様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９　（共通）

科学研究費助成事業　　研究成果報告書

令和　５ 年　 ５ 月 １２ 日現在

機関番号：３２６８９
研究種目：若手研究
研究期間：2021～2022
課題番号：２１Ｋ１７９３０

研究課題名（和文）Addressing the sustainability challenges of off-grid renewable energy systems: The smart community reverse innovation

研究課題名（英文）Addressing the sustainability challenges of off-grid renewable energy systems: The smart community reverse innovation

研究代表者

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研究者番号：１０８２６０９３

交付決定額（研究期間全体）：（直接経費）　　2,100,000円

研究成果の概要（和文）：このプロジェクトの初年度は、非電化地域における調査票の開発、配布、回収が行なっていた。また、持続可能なエネルギーシステムを構築するために、コミュニティの社会・技術・経済的側面を評価する手法も開発していた。

加速度的に進展したため、研究の2年目を有効活用して、異なる環境設定での手法の再現を行っていた。さらに、このプロジェクトの最終目的は、スマートコミュニティの基盤を確立することであったため、人工知能（AI）に関するレビュー研究を開始してた。AIテーマは次の科研費プロジェクトで継続される予定である。本研究の成果は、国際的な査読付き学術誌に掲載され、国内外の学会で発表され、国際学会で賞を受賞していた。

研究成果の学術的意義や社会的意義
A sustainable system must be responsive to people's values. This study have provided key policy recommendations and developed a tool for practicitoners and decision makers to assess the social, economic, and technical aspects of a community to establish a sustainable off-grid electrification system.

研究成果の概要（英文）：In the first year of this project, we developed, distributed, and collected surveys in off-grid communities. We also have developed a method to assess the socio-techno-economic aspects of communities to build a sustainable energy system. These milestones were achieved earlier than planned despite the pandemic due to the effective international collaboration with institutions abroad.

Due to the accelerated progress, we effectively used the 2nd year of the study to replicate the method in different environmental settings. Furthermore, as the ultimate aim of this project was to establish a foundation of a smart community, we have initiated some review studies on the artificial intelligence (AI) topic. Results of this study have been published in international peer-reviewed journals, presented at domestic and international conferences, and awarded at the international conferences. The AI topic will be continued in a following kakenhi project that the Principal Investigator has secured.

研究分野：Environmental Policy and Social Systems

キーワード：renewable energy　sustainable development　social assessment　off-grid electrification　smart community　developing countries　artificial intelligence　sustainability

様　式　Ｃ－１９、Ｆ－１９－１、Ｚ－１９（共通）

１．研究開始当初の背景

(1) Off-grid communities with various socio-economic conditions need more sustainable and cleaner energy systems. These communities are not limited to those in developing countries with challenging geographical characteristics. In the future, communities in developed countries with declining populations will also require smaller, more demand-capacity-appropriate, more manageable, and more cost-effective off-grid energy systems.

(2) In line with Sustainable Development Goals (SDGs) number 7, to "Ensure access to affordable, reliable, sustainable and modern energy for all", many countries are closing the gap by getting closer to their universal electrification targets. However, the remaining population without access to electricity still amounts to millions worldwide. Furthermore, the quality and reliability of energy in many communities in developing countries are poor. Many communities also faced difficulties in sustaining the systems.

2. 研究の目的

(1) Identify and organize sustainability challenges of small-scale off-grid RE system projects worldwide.

(2) To create a methodology that could help practitioners design a sustainable off-grid renewable energy system.

3. 研究の方法

(1) Literature reviews

I have conducted structured literature reviews from peer-reviewed journal articles, conference papers, reports from international organizations, and national newspapers of relevant countries. The literature reviews helped me identify the specific research gaps and make arguments about the importance of the study in each of my published research papers in this project.

(2) Existing data analysis with descriptive statistics methods

During the literature review, I discovered an existing open database containing detailed information about off-grid systems worldwide (Mini-Grid Database 1.0) developed by Bloomberg New Energy Finance (BloombergNEF). Moreover, the database was relatively new (2020) and quite comprehensive. Therefore, I performed a descriptive statistical analysis of the off-grid system's data from the database to grasp the current situation and distribution of off-grid energy systems, the types of energy resources, the funding modalities, and other key factors' characteristics.

(3) Survey Questionnaire and data analysis with multivariate analysis methods

I build a microdata database about the socio-economic situations of individuals and households in off-grid communities. To do this, I developed a survey questionnaire for the residents and community leaders in off-grid Indonesian communities. I made use of existing networks as well as established new partnerships with scholars in Indonesia to distribute and collect the survey questionnaires. While most respondents had low literacy levels and access to the communities was geographically challenging, my research partners were able to mobilize their human resources to perform the survey. Various methods such as multiple correspondence analysis (MCA) and non-parametric tests such as Chi-Square, Cramer's V, and Fisher's Exact were employed.

