A cost-effective approach for reliable operation of sustainable industrial multi-energy systems

Tonnaer, Coen; Castrillón-Franco, Camila; Rueda-Torres, Jose Luis; Aviles-Cedeno, Jonathan; Palensky, Peter

DOI
10.1109/GPECOM65896.2025.11061845

Publication date
2025

Document Version
Final published version

Published in
Proceedings - 2025 IEEE 7th Global Power, Energy and Communication Conference, GPECOM 2025

Citation (APA)
Tonnaer, C., Castrillón-Franco, C., Rueda-Torres, J. L., Aviles-Cedeno, J., & Palensky, P. (2025). A cost-effective approach for reliable operation of sustainable industrial multi-energy systems. In *Proceedings - 2025 IEEE 7th Global Power, Energy and Communication Conference, GPECOM 2025* (pp. 756-761). (Proceedings - 2025 IEEE 7th Global Power, Energy and Communication Conference, GPECOM 2025). IEEE. https://doi.org/10.1109/GPECOM65896.2025.11061845

2025 7th Global Power, Energy and Communication Conference (IEEE GPECOM2025), June 11-13, 2025, Bochum/Germany

2025 7th Global Power, Energy and Communication Conference (GPECOM) | 979-8-3315-1323-8/25/$31.00 ©2025 IEEE | DOI: 10.1109/GPECOM65896.2025.11061845

A cost-effective approach for reliable operation of sustainable industrial multi-energy systems

Coen Tonnaer
Intelligent Electrical Power Grids
Delft University of Technology
Delft, The Netherlands
C.S.Tonnaer@student.tudelft.nl

Camila Castrillón-Franco
Intelligent Electrical Power Grids
Delft University of Technology
Delft, The Netherlands
mcastrillonfra@tudelft.nl

Jose Luis Rueda-Torres
Intelligent Electrical Power Grids
Delft University of Technology
Delft, The Netherlands
j.l.ruedatorres@tudelft.nl

Jonathan Aviles-Cedeno
Intelligent Electrical Power Grids
Delft University of Technology
Delft, The Netherlands
J.A.AvilesCedeno@tudelft.nl

Peter Palensky
Intelligent Electrical Power Grids
Delft University of Technology
Delft, The Netherlands
p.palensky@tudelft.nl

***Abstract*—Industrial electrification plays a crucial role in reducing carbon dioxide emissions, and ensuring power reliability is important in this process. Reliability and techno-economic evaluations are fundamental to designing, operating, and managing power systems, ensuring that electricity is delivered continuously and securely under various conditions. In particular, maintaining a reliable power supply to industrial loads is critical, especially when renewable sources are present, as these introduce greater variability and uncertainty into the operation of industrial systems. Therefore, this document aims to use a cost-effective storage approach to ensure the reliable operation of sustainable industrial multi-energy systems. In addition, three storage mitigation strategies against random operation are formulated based on financial, technical, practical, and other aspects. A synthetic industrial model consisting of generic component representations in DIgSILENT PowerFactory 2024 is taken as a case study. The structure and parameters of the synthetic model are inspired by data from the literature and a hypothetical projection of a future evolution of a 500 MW sustainable industrial multi-energy system in Rotterdam by 2035. Numerical results provide insight into the flexible and cost-effective operation of sustainable industrial multi-energy systems within the context of decarbonised future Dutch energy systems.**

***Index Terms*—industrial systems, reliability, storage systems, uncertainty mitigation, techno-economic evaluation.**

I. INTRODUCTION

Climate change demands urgent decarbonisation to reduce CO2 emissions. In the Netherlands, the industrial sector is a significant contributor, accounting for approximately 16.5% of emissions in 2024, as reported by the International Energy Agency (IEA) [1]. This gives the sector a crucial part to play in the energy transition. The Dutch government has acknowledged this in their climate policy 2019 and the recent additional climate policy 2023 [2] [3].

As outlined by the government-commissioned route-map to electrification report, achieving full electrification of the industrial sector requires a significant increase in electricity use from 80 to 130 TWh [4]. Some studies about futuristic operational scenarios point out, for instance, a hypothetical increase of the number of loss of load expectancy hours if mitigation measures are not implemented [5].

