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Wrocław, 27 October 2025

REVIEW

of a PhD thesis by Mr. Hamed Ghiasirad

Optimization of polygeneration systems using hydrogen as an energy carrier

This review has been prepared based on a Resolution No. RDIŚGE.0211.203.2025 of the Scientific Council of the Discipline of Environmental Engineering, Mining and Energy of the Silesian University of Technology dated September 25th, 2025, and the letter from Prof. Krzysztof Labus, DSc, Eng., Chairman of the Scientific Council of the Discipline of Environmental Engineering, Mining and Energy at the Silesian University of Technology.

The supervisor of the doctoral dissertation is Prof. Anna Skorek-Osikowska.

1. RELEVANCE OF THE THESIS

In recent decades, the growing need to minimize greenhouse gas emissions and mitigate environmental pollution has brought hydrogen energy systems to the forefront as promising alternatives to conventional fossil-fuel-based power and heat generation. Fuel cells and electrolyzers offer pathways not only for efficient electricity and heat production but also for energy storage and sectoral coupling, enabling the integration of variable renewable energy sources into stable energy systems. Hydrogen, as a clean and flexible energy carrier, can connect renewable electricity with industrial, transport, and chemical sectors, allowing for the conversion of renewable and biogenic resources into fuels and chemicals with low or even negative carbon footprints. The key advantage of hydrogen-based polygeneration systems lies in their ability to transform chemical energy from diverse feedstocks, such as biogas, biomass, and captured CO_2, into electricity, heat, and synthetic fuels including methanol, ammonia, and sustainable aviation fuel.

The topic of the dissertation fits well within current international research trends focused on decarbonization, sector coupling, and circular economy solutions in the energy sector. It directly supports the European Union's and

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Poland's long-term climate strategies aimed at achieving climate neutrality by 2050. Given the scientific complexity of the subject and its significant practical relevance to future energy systems, the topic of this dissertation should be considered fully justified and timely.

2. THESIS OVERVIEW

The thesis consists of 11 chapters proceeded by abstract in both Polish and English and concluded with appendix and references list. References list has 206 positions where the PhD student has co-authored 12. Out of which 3 are conference proceedings, 8 are journal chapters and 1 seems to be a book chapter. This is quite substantial scientific contribution for a PhD student. Especially, considering the fact that most of them were published in reputable journals like Energy or Energy Conversion and Management (both from Elsevier). In several works Mr. Ghiasirad is listed as first Author. However, there is no clear or explicit statement that the dissertation is based on the Author's previously published manuscripts – also now as "zszywka". Consequently, I am not going to dive into them and I will be considering the provided thesis as a self-standing document.

Below I will provide a brief summary of each chapter, however I will refrain myself from making at this stage any positive or negative comments regarding their content.

Chapter 1 Outlines the motivation for hydrogen-based energy transition, the EU and Polish decarbonization context, and reviews major hydrogen production, storage, and utilization pathways that define the study's scope. **Chapter 2** Defines the research hypothesis, objectives, and system boundaries, emphasizing the need for an integrated optimization framework linking thermodynamic, economic, and environmental analyses of hydrogen-centered polygeneration. **Chapter 3** Develops detailed Aspen Plus and EES models for all key subsystems namely electrolysis, anaerobic digestion, gasification, methanol and ammonia synthesis, energy storage, and power generation thereby, establishing a modular simulation platform. **Chapter 4** Formulates the analytical framework coupling techno-economic assessment with attributional and consequential LCA, defining key performance indicators such as efficiency, levelized cost, and environmental impacts. **Chapter 5** Analyzes baseline and improved biogas-to-methanol configurations, showing that integrating LNG cold-energy recovery and oxy-fuel gas turbines enhances efficiency and reduces both cost and greenhouse-gas emissions. **Chapter 6** Assesses a gasification-based pathway, quantifying how thermal integration

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and CO_2 management raise overall conversion efficiency and yield favorable techno-economic and environmental results. **Chapter 7** Demonstrates that coupling compressed-air and thermal energy storage with methanol synthesis smooths operation, boosts efficiency to about 95%, and markedly improves system flexibility. **Chapter 8** Compares power- and biomass-to-ammonia routes, identifying the counter-current membrane water-gas-shift design as the most efficient and environmentally "friendly" option. **Chapter 9** Models a Fischer–Tropsch–based sustainable aviation-fuel chain, evaluates its technical and economic feasibility, and highlights trade-offs between electrification level, cost, and life-cycle emissions. **Chapter 10** Synthesizes all case-study outcomes, benchmarking efficiencies, costs, and environmental indicators across pathways to establish general design rules for hydrogen-based polygeneration. **Chapter 11** Summarizes key findings, confirms the thesis hypothesis that electrolyzer-centric integration improves performance, and provides design and policy recommendations for future renewable-hydrogen systems.

