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博士論文審査結果報告
Doctoral Dissertation Defense Results

審査委員会を代表し、以下のとおり、当該学生が博士論文審査に合格したことを報告します。
On behalf of the Examination Committee, I am pleased to report that the student indicated below has successfully defended her/his dissertation.

政策研究大学院大学　　教授　　田中　誠
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プログラム名 Program	科学技術イノベーション政策プログラム Science, Technology and Innovation Policy Program	
学位申請者氏名（学籍番号） Name of the Candidate (ID)	Mr. MISHREF Mohammed Mahmoud Ali (DOC21153)	
論文タイトル/ Dissertation Title	Techno-Economic Analysis of Hydrogen and Ammonia Production in Isolated Microgrids for Sustainable Development	
(和訳/ English Translation)	（持続的発展に向けた孤立型マイクログリッドにおける水素とアンモニア製造の技術・経済分析）	
学位名（専攻） Degree Name	博士（公共政策分析） Ph.D. in Public Policy	
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1. Summary of the Dissertation and the Committee's Evaluation

Isolated microgrids with diverse onshore natural gas resources have the potential to produce hydrogen and ammonia. This dissertation conducts a techno-economic and environmental analysis of a hybrid renewable isolated microgrid with hydrogen and ammonia production. The main components of the hybrid renewable energy system (HRES) in this study are photovoltaic (PV) cells, wind units, battery storage systems, and microturbines along with facilities to generate hydrogen and ammonia. Using the HOMER Pro software, the models are applied to an isolated microgrid in East Owienat, Egypt, as a case study.

Chapter 3 focuses on the process for hydrogen production. Based on thermodynamic models, the heat for the endothermic process is provided by four different approaches, i.e., combined heat and power (CHP) boiler, gas boiler, electric boiler, and hybrid boiler systems. This chapter examines how different thermal sources for hydrogen production affect the optimal configuration and sizing, net present cost (NPC), and CO2 emissions. The results indicate that the CHP boiler system exhibits the lowest NPC and levelized cost of hydrogen (LCOH), although its CO2 emissions are relatively high. The NPC is the highest when using an electric boiler because of the increased capacities for PV, wind turbines, and battery storage with higher costs, whereas CO2 emissions are the lowest. On the other hand, Chapter 4 examines the process for ammonia production under multiple seasonal gas prices. The results show that when there is a significant difference in the gas prices, it is cost effective to store gas-based ammonia during low gas-price periods. As price gaps narrow, it becomes more efficient to store both gas-based and renewable-based ammonia during low gas-price periods.

Chapter 3 contributes to the literature in that economic and environmental aspects of heat sources for hydrogen production are studied, specifically in terms of the total costs of the entire system over the project lifetime. This contrasts with most existing studies that focus on the technological aspects of heat sources. Moreover, four different approaches for supplying heat are compared in detail in the context of isolated microgrids with HRES, which contrasts to most existing studies that examined only a single heat source. Chapter 4 contributes to the literature in that it explores the economic feasibility of ammonia production in isolated microgrids with HRES, expanding beyond previous studies that mostly focus on hydrogen production. Furthermore, it compares various systems for ammonia production subject to multiple gas prices, thus diverting from the existing studies that typically consider a fixed single gas price.

The referees were generally satisfied with the contribution of the dissertation. They however suggested several areas for improvement. After several revisions to the dissertation, the main referee was satisfied that the revisions were made appropriately in line with the suggestions by the referees. The doctoral dissertation review committee recommends that GRIPS award the degree of Ph.D. in Public Policy to Mr. Mishref.

2. The Dissertation's Findings, Methodologies, and its Academic Contribution

After an introduction in Chapter 1 and an extensive literature review in Chapter 2, Chapter 3 conducts a techno-economic and environmental analysis of a hybrid renewable isolated microgrid with a steam reformer that produces gas-based grey hydrogen, supported by different approaches to supplying heat. This chapter considers an HRES comprising of PVs, wind units, battery storage systems, microturbines, and steam reformers. Based on the thermodynamic models, the heat for steam methane reforming (SMR) is provided by four different approaches, i.e., CHP boiler, gas boiler, electric boiler, and a hybrid boiler system of these components. In the study, the CHP boiler system combines waste heat from a microturbine with heat from a gas boiler using natural gas. An electric boiler uses electricity generated by a PV system, wind turbine, or microturbine in a microgrid. For the hybrid boiler system, the CHP and electric boilers supply heat concurrently. The study analyzes the impact of different thermal sources of SMR on the optimal configuration and sizing, NPC, and CO2 emissions of a hybrid renewable microgrid. The NPC is calculated as the present value of all the costs of the system over its project lifetime, including capital cost, replacement cost, operation and maintenance cost, fuel cost, and salvage value. A project lifetime of 25 years and a discount rate of 6 % are assumed. To evaluate the impact on emissions, the NPC is compared with and without considering the CO2 penalty cost (e.g., carbon tax payment) in the optimization. Using the HOMER Pro software, the models are applied to an isolated microgrid in East Owienat, Egypt, as a case study.

