UNIVERSITY OF TWENTE.

A Reference Model of Operation and Maintenance (O&M) Strategies for Community-based Photovoltaic (PV) Microgrids on Small Islands

Elvin Khoirunnisa

Study Program : Master in Business Information Technology
Faculty : Electrical Engineering, Mathematics, and Computer Science
Supervisors : prof. dr. Maria E. Iacob
dr. ing. Jelena Popović

January 2024

Abstract

Operation and Maintenance (O&M) practices within community-based photovoltaic (PV) microgrids on small islands involve intricate processes, stakeholders, and technological components. To encapsulate these complexities, a reference model serves as a standardised graphical representation, aiding stakeholder communication and comprehension. This thesis endeavours to delve into the development of a comprehensive reference model tailored explicitly for the O&M of PV microgrids in small island communities.

Utilising insights from Design Science Research Methodology (DSRM), this research combines literature review, site observations, and stakeholder interviews to construct the reference model by implementing ArchiMate modelling techniques. The resulting model aims to provide a structured guideline, facilitating better comprehension, organisation, and sustainable operation of PV microgrid systems within small islands' distinct and challenging environments.

A validation process was initiated to ensure the relevance and practicality of the reference model in the unique setting of remote islands. The validation method involved a case study and expert opinion. During the validation interview sessions, the Likert scale yielded an average score between 4.0 and 4.8 out of 5, with a standard deviation of less than 1. The validation activity confirms the model's strength and its contribution in promoting sustainable operation and maintenance solutions for PV microgrids in isolated island environments.

Keywords: Operation and Maintenance, Community-based Photovoltaic Microgrids, Sustainability, Reference Model, ArchiMate

Acknowledgements

This thesis acknowledgement serves as a tribute to the collective effort that has enriched my academic journey.

I wish to express my heartfelt gratitude to the Government of Republic of Indonesia for awarding me the Indonesian Education Scholarship (BPI). This invaluable support has enabled me to pursue a two-year Master's degree at the University of Twente in the Netherlands.

Subsequently, I sincerely thank my esteemed supervisors, prof. dr. Maria E. Iacob and dr. ing. Jelena Popović. Their guidance and constructive feedback have been instrumental in significantly enhancing my research and fostering my academic growth. Special thanks to the Power Electronics & EMC (PE) team at the University of Twente, particularly dr.ir. D.J.G. Moonen (Niek) and the members of the ANRGI project team, for their invaluable collaboration. I am also indebted to Amalia Suryani, M.Sc., her constructive comments and unwavering support have illuminated my path throughout this research pursuit.

I acknowledge that this final project is financially supported by the Moluccan Development Fund, a named fund established by a donor through the Twente University Fund. I also express gratitude to the research participants, experts, and stakeholders whose contributions are acknowledged professionally.

Furthermore, my heartfelt appreciation goes to my family, my husband—Dadan Sukma— and my 7-year-old son—Muhammad Abqori. Despite the months of separation, your patience and unwavering prayers have been a steadfast source of support. To my son, I trust this experience will continue to nurture your growth. I am confident that our lives will flourish further after this transformative journey.

I express my special thanks to my friends—Tifani, Danniar, Dea, Dimas, Hafidz, Michael, my MBIT classmates, and all who stood by me throughout this journey—your encouragement and camaraderie have been memorable. Gratitude is also owed to the nurturing communities of the Indonesian Moslem Association in Enschede (IMEA), the Muslimah community on the UT campus, and the Indonesian Student Association in Enschede (PPI Enschede), where I found support and a profound sense of belonging during both personal and academic growth.

Lastly, I express my sincere gratitude to my one and only God, Allah *subhanahu wata'ala*. Without the grace and blessings of Allah, it would have been impossible to accomplish any of these undertakings. I believe that "*laa hawla walaa quwwata illa billah"* which means *"There is no power nor strength except with Allah"*.