Overall, I feel that the title of the thesis is correctly selected and fits well the scope of the presented material. The structure of the thesis is logical and guides the reader through the thinking process of the Author.

3. THESIS EVALUATION

My overall evaluation of the thesis is positive. The topic undertaken is very relevant and important from the scientific and economic point of view. The work sets some foundation for future research. The Author has compared multiple different systems which itself is a huge effort.

However, the thesis has some weaknesses which I will describe in more details in section 5 of this review with a request to the Author to provide detailed written feedback and the recommended improvements should be considered in Author's future research works.

4. BASIC RESEARCH ACCOMPLISHMENTS

After analyzing the entire dissertation, I believe that the following main scientific achievements and elements of novelty can be identified:

- Comprehensive literature review on hydrogen's role as an energy carrier and its integration into polygeneration systems combining electricity, heat, and fuel production. Side note – this is rather a must-have in each thesis.
- Execution of multi-variant optimization studies for eight hydrogen-integrated polygeneration systems, identifying process couplings that

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maximize energy efficiency and minimize levelized cost and greenhouse-gas emissions.

- Identification of optimal integration strategies - in particular, the use of high-temperature solid-oxide electrolysis, counter-current membrane water-gas-shift reactors, and combined thermal-energy storage, as key levers to improve system performance.
- Development of detailed process models of key subsystems - including electrolysis, gasification, biogas reforming, methanol and ammonia synthesis, Fischer–Tropsch fuel production, and thermal and compressed-air energy storage.

5. CRITICAL COMMENTS AND QUESTIONS

The comments provided here require feedback from the Author in written form (email) to be provided to the reviewer before the defense. Here, I limit myself to most relevant concerns. Further feedback will be provided in oral form after the presentation and during the discussion. Where necessary I will refer to specific sections of the thesis.

Major issues:

1. **Page 11** "promote long-term energy security." – how do you understand energy security via "Increasing the share of renewables"? Could you elaborate on this connection?
2. **Chapter 1.1** sets well the thesis scope within the context of the EU and national regulations. What itself is very good. However, I am missing a bit the international context. Would be beneficial to shed some light on this issue. In other words, is the EU setting the direction? Following the others? Or just alone in this kind of activities?
3. **Page 14** "Electrolysis powered by renewables is technologically mature," - but what about market maturity? Is the technology mature in the market sense? What is the current situation of the H2 projects in Europe and Poland overall? Is H2 the only viable pathway?
4. **Page 15** "membranes, and power electronics now enable efficient, continuous production of high-purity hydrogen from renewable electricity" – what do the Author mean by continuous production? How should be this interpreted?

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5. **Page 16** "several vendors with MW-scale stacks" – certain parts of the thesis are quite poorly documented/referenced. There is no reference to this specific statement. Examples would be beneficial.
6. **Page 17** "1.65 kWh of electricity, which can produce 1600 L of hydrogen in 4 h" – is this really feasible? Perhaps I am missing sth. but this looks like a very low electricity consumption.
7. **Page 17** "Hydrogen's storage and safety constraints make direct hydrogen logistics sub-optimal" - in what context you mean here sub-optimal? What does it imply? Based on what objective is this evaluated to be sub-optimal? What is optimal then?
8. **Chapter 1.5** – general observation/question: What will be the proportion of H2 used in those sectors compared to the need of the power system itself? Are we solving a big or rather a niche problem?
9. **Table 1.1** is very dificult to understand. Could you guid us through it?
10. **Chapter 1.6.1** "Under 2022 market conditions, PtM becomes cost-competitive against natural gas part or most of the year, while all concepts provide grid-injectable biomethane and a pathway for long-duration energy storage using existing gas infrastructure [17]." - what market conditions are considered here? For which specific country?
11. **Chapter 1.8.1**. I am missing some conclusions from this chapter.
12. **Page 24** "However, when LCOA is subsidized by selling electricity, LCOA decreases to 0.58 \$/kgNH3 [58]." – what do you mean? This sentence is very unclear to me.
13. Did you take into account dynamic hourly emissions from the Polish power system? If yes, how did you estimate them or where they were taken from? If not, what are the consequences for the validity of your results? Where the systems in general simulated with hourly resolution?
14. **Page 28** "It is possible to increase overall energy efficiency of plants by adopting high-temperature electrolysis." what do the Author mean by plants? How they are defined?
15. **Page 28** "increase overall energy efficiency" vs "improve plant performance" – what is the difference between these two?
16. **Page 28** The hypotheses are of conceptual nature and do not read as "testable scientific hypotheses". I would recommend directly linking them to specyfic KPIs. For example: "It is possible to increase overall energy efficiency of plants by adopting high-temperature electrolysis."