Given the intricate and interconnected nature of industrial processes, any disruption or shortfall in electricity supply could have severe consequences. Downtime in such large operations leads to considerable financial losses. This poses a liability that could hinder the decarbonisation of industrial areas. Several studies are dedicated to optimizing reliability on a small scale. In 2022, for example, in [6], combined optimal sizing of storage and renewables with grid interaction, uncertainty and reliability demands on a long-term time scale for a microgrid. Components are limited to a photovoltaic (PV) panel, wind generation, hydrogen tank and fuel cells. Reliability is assessed using the loss of load expectation (LOLE), expected energy not supplied (EENS), loss of power supply probability (LPSP), and equivalent loss factor (ELF).

Aside from focusing on small-scale systems, distribution systems are also frequently studied . For example, in [7], a multi-objective approach is formulated to integrate storage in distribution systems to improve reliability based on the momentary average interruption index. Also in [8], the reliability assessment of a distribution system under distributed renewable energy generation and random industrial consumption is presented. [9] overviews different available energy storage systems to support reliable operation of distribution systems, discussing their sizing, placement, with emphasis on the contributions to power quality and security.

This paper takes into account the futuristic operation of industrial systems within the hypothetical context of the future Dutch energy system by 2035. Studies about projected energy infrastructure [10], [11] and future industrial electrification

---

The research work shown in this paper has received funding from Shell Global Solutions International B.V. It reflects only the authors' views, and the above indicated organization is not responsible for any use that may be made of the information it contains in.

research [4], [12], [13] are considered for the development of a synthetic model of a 500 MW sustainable industrial multi-energy system subjected to variable operating conditions. Unlike other research works of existing literature, the case study focuses on the assessment and enhancement of cost-effective operational reliability by integrating different storage technologies.

The rest of the paper is organised as follows. Section II reviews the risk assessment methodology, including the synthetic model configuration. Relevant simulation results are discussed in III, and Section IV concludes the main findings of the presented research.

II. APPLIED METHODOLOGY

A. *Implementation steps*

In Figure 1, the overall methodology to evaluate what combination of storage can cost-effectively ensure the reliable operation of a 500 MW sustainable industrial multi-energy system, by considering under quasi-dynamic performance, is presented. Three main steps are defined: first, a dispatch simulation over a year of study (2035) is done, calculating the optimal power flow throughout the topology for every point in time (e.g. every hours of a yearly study period) according to the minimization of an objective function. The objective function can minimize total costs, load shedding, renewable energy curtailment and other variables depending on the desired operational targets. Then, with these results, the systemic reliability is evaluated. Finally, a cost-effectiveness analysis is performed to conclude which storage strategy generates more benefits.