Enschede, 19 January 2024

Table of Contents

List of Figures

List of Tables

List of Abbreviation

AC	Alternating Current
BAPPEDA	Regional Development Agency (BAPPEDA)
BMS	Battery Management System
BPMD	Badan Pemberdayaan Masyarakat Desa (Village Community Empowerment Agency)
BPVP	Balai Pelatihan Vokasi dan Produktivitas (Vocational and Productivity Training Centre)
BUMD	Badan Usaha Milik Daerah (District-owned enterprise)
BUMDES	Badan Usaha Milik Desa (Village-owned Enterprise)
DC	Direct Current
DSRM	Design Science Research Methodology
EA	Enterprise Architecture
ESS	Energy Storage Systems
HH	Households
KPUPR	Kementerian Pekerjaan Umum dan Perumahan Rakyat (The Ministry of Public Works and Housing)
kWp	Kilowatt peak - The scale of measurement for the output of a solar system.
MEMR	Ministry of Energy and Mineral Resources, Republic of Indonesia
NZMATES	New Zealand-Maluku Access to Renewable Energy Support
O&M	Operation and Maintenance
PLN	Perusahaan Listrik Negara (State-owned Electricity Company)
PV	Photovoltaic

CHAPTER 1: INTRODUCTION

1. Introduction

The introduction section serves as an overview, providing insights into the background, problem statement, scope, objectives, research questions, and methodology.

1.1. Background

The Global South, comprising emerging economies and developing nations, often hosts small remote island communities that struggle with affordable and reliable energy access (Asian Development Bank, 2014). Many of these islands are geographically isolated, making integration into centralised energy grids impractical (Simatupang et al., 2021). This isolation exacerbates energy deficits, hindering development, education, healthcare, and overall prosperity (Asia-Pacific Economic Cooperation (APEC) Policy Support Unit, 2018).

Indonesia, a vast archipelago in Southeast Asia comprising around 6000 inhabited islands, faces significant energy access challenges, particularly in its eastern region, where numerous small islands are situated. Due to its decentralised nature geography, there is still the electrification ratio disparity between the western and eastern parts of the country, which underscores the need for targeted electrification efforts (The Ministry of Energy and Mineral Resources, 2017). In response to this challenge, one of the initiatives is the implementation of renewable electricity projects, with a focus on the eastern part of the country in 2023, such as Maluku, North Maluku, Papua, and Nusa Tenggara Timur (NTT) (The Ministry of Energy and Mineral Resources of the Republic of Indonesia, 2023). Renewable energy projects play essential role in this initiative, aligning with the government's commitment to increase its energy shares from renewable sources by 2025 and achieve carbon neutrality by 2060.

Solar energy, as one of the renewable energy sources, is essential in attaining those objectives. Indonesia has a technical potential of 270.8 GW and solar irradiation of 2-5 $KWh/m^2/day$ (The Ministry of Energy and Mineral Resources, 2017a). Although current absorption rates remain low, efforts to maximise usage continue, as shown in **Figure 1**. Photovoltaic (PV) microgrids are one such technology that harnesses solar energy for power generation. PV microgrids utilise solar energy, converting it into electrical energy and storing it in batteries during daylight hours to provide electricity at night (Ramadhani et al., 2019). These microgrids present a promising solution for rural electrification, especially in remote or off-grid areas benefiting from ample year-round sunlight.