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Should read: "High-temperature electrolysis increases total system energy efficiency (η_total) by ≥ 5 percentage points compared to low-temperature electrolysis under identical input conditions."

17. **Page 29** "It is possible to decrease environmental footprints by powering the plant with wind energy instead of Poland electricity mix." – it is quite weak and obvious hypothesis in my opinion. The boundary conditions are not-well specified to test it. Also, from further chapters we read that the Polish energy mix is probably not accounted for correctly due to its outdated/wrong mix and lack of hourly resolution in modelling.
18. **Page 29** "which integration effectively increases efficiency, decreases cost, and reduces environmental impacts in hydrogen-driven polygeneration systems." – what does "effectively" mean in this context? Is there some benchmark set?
19. **Figure 3.14** – could you explain the lack of axis labels?
20. **Table 4.2.** References to various values. For example, "Price of input electricity 0.05 €/kWh [142]" comes from "Katla-Milewska, D., Nazir, S. M., & Skorek-Osikowska, A. (2024). Synthetic natural gas (SNG) production with higher carbon recovery from biomass: Techno-economic assessment. *Energy Conversion and Management*, *300*, 117895." Which doesn't look like a proper reference for this kind of things. Second of all, 0.05 Euro/kWh what does it represent? Subsequently, price of electricity in the Polish energy mix comes from M. Wierzbowski, I. Filipiak, and W. Lyzwa, "Polish energy policy 2050 – An instrument to develop a diversified and sustainable electricity generation mix in coal-based energy system," Renewable and Sustainable Energy Reviews, vol. 74, pp. 51–70, Jul. 2017, doi:10.1016/J.RSER.2017.02.046. The same story. Such data should be calculated from either DA market or taken from Eurostat for industrial customers. Furthermore, the reference is dated "2017", which is old.
21. **Table 4.2.** „Price of onshore wind energy in Poland" which is said to be 83 Euros/MWh is backed up by a paper [148] published in 2019 where we read that the projects under the call dated 2018 may receive a subsidy of 83 Euros/MWh for turbines larger than 1 MW. The analysis provided by the Authors of this work clearly state that the 2030 target for Poland (10.3 GW – which has been already exceeded despite the "favorable" legislations) could be reached with the LCOE < 70

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Euros/MWh. Please provide a rationale behind the originally selected number... what are the current prices of electricity that could be purchased from a wind farm for example through a PPA or an own investment? Does building dedicated wind park supplying polygeneration site is worth considering?

22. If you provide the exchange rate (**Table 4.1**) why not providing all values (where applicable) in the same currency?
23. From reference [149] where does this specyfic cost of water come from – I couldn't identify it?
24. **Table 4.2.** Back to the water cost. You are using Poland specyfic electricity prices as well as cost of wind energy but the cost of water comes from a study handling different region. Upon checking you can see that water costs might vary significantly in Poland and for Gliwice (https://pwik.gliwice.pl/strefa-klienta/taryfy-aktualne/aktualne/) they can be almost 6x higher compared to your estimates. Please elaborate what constitutes to the "water price" and if the assumption made is realistic? How the overall, economic performance might have changed if different (higher costs) were assumed?
25. Do you consider water carbon footprint in your analysis?
26. **Table 4.7** in which scenario the Polish electricity mix has 32.6% of oil? Shouldn't this be lignite? Contribution of solar-wind is way to low 3.4% even if the the calculations were made in early years of the PhD studies you should consider at least 10%. I have checked www.iea.org/countries/poland/energy-mix it is "energy mix" not electricity mix. Consequently the values stated in Table 4.7 are wrong.
27. Photovoltaics are added in **Chapter 8**. How are they included in the LCA and economic analysis? What are their costs assumptions? What is their impact on environment from the perspective of the studied systems? Or in other words the assumed emissions? How are PV modelled in your analysis? Where they are located from the perspective of the studied system? Rooftop? Somewhere in the system and just PPA? Direct line? Unclear. Is there a difference in LCA for PV systems being rooftop compared to utility scale ground-mounted?
28. **Page 86** "The solar photovoltaic panel unit provides the electrical power needed" – I don't think this is a right way wording. There is a substantial

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difference between what we understand as PV cell, PV module, PV panel and PV system. Which one is adequate here?