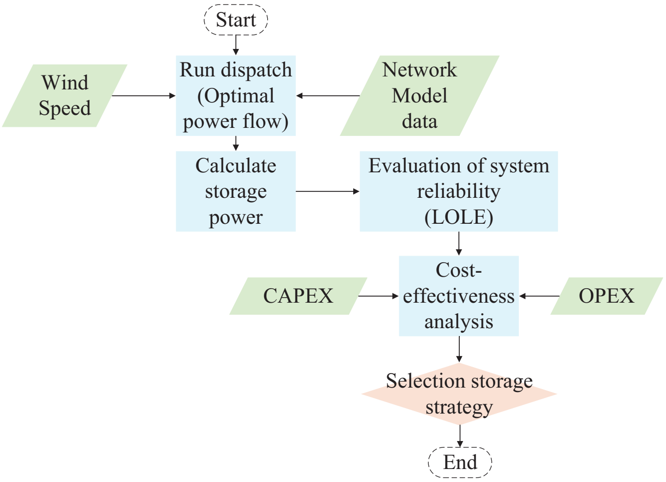

Fig. 1: Proposed software-based methodology

B. *Baseline synthetic model*

The synthetic model developed in this paper is based on the available structure and parameters from the research presented in [14]. The synthetic (futuristic) data used for the cost-effective and reliability analysis is inspired by futuristic projections for industry multi-energy systems like the ones being investigated for hypothetical future developments in Rotterdam. For instance, accessible data from [13] and [12] is used as inspiration for the synthetic model used in this paper Figure 2 illustrates the arrangement of the synthetic model, which can be adjusted to reflect operational changes like, for instance, topological variations due to control actions or maintenance, different dispatch and consumption profiles, and different operational actions. The model includes components from PowerFactory library to represent local renewable power generation and the electrical network. User defined models were done to represent electrolyzers, whereas industrial loads are represented by a constant power characteristic.

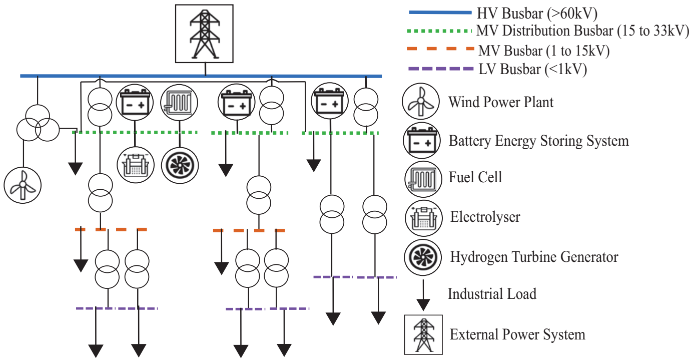

Fig. 2: Synthetic model of a sustainable industrial multi-energy system

A voltage-dependent model used in power flow modelling represents the electrical demand as constant power loads in the different processes of the multi-energy system. Example synthetic data of different assumed loads is presented in Table I.

TABLE I: Assumed load parameters

Load	Active Power [MW]	Amount
Electrolysers	150	2
Large Electric Heaters	15	3
Small Electric Heaters	5	6
Large Variable Speed Drives	30	2
Low-voltage Electronic Loads	11	6

1) Wind power plant: A 7.2 MW synthetic model of a wind generator is used as a reference to define a wind power plant with a total capacity of 86.4 MW. Specific modelling aspects can be found in [15].

2) Synchronous generators: Since the power source of the industrial system should be completely renewable, the burning of natural gas is excluded from the analysis. Therefore, the synchronous generators of the model are assumed to have hydrogen-based prime movers.

C. *Addition of storage technologies*

The following section describes how the additional storage technologies have been modelled in PowerFactory 2024, including some external controllers defined in Python 3.12.

1) Batteries: It is represented using the battery template from the library of PowerFactory. The main component for this model is a static generator (i.e., a controlled voltage source). This model enables features such as continuous active power control and optimal dispatch. An overview of the assumed model parameters can be found in Table II [16].

TABLE II: Assumed parameters for the modelling of batteries

Parameter	Value	Unit
Rated power	500	MW
Round trip efficiency	98	%
Cycle Life	2000+	cycles
SOC limits	10-90	%
CAPEX	76	€/kWh
OPEX	2	% of CAPEX p.a.

2) Electrolysers: It is represented using the general load representation template in PowerFactory (i.e., constant power behaviour). The assumed parameters (representing alkaline or proton exchange membrane technologies) are given below in Table III [17].

TABLE III: Assumed parameters of electrolysers

Parameter	Value	Unit
Efficiency(LHV)	70	%
Life Time	20	Years
Operating hours	up to 100.000	hours
Start up time	< 60	min
CAPEX	395	€/kW
OPEX	1.5-3	% of CAPEX p.a.

3) Fuel cells: It is represented using the generic fuel cell template from the library of PowerFactory. The main component of this template is a static generator (which can work as a controlled voltage source or a controlled current source). The model's parameters are given below in Table IV [18].

TABLE IV: Assumed parameters of fuel cell

Parameter	Value	Unit
Efficiency(LHV)	70	%
Life Time	15	Years
Operating hours	> 5000	hours
Start up time	< 60	min
CAPEX	493	€/kW
OPEX	1.5	% of CAPEX p.a.