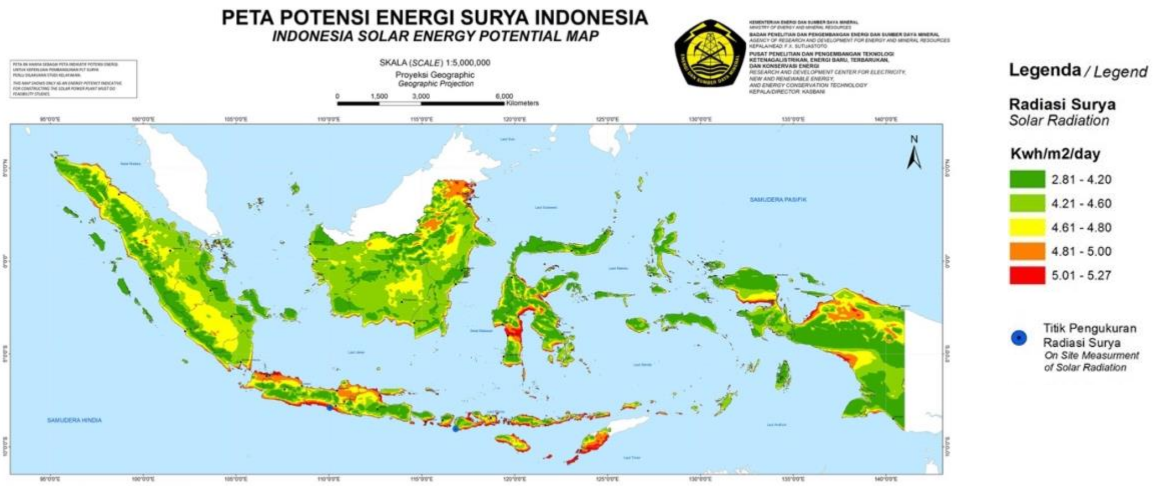

Figure 1: Indonesia Solar Energy Potential Map (Ministry of Energy and Mineral Resources, 2017)

However, despite their potential, the lack of effective Operation & Maintenance (O&M) practices has posed significant challenges to these PV microgrid systems' long-term viability and performance (Simatupang et al., 2021). These are particularly true for PV microgrids, where the infrastructure is handed over to the local community. The beneficiaries are often burdened with the O&M tasks and receive minimal support in managing this sophisticated technology and intricate responsibilities (Derks & Romijn, 2019). Furthermore, the challenge escalates because of the remoteness of these microgrids, where logistics and human capital are limited (Sulaeman et al., 2021).

In the Maluku Province, which comprises numerous small islands and exhibits one of the lowest electrification ratios, smaller grids have been established with financial support from the government and various donors. However, a notable concern is the frequent damage experienced by these microgrids; for instance, 17 out of 22 PV microgrids built between 2012 and 2016 were damaged within an average of one year of operation (Teras Maluku, 2022). Given the persistent energy access issues in the Maluku province, geographical challenges, and the need for sustainable and reliable solutions, this research focuses on designing an O&M strategies for community-based PV microgrids and chooses this region as a case study for supporting their long-term reliability and sustainability.

Sustaining PV microgrids is a collaborative effort involving a spectrum of stakeholders ranging from central and local government to the community, each with designated roles and responsibilities. Notably, the O&M activities encompass many processes, actors, information systems, and technologies. Reference model can effectively encapsulate these complexities in a standardised and graphical representation. The reference model acts as a communication tool, aiding stakeholders in understanding the complexity of O&M activities. It presents a visual representation that helps in conveying ideas, strategies, and plans for specific domains or areas of operation. Based on this preliminary observation, this Thesis aims to develop a reference model of O&M strategies for community-based PV microgrids utilising the Enterprise Architecture (EA) approach.

1.2. Problem Statement & Significance of Study

The necessity to design O&M strategies for community-based PV microgrids within small islands stems from several critical factors. Firstly, the unique and often isolated settings of small islands pose distinct challenges to the practical and sustained management of PV microgrids. The absence of tailored O&M strategies catering to these specific contexts hampers the reliability and longevity of these energy systems.

Secondly, according to the literature review in Chapter 2, it is evident that there is a notable absence of discussions regarding the O&M practices of community-based PV microgrids on small islands, especially in utilising Enterprise Architecture (EA) approach. There is a noticeable gap in understanding the intricate dynamics of O&M activities, the roles of stakeholders, and the challenges encountered in these isolated island settings. Moreover, the application of EA-based reference model to enhance the comprehension of O&M strategies in such contexts remains unexplored.

Finally, this knowledge gap necessitates an investigation into the O&M aspects of community-based PV microgrids on small islands, specifically examining the potential use of EA models to support the sustainability of these energy systems. This initiative provides a structured guideline that aligns stakeholders, clarifies operations, and supports PV microgrid systems' sustainability within these unique island environments.

1.3. Research Questions and Objectives

Based on the previous problem statement and the significance of the study, this study aims to propose an EA-based reference model of O&M strategies for community-based PV microgrids on small islands.

This research encompasses the main research question and sub-questions (SQ), and objectives as follows:

Main research question:

How can we improve O&M practices for community-based PV microgrids by designing a reference model of O&M strategies that supports these microgrids' sustainability?

Sub-research questions:

SQ#1: *What is the state-of-art of O&M for community-based PV microgrids?*

This sub-research question aims to provide a comprehensive understanding of the current state-of-the-art in O&M for community-based PV microgrids. It encompasses delineating the fundamental concept of PV microgrids and investigating existing studies focusing on the O&M aspects of community-based PV microgrids. This involves an in-depth exploration of the activities engaged in O&M and the stakeholders involved in their operation and maintenance.