(4) Stakeholders Interview

Other than the communities and community leaders, I also interviewed academicians and researchers, the private sector, and the government. Finally, as the ultimate goal of the study is to demonstrate a bottom-up innovation for the foundation of smart communities, I also covered the topic of sustainable mobility using this method.

(5) Technology Readiness Assessment

I applied the Japanese Technology Readiness Assessment (J-TRA) method to measure the technology readiness of various new technologies for smart communities, particularly the electric vehicle and various Artificial Intelligence (AI) based

mobility technologies. The Japanese Technology Readiness Assessment (J-TRA) method was developed in my previous study and consists of 7 parameters (market, technology development, system integration, sustainability verification, safety, commercialization, cost, and risk).

4. **研究成果**

Analysis of the existing data showed that over 50% of global off-grid electrification systems are using a combination of solar PV and diesel engine (Fig. 1). This type of hybrid system is also among the kind that is under new construction as well as among the ones not operating anymore. Existing literature mentions the challenges of having reliable storage technologies as the key technical problem. High battery price at the initial cost and its replacement to maintain the system are also identified as key financial problems. While numerous studies examine the techno-economic side of off-grid energy systems, limited discussions address the social causes. General social problems such as organizational infrastructure, competency, and poor policy implementation are known. However, specific problems in that area are unique to each location. I collaborated with my international research partners to conduct surveys in off-grid communities (Fig. 2) to conduct door-to-door survey in these challenging locations and managed to collect the social, technical, and financial micro-data from the communities.

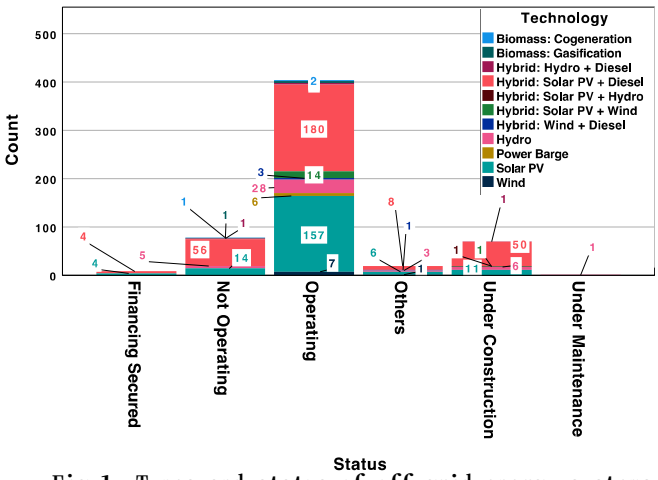


Fig 1. Types and status of off-grid energy systems worldwide (Pandyaswargo and Onoda, 2021)

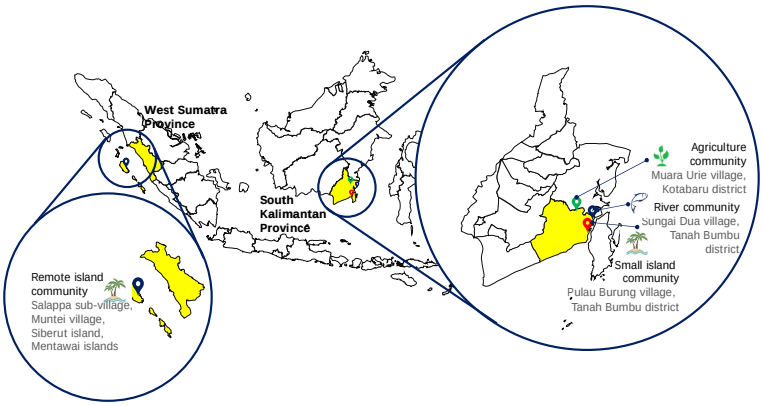


Fig 2. Locations of off-grid village door-to-door survey collection in this research project

I then performed the MCA methodology to find social patterns and correlations between the respondents' characteristics and attributes and tested the significance of the identified correlations with nonparametric tests. For the techno-economic assessment, I processed information from the field with the HOMER software. The software was selected after reviewing the pros and cons of commonly used commercially available software for energy system design. A sensitivity analysis was also performed to identify how the system functions during fluctuating prices and resource availability. These steps are summarized (Fig. 3) as the guideline for implementing a socio-techno-economic assessment to design an appropriate off-grid energy system. I identified the following challenges in the case study of Indonesia: 1) The price caps determined by the government per kWh of electricity are much lower than what it costs to generate it. 2) Although Feed-in-Tariff regulation is in place, the actual implementation and mechanism to monetize it are uncertain. These two factors made the off-grid electrification businesses very unattractive to the private sector.