The main findings of Chapter 3 are as follows. (1) The CHP boiler system outperforms the other types of boilers in terms of NPC. In particular, the NPCs of the CHP boiler are lower than those of the electric boiler by 16.2 % and 13.6 % without and with a CO2 penalty cost in the optimization, respectively. (2) In contrast, the CO2 emissions from the CHP boiler are greater than those from the electric boiler by 11.2 % and 8.9 % without and with a CO2 penalty cost, respectively. (3) The CO2 penalty cost has an asymmetric impact on the sizes of the PV and wind units; that is, it incentivizes more PV units than wind units. (4) The LCOH ranges from 2.1 to 2.8 $/kg. Specifically, the LCOH is the lowest for the CHP boiler, whereas it is the highest for the electric boiler. The electric boiler is the least cost effective because of the increased capacities for PV, wind turbines, and battery storage with higher costs. One may think that the CHP boiler system faces a trade-off between the NPC and CO2 emissions. However, the overall NPC in the study considers the CO2 penalty cost as a monetized environmental impact. Thus, the CHP boiler system for SMR in microgrids outperforms other boiler options, even when the impact of CO2 emissions is considered. This study provides practical insights into the approaches for supplying heat to the SMR process in isolated microgrids.

The main contribution of Chapter 3 can be summarized as follows. The techno-economic and environmental aspects of heat sources for SMR are studied, specifically in terms of the total costs of the entire system over the project lifetime. This contrasts with most existing studies that focus on the technological aspects of heat sources. Four different approaches for supplying heat, crucial for the endothermic process of SMR, are compared in detail in the context of isolated microgrids with HRESs, which contrasts to most existing studies that examined a single heat source. Although the primary targets of this study are isolated microgrids with onshore natural gas resources as seen in Africa and Asia, the approach is also applicable to microgrids spanning rural to suburban areas that have access to diverse natural gas resources including gas pipelines.

Extending the study in Chapter 3, Chapter 4 conducts a techno-economic analysis of an HRES, equipped with a steam reformer and an electrolyzer for supplying hydrogen, which is then used to produce ammonia through the Haber-Bosch (HB) process. Ammonia is utilized for fertilizer in agriculture in remote areas in addition to industrial use. This chapter examines three systems facing multiple seasonal gas prices in low and peak demand seasons. Those systems involve adjusting ammonia generation and storage strategies during low gas-price periods to avoid the burden of expenses during high gas-price periods. Specifically, during low gas-price periods, the first system stores gas-based grey ammonia, while the second system stores renewable-based green ammonia. Both green and grey ammonia are stored during low gas-price periods in the third system. Comparative analyses of NPC and levelized cost of ammonia (LCOA) under three systems are conducted, considering various scenarios for gas price differences. As in Chapter 3, the HOMER Pro software is used to model an isolated grid supporting an agricultural area in East Owienat, Egypt.

The results of Chapter 4 indicate that when there is a significant difference in the gas prices, it is cost effective to store gas-based grey ammonia during low gas-price periods as in the first system. In this case, the capacity of the steam reformer is increased without using the electrolyzer (3.2 MW unit). As price gaps narrow, it becomes more efficient to store both gas-based grey and renewable-based green ammonia during low gas-price periods as in the third system. Thus, combination of the steam reformer and the electrolyzer (3.2 MW unit) becomes preferable. The results demonstrate that ammonia generation and storage strategies should be adjusted in terms of NPC and LCOA by responding to the fluctuation in the seasonal gas prices.

Chapter 4 contributes to the literature in the sense that it explores the economic feasibility of ammonia production in isolated microgrids with HRES, expanding beyond previous studies that mostly focus on hydrogen production. Moreover, it compares various systems for ammonia production subject to multiple gas prices, thus diverting from the existing studies that typically consider a fixed single gas price. Similar to Chapter 3, the approach of ammonia generation and storage strategies is applicable to microgrids spanning rural to suburban areas that have access to diverse natural gas resources.

3. Comments by the Examiners and the Revisions Made

The referees were generally satisfied with the contribution of the dissertation. They however suggested several areas for improvement, particularly better exposition of the dissertation. The comments from the referees include:

- Elaborate on the optimization problems and the relevant conditions of the system in this study.
- Discuss the limitation of the methodology the candidate applied. Specifically, the candidate assumes a static setting on prices and technology.
- Better justify the assumptions in the study, e.g., the project lifetime, the discount rate, and local demand growth.
- Describe the research questions more explicitly in the main text.
- Improve the exposition of the literature review, e.g., adding subheading.

Under the rules of the defense, the confirmation of satisfaction was delegated to the main referee. The candidate addressed all the issues raised by the referees. Particularly, he elaborated on the minimization of the NPC and modeling of the microgrid components. He acknowledged the limitation of the static approach and discussed the possibility of applying dynamic price and potential technological change to investigate different types of policy implications. He also clarified the setup of the study such as the project lifetime, the discount rate, and local demand growth. After several further revisions to the dissertation, the main referee was satisfied that the revisions were made appropriately in line with the suggestions by the referees.

After a plagiarism check, the main referee confirmed that the revisions were satisfactory, and the quality of the dissertation was improved. On August 21, 2024, the final version of the dissertation was submitted to GRIPS. The doctoral dissertation review committee recommends that GRIPS award the degree of Ph.D. in Public Policy to Mr. Mohammed Mishref.