SQ#2: *What is the contextual overview of the case study location, and how do the actual O&M activities and PV microgrids perform on small islands?*

The objective of this sub-research question is to provide an understanding of the contextual landscape, encompassing the geographical, social, and energy accessibility aspects, specific to the case study location within small islands. This investigation sheds light on the unique circumstances and challenges related to energy access faced by small island communities, allowing for a contextualised overview that forms the foundation for designing appropriate O&M strategies. Another objective of this sub-research question is to assess the practical performance of O&M activities and PV microgrids within the context of small islands. Through this assessment, the research aims to gain insights into the real-world functioning of PV microgrids, enabling a deeper understanding of the challenges and opportunities inherent in their O&M within small island settings.

SQ#3: *How can the reference model of O&M strategies for community-based PV microgrids be specified?*

This research question aims to design a generic reference model of O&M strategies for community-based PV microgrids on small islands based on the literature and theoretical background. Additionally, this research aims to investigate how a strategy can be effectively mapped, visualised, and integrated, particularly by employing the ArchiMate notation.

SQ#4: *How can the reference model of the O&M strategies be operationalised to support community-based PV microgrids in a case study such as Tanimbar Islands District, Indonesia?*

The objective of this sub-question is to operationalise the reference model of O&M strategies based on the generic reference model. This process elaborates on considerations necessary to support the application of O&M reference model for community-based PV microgrids in Tanimbar Islands District, Indonesia, considering the unique challenges and characteristics of this location as a case study.

SQ#5: *What is the feedback from experts on the proposed reference model for O&M strategies in community-based PV microgrids?*

The objective of this sub-question is to validate the relevance of the proposed O&M strategies through expert opinion and insights. Additionally, this feedback will aid in optimising the strategies in the future, ensuring that it aligns with practical needs and expectations.

The research structure for this Thesis is inspired by Savitri, (2023) and shown in **Figure 2**.