4) Hydrogen generator: It is represented using the PowerFactory template for synchronous generators. It is worth pointing out that the template was modified to make it work as a system with a hydrogen-based prime mover. The model parameters are given below in Table V [19].

TABLE V: Assumed parameters of hydrogen generator

Parameter	Value	Unit
Electrical efficiency	45	%
Life Time	25	Years
Operating hours	> 5000	hours
Start up time	< 60	min
CAPEX	498	€/kW
OPEX	1	% of CAPEX p.a.

D. Metric for evaluation of reliability

The Loss of Load Expectation (LOLE) is chosen to evaluate the system's reliability. The LOLE is defined as the number of hours per year during which the total demand is expected to not be fully met. Since reliability maximisation needs to be cost-effective, the expected interruption costs (EIC) are considered as a supplementary metric. The Value of Lost Load (VOLL) and Expected Energy Not Served (EENS) are necessary to calculate this.

E. Cost analysis

This analysis considers the total system costs per year as follows:

$$C_{\text{total}} = \text{CAPEX} + \text{OPEX} + C_{\text{Interruption}} \tag{1}$$

where:

- C_{total}: Total system costs per year in €
- CAPEX: Annualized Capital Expenditure in € per year
- OPEX: Operational Expenditure in € per year
- $C_{\text{Interruption}}$: Plant Interruption costs in € per year

Unless otherwise mentioned, all costs are yearly and are based on the currency year 2024. The equivalent annual costs of the capital expenditures are calculated by dividing the CAPEX by the annuity factor, or multiplying by the inverse:

$$\text{CAPEX} = \text{total CAPEX} \times \frac{r}{1-(1+r)^{-n}} \tag{2}$$

where:

- r: Discount rate in %
- n: Lifetime of the asset in years

Plant interruption costs are calculated as follows:

$$C_{\text{Interruption}} = \text{VOLL} \times \text{EENS} \tag{3}$$

where:

- $VOLL$: Value Of Lost Load in €/MWh
- $EENS$: Expected Energy Not Supplied in MWh

To calculate the total interruption costs, the EENS consists of the expected energy not supplied and the lost production during the plant's start-up time after an outage. Parametric sensitivities to CAPEX and lifetime are also included in the cost analysis, and electricity costs are compared.

III. ANALYSIS OF PERFORMED SIMULATION

Dispatch simulations were executed after integrating the storage technologies and the definition of model inputs. In the following subsections, the results are discussed. The compared storage strategies are presented in Table VI.

TABLE VI: Selected storage strategies

Component	Strategy 1	Strategy 2	Strategy 3
Battery	500 MW Lithium-Ion 1 - 5.7 GWh	500 MW Lithium-Ion 0.65 GWh	500 MW Lithium-Ion 0.65 GWh
Hydrogen Production	N/A	100 MW Alkaline Electrolyser	100 MW Alkaline Electrolyser
Electricity Production	N/A	100 MW Fuel Cell	100 MW Hydrogen Turbine
Hydrogen Storage	N/A	100 bar Tanks 1 - 6 GWh	Magnesium Hydride 6 - 9.5 GWh

A. *Strategy 1: Electrical battery storage*

First, a dispatch is simulated over a year to assess the battery-only storage configuration. Table VII shows the simulated dispatch in PowerFactory. This table presents the LOLE and EENS associated with this option. It can be observed that a battery size of 5700 MWh can theoretically reduce the LOLE to zero. Figure 3 plots the total costs for the simulated storage sizes against LOLE. It illustrates the relationship between costs and a certain reliability level expressed by LOLE. Reducing the LOLE to zero is not the most cost-effective option. A 3 GWh battery storage system with a LOLE of 91 hours would be a better choice.

