.fi/uutiset/maaseudulla_ei_eino_hatkayta_-_jopa_17_tunnin_sahkokatkoihin_on_totuttu/6938890 (accessed on 18 December 2021).
35. Laurikko, J.; Pihlatie, M.; Nylund, N.O.; Halmeaho, T.; Kukkonen, S.; Lehtinen, A.; Karvonen, V.; Mäkinen, R.; Ahtiainen, S. Electric city bus and infrastructure demonstration environment in Espoo, Finland. In Proceedings of the International Electric Vehicle Symposium and Exhibition (EVS28), Goyang, Republic of Korea, 3–6 May 2015; pp. 1–11.
36. Nordpool. Market Data. Available online: https://www.nordpoolgroup.com/en/Market-data1/Dayahead/Area-Prices/FI/Monthly/ (accessed on 22 October 2021).
37. Ministry of Economic Affairs and Employment. *Finland's Integrated Energy and Climate Plan*; Ministry of Economic Affairs and Employment: Helsinki, Finland, 2019.
38. Skarha, J.; Gordon, L.; Sakib, N.; June, J.; Jester, D.J.; Peterson, L.J.; Andel, R.; Dosa, D.M. Association of Power Outage with Mortality and Hospitalizations among Florida Nursing Home Residents after Hurricane Irma. *JAMA Health Forum* **2021**, *2*, e213900. [CrossRef] [PubMed]
39. Sapat, A.; Mitsova, D.; Balilaj, A.; Esnard, A. Policy mandates and organizational compliance: A spatial analysis of the factors affecting the adoption and implementation of emergency power plans by nursing homes. *Risk Hazards Crisis Public Policy* **2022**, *13*, 64–93. [CrossRef]
40. Yle. Expert: Finland Needs 30 k More Healthcare Workers by 2030. 10 February 2021. Available online: https://yle.fi/news/3-11782213 (accessed on 13 December 2021).
41. Brehovská, L.; Nešporová, V.; Řehák, D. Approach to Assessing the Preparedness of Hospitals to Power Outages. *Trans. VSB—Tech. Univ. Ostrav. Saf. Eng. Ser.* **2017**, *12*, 30–40. [CrossRef]
42. Kiprop, E.; Matsui, K.; Maundu, N. The Role of Household Consumers in Adopting Renewable Energy Technologies in Kenya. *Environments* **2019**, *6*, 95. [CrossRef]
43. Ribbing, S.; Xydis, G. Renewable Energy at Home: A Look into Purchasing a Wind Turbine for Home Use—The Cost of Blindly Relying on One Tool in Decision Making. *Clean Technol.* **2021**, *3*, 17. [CrossRef]
44. Spezakis, Z.; Xydis, G. Transporting offshore wind power in the Western Gulf of Mexico: Retrofitting existing assets for power transmission via green hydrogen—A review. *Environ. Sci. Pollut. Res.* **2022**, 1–12. [CrossRef] [PubMed]
45. Owusu-Manu, D.G.; Adjei, T.K.; Sackey, D.M.; Edwards, D.J.; Hosseini, R.M. Mainstreaming sustainable development goals in Ghana's energy sector within the framework of public–private partnerships: Challenges, opportunities and strategies. *J. Eng. Des. Technol.* **2021**, *19*, 605–624. [CrossRef]