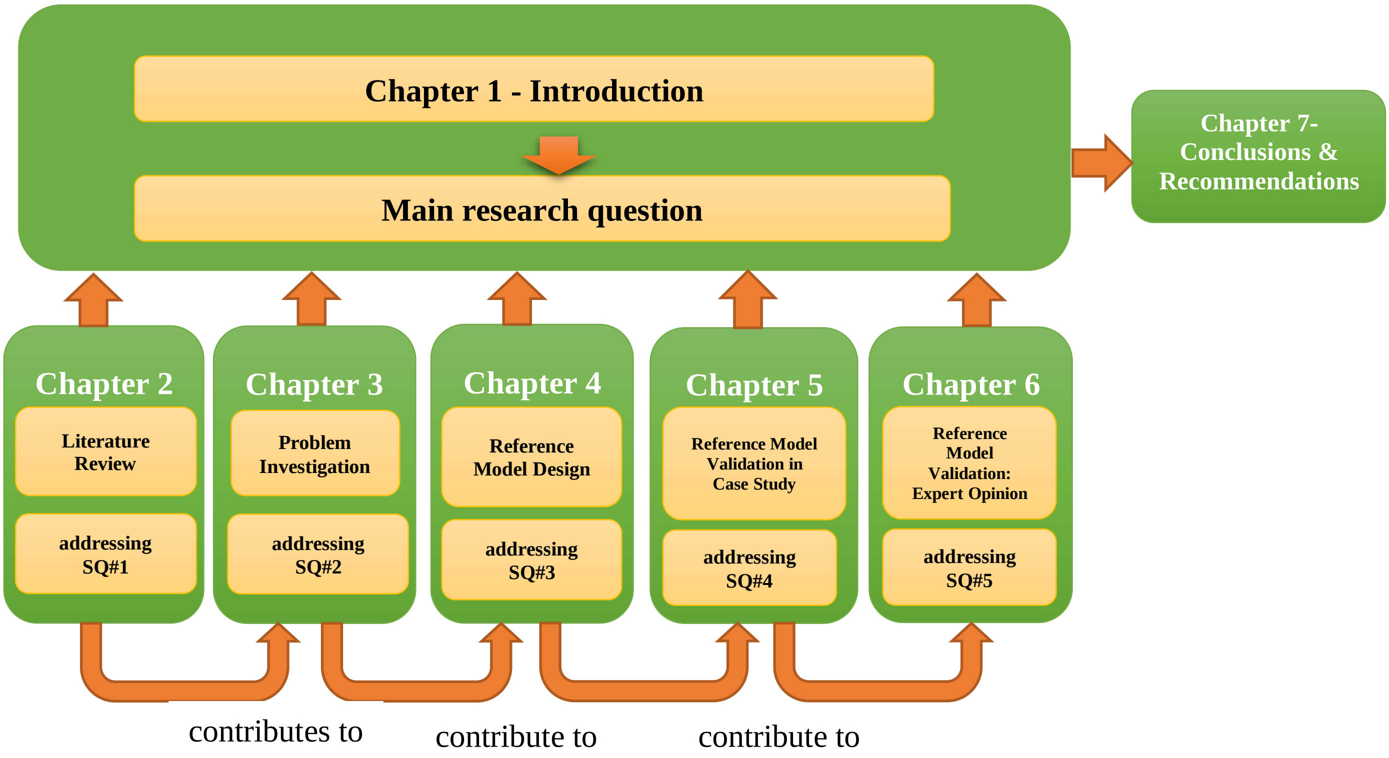

Figure 2: The Thesis Research Structure

1.4. Research Scope

The scope encompasses the domains of reference model and O&M for PV microgrids. This study identified the performance, activities, and challenges associated with O&M for community-based PV microgrids. The examination will focus on off-grid microgrids (not connected to the main grid), ground-mounted microgrids (installed above the land), and centralised microgrids managed by community. The project focuses on developing and designing an EA-based reference model for O&M strategies in community-based PV microgrids on small islands. This reference model will adopt the EA approach and ArchiMate as a recognised standard of modelling language. The reference model will also be validated through a case study and expert opinion.

1.5. Definitions and Research Methodology

To obtain a comprehensive understanding of the topic, it is essential to establish a unified definition consolidated from various studies. The subsequent subsection will elaborate on this process of deriving a precise definition. Moreover, given that the objective involves designing and delivering a reference model, the methodologies guiding this endeavour will be outlined.

Furthermore, the research methodology shaping and organising this study's progression will be detailed in subsequent subsections.

1.5.1. PV Microgrids

Microgrids, characterised by various interpretations, often vary based on context, organisation, or industry using the term. The concept of microgrids is flexible, resulting in diverse definitions that encapsulate different aspects of their features and applications.

Microgrids represent electricity generation and distribution networks that supply the energy demands of local communities, servicing residential, commercial, and industrial consumption (Energy Sector Management Assistance Program (ESMAP), 2022). These grids can function independently (islanded mode) or interconnect with the primary grid (grid-connected mode) (Chowdhury et al., 2009). In the context of rural electrification, microgrids operate as autonomous power distribution networks primarily serving rural and remote communities, relying predominantly on solar energy (Schnitzer et al., 2014).

This research concentrates explicitly on PV microgrids situated on small islands with limited access to electricity. Here, PV microgrids refer to systems solely powered by Photovoltaics (PV) and Energy Storage Systems (ESS), whereas PV hybrids encompass PV systems along with diesel power plants as hybrid options.

Therefore, the primary emphasis of this study is centred on the O&M aspects related to off-grid or standalone PV microgrids, specifically managed by local communities, often termed as community-based PV microgrids. To refine the focus further, this research is dedicated to investigating these microgrids situated on small islands. There are various definitions of a small island. According to the Decree of the Minister of Maritime Affairs and Fisheries, Republic of Indonesia, No. 41/2000 in accordance with Decree of the Minister of Maritime Affairs and Fisheries No. 67/2002, that a small island is defined as an island measuring less than or equal to 10,000 km^2, with a population of less than or equal to 200,000 people. Small islands often face challenges in terms of infrastructure, communication, transportation, access to clean water, irrigation, health, education, and other essential services, hindering their development (Tjahjati (1997) in KontraS (2019)). Therefore, in this study, a small island is characterised by limited population, remoteness, and constrained infrastructure. In summary, the identity of a "small island" in this study is not solely determined by its geographical or population size but also by its economic status.