TABLE VII: Strategy 1: summary of reliability assessment

Battery [MWh]	**LOLE [hours]**	**EENS [MWh]**	**Outages**	**Outage Duration [hours]**	**Downtime [hours]**
5700	0	0	0	0	0
5500	2	56.5	1	1	49
5000	11	437.8	1	2	50
3000	91	5095.1	5	60	300
2000	191	10545.3	9	96	528
1000	375	25275.9	20	155	1115

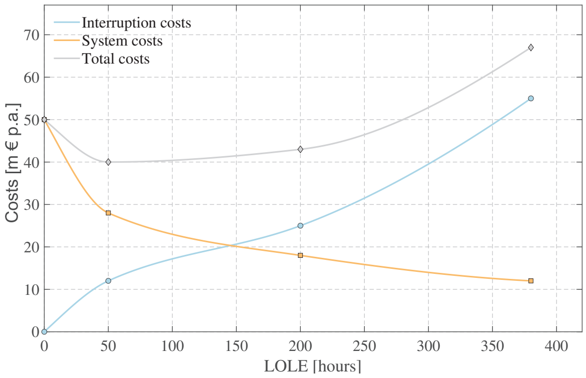

Fig. 3: Battery storage: Annual costs VS LOLE

B. *Strategy 2: Battery + Fuel cell*

Table VIII shows the simulated sizes for the battery, electrolyser, compressed hydrogen and fuel cell storage strategy. In this case, a hydrogen storage size of 6 GWh can bring the LOLE to zero.

TABLE VIII: Strategy 2: summary of reliability assessment

Hydrogen [MWh]	**LOLE [hours]**	**EENS [MWh]**	**Outages**	**Outage Duration [hours]**	**Downtime [hours]**
6000	1	6.7	0	0	0
5000	12	444.5	1	2	50
4000	37	1972.9	4	22	214
3000	92	5026.3	6	60	348
2000	170	9248.0	11	79	607
1000	351	17978.9	18	179	1043

Figure 4 shows the annual costs plotted against LOLE. A 6 GWh storage system achieves the lowest costs at a zero LOLE.

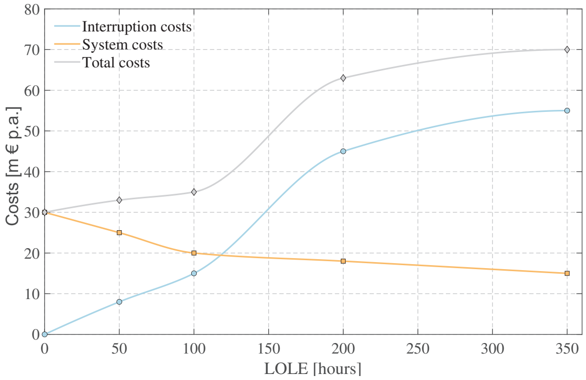

Fig. 4: Battery, Compressed Hydrogen and Fuel Cell: Annual Costs VS LOLE

C. *Strategy 3: Battery + hybrid storage*

Table IX shows the simulated sizes for the battery, electrolyser, magnesium hybrid hydrogen and turbine storage strategy. In this case, a hydrogen storage size of 9500 MWh can bring the LOLE to near zero.

TABLE IX: Strategy 3: summary of reliability assessment

Battery [MWh]	**LOLE [hours]**	**EENS [MWh]**	**Outages**	**Outage Duration [hours]**	**Downtime [hours]**
9500	2	17.8	0	0	0
9000	3	40.2	2	2	98
8000	13	455.6	2	3	99
7000	27	1344.5	4	13	205
6000	49	2637.8	5	32	272

The annual costs are plotted against the LOLE in Figure 5. As in strategy 2, the lowest costs are achieved at an LOLE of almost zero.

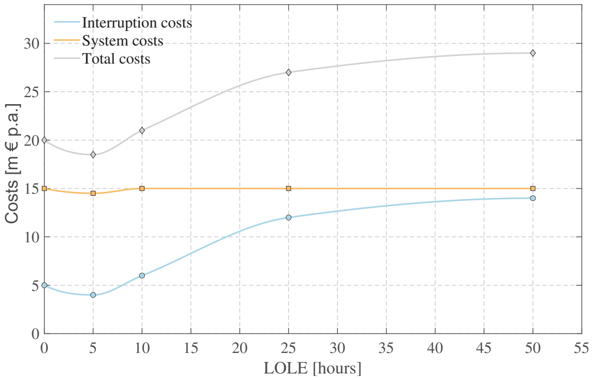

Fig. 5: Battery and hydride storage: Annual costs VS LOLE

D. Comparative parametric performance assessment

The most cost-effective configurations per strategy are comparatively shown in Figure 6. Note that the third storage strategy is the most cost-effective.