In one of my case study villages, I found that the community could not purchase new batteries to sustain the system that the government introduced for a fixed period. Using the social analysis results in the research, I made several suggestions on how to use the solar panels that are still functioning but are not used due to the battery

problem. I propose the use of these solar panel to create a sustainable transportation system (Fig 4 a.) and to improve access to information and communication (Fig 4 b.). Other studies have confirmed that access to information and communication can contribute to the improvement of the capacity and economic status of a community. Moreover, challenging transportation is commonly found in sparsely habituated off-grid areas with difficult topography and other geographical challenges. I also performed a financial assessment study to provide practitioners with estimated capital costs and projected periods of returns.

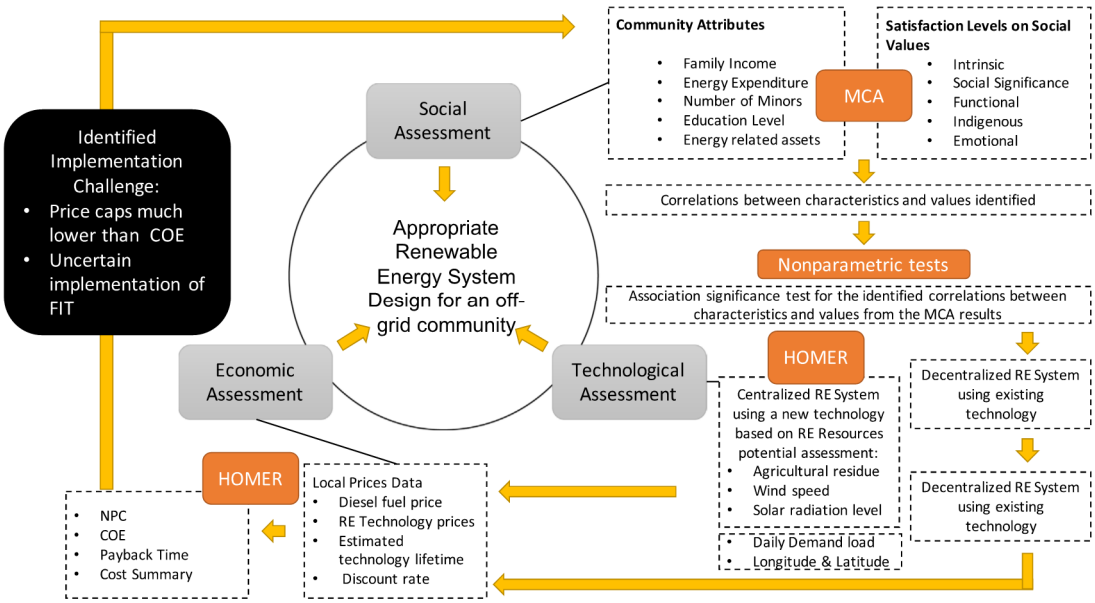
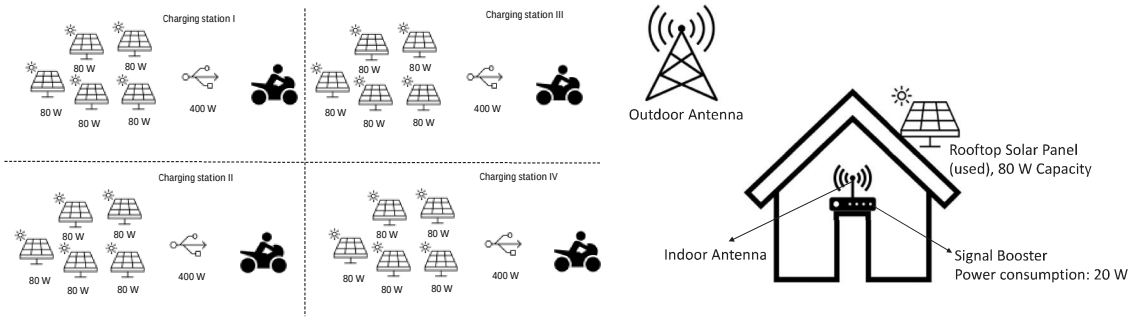