The terms "mini-grid" and "microgrid" are used interchangeably within this study, as microgrids are occasionally denoted as mini-grids in different contexts. Furthermore, terms like "isolated," "off-grid," "islanded," and "standalone" are often employed interchangeably to describe self-contained microgrids disconnected from the larger utility grid. Likewise, "solar" and "photovoltaic" are also used interchangeably to refer to the generation of electrical energy from sunlight.

1.5.2. Reference Model

According to The Open Group (n.d.-b) on TOGAF 9.1, the definition of "model" is "*a smaller scale, simplified, or abstract representation of the subject matter. The model is used to construct views that address the concerns of particular stakeholders. Models show components and the relationships between them*".

The definition of “reference model” according to OASIS (Organization for the Advancement of Structured Information Standards) is:

“*A reference model is an abstract framework for understanding significant relationships among the entities of some environment, and for the development of consistent standards or specifications supporting that environment. A reference model is based on a small number of unifying concepts and may be used as a basis for education and explaining standards to a non-specialist. A reference model is not directly tied to any standards, technologies or other concrete implementation details, but it does seek to provide a common semantics that can be used unambiguously across and between different implementations*”(OASIS SOA Technical Committee., n.d.).

From definition above, a reference model is an abstract framework that helps in understanding the relationships between entities within a particular environment. It is designed to establish consistent standards or specifications by using fundamental concepts and is often utilised for educational purposes to explain standards to non-experts.

To differentiate between a reference model with other terms, such as reference architecture and concrete architecture, the conceptual framework is illustrated in **Figure 3**, adapted from Candela et al. (2007). Candela et. al. (2007) developed conceptual models that demonstrate the positioning of a reference model in the development of a Digital Library System, as and the figure is inspired by “Reference Model for Service Oriented Architecture 1.0” (OASIS, 2006). According to insights from Candela et. al. (2007), the reference model serves as the nucleus of the development framework and it encompasses inputs such as stakeholder goals, requirements, and motivations, integrating relevant practices and research. The conceptual framework also aligns with this study scope, specifically presents a reference model focusing on the abstract level of O&M strategies within its context.

In brief, a reference model furnishes an abstract framework, a reference architecture presents guidance for designing systems within a specific domain, and concrete architecture signifies the tangible, realised structure of a system through its implementation. In essence, as the level progresses, the level of specificity and detail increases to more precise and realistic specifications. This study will specifically concentrate on the reference model.