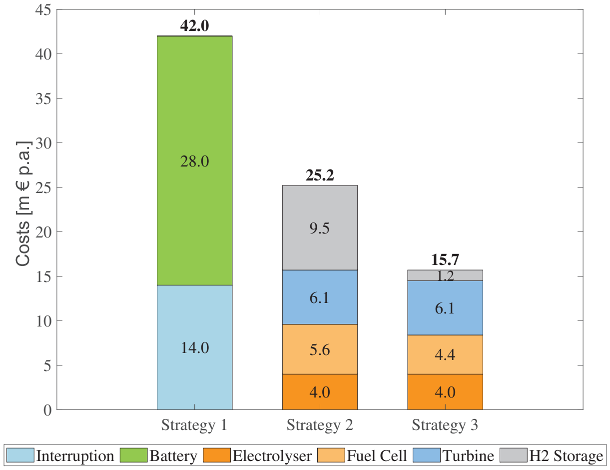

Fig. 6: Annual costs

However, this analysis is subject to CAPEX investment and lifetime estimates. Therefore, in Table X parameters have been changed to illustrate their sensitivity to the optimal strategy. For the first two scenarios, an optimistic case is presented. A pessimistic case is shown for the third strategy. This ensures that if cost and lifetime estimates are off, the outcome of the best strategy is still valid.

TABLE X: Comparison of different strategies

Parameter	Strategy 1	Strategy 2	Strategy 3
Electricity demand grid (TWh)	3.90	3.96	4.01
Electricity delivered by storage (TWh)	0.067	0.072	0.072
Utilisation factor battery	0.36	0.27	0.27
Capacity factor battery	0.032	0.020	0.020
Utilisation factor hydrogen	–	0.21	0.28
Capacity factor hydrogen	–	0.13	0.19

In Figure 7, the annual costs are presented after changing the parameters for each strategy. In this case, the Lithium-Ion, fuel cell, and compressed hydrogen storage CAPEX costs have decreased by 15% ; on the other hand, the hydrogen turbine has increased CAPEX by 15%. This change is because hydrogen turbine technology is less mature, with fewer future CAPEX and lifetime estimates available.

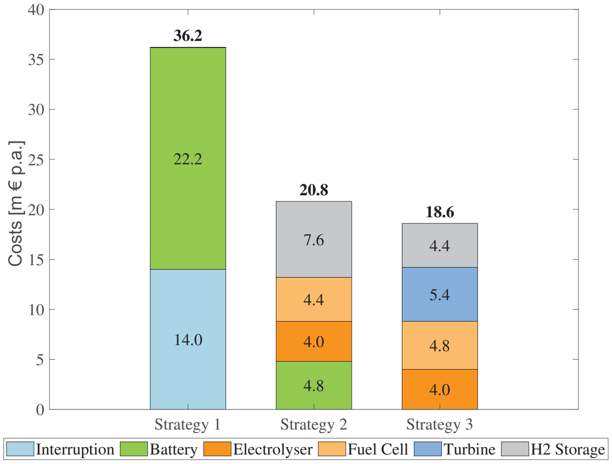

Fig. 7: Annual Costs Comparison Sensitivity

E. Electricity cost

In addition to the annual costs for the storage system, and in the case of the first strategy, interruption costs, electricity is bought from an external power source. The amount and timing of electricity consumption differ between strategies due to efficiency and size differences. The electricity costs are included in Figure 8, comparing the three strategies. Again, the most cost-effective system per strategy has been used in this comparison. As mentioned in the methodology section, all costs are annual. From this figure, it is possible to see that the third strategy's electricity costs are higher. However, this alternative's overall annual cost is lower than the other two strategies. If the electricity profile looks different or if the industrial area is subject to a fixed price, this could lead to the third strategy becoming more expensive.