29. **Figure 8.1** what kind of electrical power is being fed from PV to other subsystems? Is it DC or AC?
30. **Page 111** "Chemical storage of liquid biofuels is easier and safer than compressed/cryogenic H_2 gas storage." – is it truly the conclusion that can be formulate from the research conducted in this thesis? It seems to be very-well known fact.
31. **Page 111** "Renewable energy is chosen when environmental sustainability is prioritized." – could you elaborate on these conclusions? Does it stand the test of the sensitivity analysis? Cost of energy from the grid vs cost of electricity from VRES?
32. **Page 111** "The Polish energy mix is the more economically viable option than wind turbines. However, wind energy outperforms Poland's electricity mix in most of the environmental indicators." – these conclusions is based on a simplified assumptions when it comes to the modelling of the system.
33. The methodology does not include any formal uncertainty or error analysis. All results are presented as point estimates (deterministic outcomes). While there are some sensitivity cases on specific parameters (e.g. electricity price, cell count), there is no Monte Carlo simulation or confidence interval given for the techno-economic or LCA results. This is a methodological gap because it's unclear how robust the conclusions are to input uncertainty.
34. The work analyzes plant-level efficiencies, levelized costs, and environmental indicators using deterministic steady-state models. Energy storage (CAES, TES) is considered conceptually or via capacity scaling, not dynamically optimized across fluctuating inputs or prices. I am missing any insights into the hourly performance of these systems. This is crucial from the perspective of the market situation prices/CO2 emissions. Or in other words: The dissertation provides a comprehensive steady-state assessment of hydrogen-based polygeneration pathways; however, it lacks any time-resolved (hourly) analysis of system operation. Such dynamic evaluation would be crucial to understand how electricity market conditions, renewable variability,

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and CO_2 intensity affect the performance, costs, and environmental outcomes of the proposed systems.

35. Each case study is modeled at a specific scale (with given flow rates, capacities as per Appendix assumptions). The methodology does not examine how results change with plant scale. For example, some economic assumptions (like specific capital costs) might differ in a small pilot versus a large commercial plant. The thesis presents results for one scale per configuration, so it's unclear if the conclusions (e.g., that one route is cheaper or more efficient) would hold at a different scale.
36. From my point of view the limitations and future research directions are not clearly outlined.
37. The general policy recommendations are not provided and I think the Author should at least try providing some.

Minor issues:

1. The work is full of unclear phrases like "coal/lignite retirement" – which is very confusing for the reader.
2. Thesis was submitted in 2025. In many instances the Author could have used more recent data.
3. The Author notoriously does not use capital letter at the beginning of each sentence. Which shows that the thesis was either written very quickly or there is little attention to the details. This potentially can impact the modelling phase.
4. My general observation is that the Author is using very long sentences and sometimes it is very hard to get a good understanding of the messages conveyed.
5. Figures are in general blurry and of quite low resolution. Many of them are unnecessarily taken from original sources where the Author could have instead obtain the original database and create his own version and interpretations of the data.
6. "[18], [19], [20]:" lumping up citations should be avoided.
7. Overall, there is a lack of a good overview figure of the thesis content that will nicely sum it up and show logical connection between the chapters.

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6. FINAL CONCLUSION

The remarks presented in this review do not negate the scientific relevance of the dissertation but considerably temper my overall assessment of its completeness and rigor. A few of the comments raised above concern substantial issues that require clarification or additional justification from the Author, particularly those related to data sources, methodological consistency, and the interpretation of key results. These remarks should not be viewed solely as suggestions for future work but rather as points that must be explicitly addressed and discussed by the doctoral candidate during the public defense.

While the general structure of the dissertation is acceptable and the research topic remains timely and relevant, a more critical approach to data selection, clearer presentation of results, and stronger linkage between hypotheses, indicators, and conclusions are necessary for the Author to be considered in the future research activities while for know these aspects should be clearly explained during the defence.

Taking into account all the adopted evaluation criteria, I state that the doctoral dissertation by Mr. Hamed Ghiasirad entitled *"Optimization of polygeneration systems using hydrogen as an energy carrier"* meets the conditions and requirements set for doctoral dissertations as defined in Article 14, paragraph 1 of the Act of March 14, 2023, on academic degrees and titles and on degrees and titles in the field of art (Journal of Laws of 2017, item 1789, as amended).

In connection with the above, **I propose to the Discipline Council of Environmental Engineering, Mining and Energy at the Silesian University of Technology that by Mr. Hamed Ghiasirad be allowed to proceed to the public defense of his doctoral dissertation.**

Podpisał Jakub Jurasz

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