Fig 3. Methodological framework to design an appropriate off-grid energy system (Pandyaswargo, Wibowo and Onoda, 2022b)



(a) (b)

Fig 4. Example of reusing solar panels for (a) a sustainable transport system (Pandyaswargo, Wibowo and Onoda, 2022b) and (b) improving the information and communication access in off-grid villages (Pandyaswargo, Wibowo and Onoda, 2022a)

When I was designing the sustainable transport system for off-grid areas, I came across the information about recent development of Electric Vehicles (EVs) in the Southeast Asian region. Particularly in Indonesia, the Nickel resource for battery is abundant. In Thailand, the automotive industry is growing rapidly. These new developments may largely impact the growth of the battery industry in the area, reduce the price of batteries, and eventually address the energy storage challenge of renewable energy. Therefore, I initiated a review study on this area involving discussions with various stakeholders such as the industry, government, scholars, and the end users of EVs. Based on the review, I developed a framework of key elements that could help promote the EV industry in developing countries (Fig. 5).

Recent accelerated progress in the development of Artificial Intelligence (AI) is also affecting the energy sector. Specifically, AI may improve efficiency of energy-use. Following up the off-grid energy system study, anticipating progress in the transportation and battery industries, and wrapping up this research that was ultimately designed to contribute to smart city development, I built a mini-database of AI-based mobility projects worldwide (Fig 6).

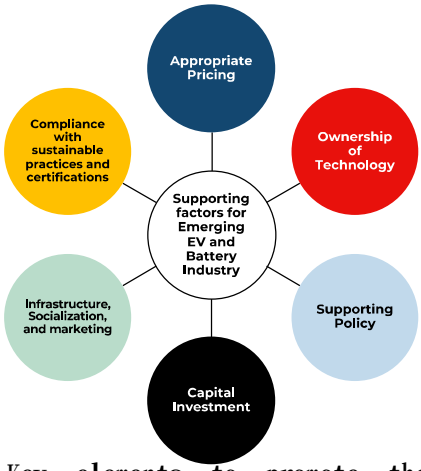


Fig 5. Key elements to promote the electric vehicle industry in developing countries (Pandyaswargo *et al.*, 2021)

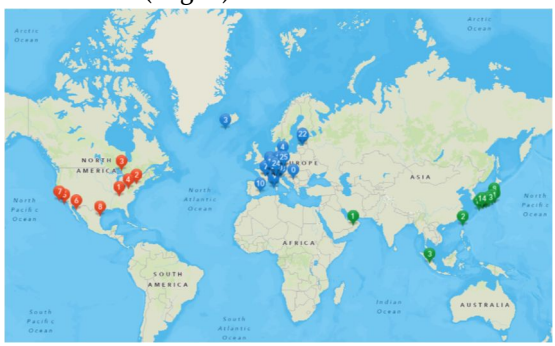


Fig 6. Global distribution of artificial intelligence application projects on mobility (Pandyaswargo, Maghfiroh and Onoda, 2023)

The results show that most of the projects are located in European countries. The three most common applications of AI in mobility are charging system optimization, autonomous driving, and traffic control technologies. The readiness level analysis conducted in the study revealed that the smart parking system and lane tracing assistance technologies are the most advanced. Advancing the readiness levels of the other technology categories can be achieved by further training AI to be fully compatible with real operating environments. Moreover, updates to traffic policies are necessary.

For future study, I would like to support the development of AI in improving people's wellbeing. Autonomous driving, in particular, has the potential to help maintain the mobility of the aging society in Japan. Older adults and people with disabilities have been predicted to be early adopters of autonomous vehicles. Furthermore, the automobile industry has been one of Japan's core industries for decades. New development in this area in Japan will set example to other countries following the trend of longevity. Additionally, the COVID-19 pandemic has created new needs for contactless technologies. In the waste management sector, as transportation is one of the costliest activities, using man-less and contactless technologies to transport waste is gaining importance. Considering all of the above, I will explore the social acceptance of smart technologies topic in my next research project.

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３．雑誌名 Sustainable Production and Consumption	６．最初と最後の頁 492～511
掲載論文のDOI（デジタルオブジェクト識別子） 10.1016/j.spc.2022.03.009	査読の有無 有
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１．発表者名
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〔図書〕　計0件

〔産業財産権〕

〔その他〕

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６．研究組織

	氏名 （ローマ字氏名） （研究者番号）	所属研究機関・部局・職 （機関番号）	備考

７．科研費を使用して開催した国際研究集会

〔国際研究集会〕　計0件

８．本研究に関連して実施した国際共同研究の実施状況

共同研究相手国	相手方研究機関