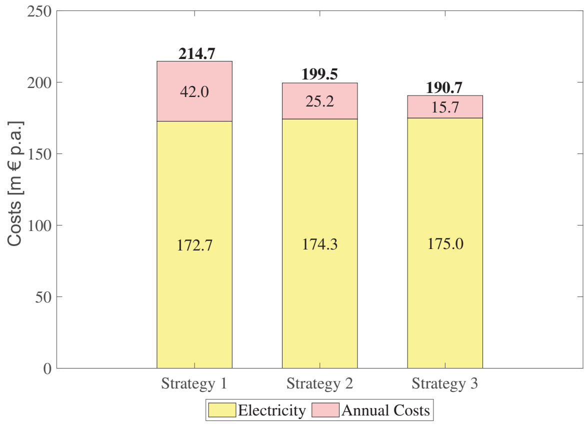

Fig. 8: Annual Costs and Electricity Costs Comparison

F. Evaluation of strategies

Considering the results of the analysis and comparisons presented in sections III-A, III-B, III-C, III-D and III-E the third storage strategy, which uses a Lithium-Ion battery, alkaline electrolyser, magnesium hydride storage, and a hydrogen turbine, is found to be the best-suited storage solution because it is the most cost-effective regardless of its low efficiency. In general, Low efficiency leads to more electricity consumption for storage and a higher amount of required hydrogen storage capacity. However, since the electricity costs are expected to be low when energy is consumed for hydrogen production, and magnesium hydride storage costs are low, this does not significantly influence the total costs. The hydrogen turbine also has an excellent lifetime, contributing to lower annual costs. Another interesting observation is that the curve of the system costs compared to the amount of LOLE hours differs significantly between the first and the last two strategies. This indicates that a large amount of the system costs for the second and third strategies are for the conversion technology, and the increase in hydrogen storage capacity has a lesser influence on total costs. This makes demand response interesting since this could lead to decreased fuel cell or turbine capacity, which is financially attractive.

IV. CONCLUSIONS

This research aimed to cost-effectively ensure the reliable operation of a 500 MW multi-energy system, integrating electrical storage assets under variable operation. Numerical results show that the third strategy is the most cost-effective option, regardless of its low efficiency. Low efficiency leads to more electricity consumption for storage and a higher amount of required hydrogen storage capacity. However, since the electricity costs are expected to be low when energy is consumed for hydrogen production, and magnesium hybrid storage costs are low, this does not have a large influence on the total costs. Next to that, the hydrogen turbine has an excellent lifetime, which contributes to lower annual costs. The comparative parametric performance assessment shows that this evaluation and the subsequent result have quite a large margin, considering that electricity costs are higher for the third strategy. If the electricity profile looks different or if the industrial system is subject to a fixed price, the third strategy becomes more expensive. Another interesting observation is that the curve of the system costs compared to the amount of LOLE hours differs significantly between the first and the other two strategies. This indicates that a large amount of the system costs for the second and third strategies is for the conversion technology, and the increase in hydrogen storage capacity has a lesser influence on total costs. This makes demand response interesting since this could lead to decreased fuel cell or turbine capacity, which is financially attractive.

REFERENCES

[1] Iea, "The netherlands - countries and regions." [Online]. Available: https://www.iea.org/countries/the-netherlands/emissions

[2] L. e. I. Ministerie van Economische Zaken, "Climate policy - Climate change - Government.nl," Feb. 2019, last Modified: 2020-01-31T12:12 Publisher: Ministerie van Algemene Zaken. [Online]. Available: https://www.government.nl/topics/climate-change/climate-policy

[3] M. v. E. Z. e. Klimaat, "Extra pakket maatregelen dicht gat tot klimaatdoel 2030 - Nieuwsbericht - Rijksoverheid.nl," Apr. 2023, last Modified: 2023-08-30T13:39 Publisher: Ministerie van Algemene Zaken. [Online]. Available: https://www.rijksoverheid.nl/actueel/nieuws/2023/04/26/extra-pakket-maatregelen-dicht-gat-tot-klimaatdoel-2030

[4] K. M. van Economische Zaken en, "Routekaart elektrificatie in de industrie, rapport, rijksoverheid.nl," oct 2021, last Modified: 2023-02-22T14:07 Publisher: Ministerie van Algemene Zaken. [Online]. Available: https://www.rijksoverheid.nl/documenten/rapporten/2022/09/19/routekaart-elektrificatie-in-de-industrie

[5] IEA, "Rapport monitoring leveringszekerheid 2022." [Online]. Available: https://www.tennet.eu/nl/over-tennet/publicaties/rapport-monitoring-leveringszekerheid

[6] S. Hakimi, A. Hasankhani, M. Shafie-khah, M. Lotfi, and J. Catalão, "Optimal sizing of renewable energy systems in a Microgrid considering electricity market interaction and reliability analysis," *Electric Power Systems Research*, vol. 203, 2022.

[7] A. Vieira Pombo, J. Murta-Pina, and V. Fernão Pires, "Multiobjective formulation of the integration of storage systems within distribution networks for improving reliability," *Electric Power Systems Research*, vol. 148, pp. 87–96, 2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0378779617301128

[8] T. Adefarati and R. Bansal, "Reliability assessment of distribution system with the integration of renewable distributed generation," *Applied Energy*, vol. 185, pp. 158–171, 2017. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S0306261916315318

[9] C. K. Das, O. Bass, G. Kothapalli, T. S. Mahmoud, and D. Habibi, "Overview of energy storage systems in distribution networks: Placement, sizing, operation, and power quality," *Renewable and Sustainable Energy Reviews*, vol. 91, pp. 1205–1230, 2018. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S1364032118301606

[10] TenneT, "Adequacy outlook 2023," TenneT, Tech. Rep., 2023, accessed: 2024-05-27.

[11] TenneT, "Monitor leveringszekerheid 2024," TenneT, Tech. Rep., 2024, accessed: 2024-05-29.

[12] T. van Dril and J. de Haas, "Decarbonisation options for the dutch refinery sector," 2020, accessed: 2024-05-27. [Online]. Available: https://www.pbl.nl/sites/default/files/downloads/pbl-2020-decarbonisation-options-for-the-dutch-refinery-sector-3659-0.pdf

[13] J. de Haas and T. van Dril, "Decarbonisation of the industry cluster botlek/pernis rotterdam," 2022, accessed: 2024-05-27. [Online]. Available: https://www.pbl.nl/sites/default/files/downloads/pbl-2022-decarbonisation-of-the-industry-cluster-botlek-pernis-rotterdam-4946.pdf

[14] D. A. Irazoqui, "Dynamic model and security assessment of highly electrified industrial hubs with power-to-x assets: Numerical simulation-based analysis," Master's thesis, 2024. [Online]. Available: https://repository.tudelft.nl/islandora/object/uuid:c7ed6106-4380-45c3-830d-4dd6903f6215?collection=education

[15] Vestas. (2024) Enventus platform brochure. Accessed: 2024-05-27.

[16] X. Fan, B. Liu, J. Liu, J. Ding, X. Han, Y. Deng, X. Lv, Y. Xie, B. Chen, W. Hu, and C. Zhong, "Battery technologies for grid-level large-scale electrical energy storage," *Transactions of Tianjin University*, vol. 26, pp. 92–103, 2020. [Online]. Available: https://link.springer.com/article/10.1007/s12209-019-00231-w

[17] IRENA, "Green hydrogen cost reduction: Scaling up electrolysers to meet the 1.5°c climate goal," 2020, accessed: 2024-06-08. [Online]. Available: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Dec/IRENA-Green-hydrogen-cost-2020.pdf

[18] M. J. Palys and P. Daoutidis, "Power-to-x: A review and perspective," *Computers and Chemical Engineering*, vol. 165, p. 107948, 2022. [Online]. Available: https://www.sciencedirect.com/science/article/pii/S009813542200285X

[19] Gevernova. (2024) Gevernova hydrogen gas turbine. Accessed: 2024-06-05. [Online]. Available: https://www.gevernova.com/gas-power/products/gas-turbines/9ha