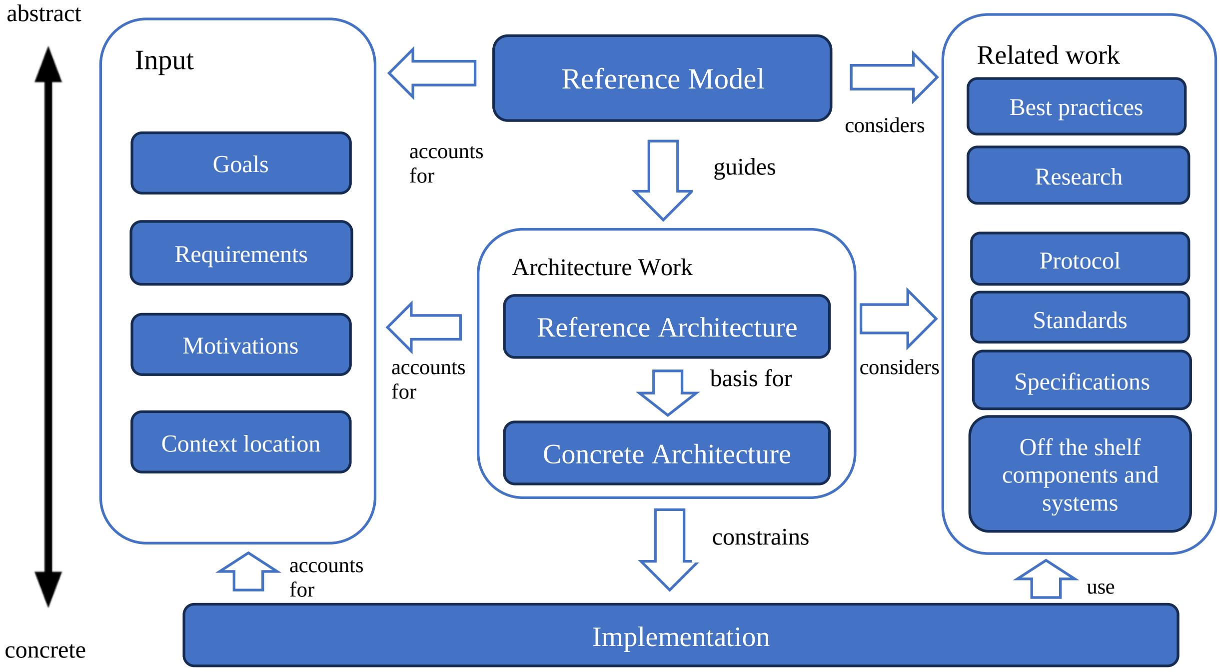

Figure 3: The Reference Model position in a development framework (adapted from Candela et. al., 2007)

1.5.3. Enterprise Architecture and ArchiMate Modelling Language

According to The Open Group (2001), an enterprise could represent a government entity, an entire company, a division within a company, an individual department, or a network of geographically dispersed organisations connected through shared ownership.

The Open Group is an international consortium whose mission is to facilitate the accomplishment of business goals by establishing and utilising technology standards (The Open Group, n.d.). The organisation functions in a technology-neutral and vendor-neutral manner, facilitating the collaboration of a wide array of professionals and experts from different sectors. Enterprise architecture, security, and risk management are the primary areas of emphasis for the Open Group's open, vendor-neutral IT standards and certifications.

While in The Open Group Architecture Framework (TOGAF), "architecture" has two meanings depending upon the context (The Open Group, 2009):

1. *"A formal description of a system, or a detailed plan of the system at component level to guide its implementation"*
2. *"The structure of components, their inter-relationships, and the principles and guidelines governing their design and evolution over time"*

TOGAF, also known as The Open Group Architecture Framework, operates on a broader and more intricate scale, encompassing various domains, phases, and artifacts within the architecture development process. It presents a framework and methodology for Enterprise Architecture (EA). The TOGAF ADM is a comprehensive process for designing, implementing, and managing EA.

The meaning of Enterprise Architecture, according to Lankhorst (2009), is:

> *"A coherent whole of principles, methods, and models that are used in the design and realisation of an enterprise's organisational structure, business processes, information systems, and infrastructure."*

EA translates goals into changes to the company's daily operations. It provides a comprehensive view of the latest and prospective operations, as well as the steps necessary to attain the goals of the company (Lankhorst, 2009).

However, unlike the earlier model-based nature of EA, TOGAF does not inherently facilitate the modelling aspect of EA. To address this limitation, The Open Group introduced the ArchiMate language specifically for enterprise architecture modelling. ArchiMate is the Open Group's open and independent modelling language for enterprise architecture (Lankhorst, 2009). It serves as a means to describe, analyse, and communicate various aspects of an organisation's architecture, offering a graphical representation of different layers and relationships. The fundamental components of the ArchiMate language comprise three primary layers:

1) The business layer, responsible for delivering products and services to external customers. It embodies business processes, functions, and services within the organisation.
2) The application layer which backs the business layer with application services through application components.
3) The technology layer, providing essential infrastructural services necessary for running applications, consisting of system software, computer and communication devices.

Expanding beyond this core language, the complete ArchiMate language incorporates additional layers and concepts, offering comprehensive support for the architecture development process, such as:

4) Motivation concepts, facilitating the modelling of the rationale behind architectural choices.
5) Strategy concepts, focusing on the strategic aspects of the enterprise, including its capabilities, resources, and potential courses of action.
6) Physical concepts, enabling the modelling of the physical realm, encompassing equipment, materials, and transportation.
7) Implementation and migration concepts, supporting project portfolio management, gap analysis, and migration planning.

ArchiMate is a uniform, user-friendly language for modelling and visualising enterprise architectures (Lankhorst, 2009). Its intuitive design makes it accessible to both technical experts and non-technical stakeholders. It provides a visual language for modelling diverse aspects of an enterprise, including business processes, applications, data, and infrastructure.

In summary, TOGAF ADM is a methodology for architecture development, while ArchiMate is a modelling language used within the framework of enterprise architecture. The two standards can be used together and complement each other. However, both remain independent and can be used separately (The Open Group, 2019). The correlation between TOGAF ADM and ArchiMate is shown in **Figure 4**.

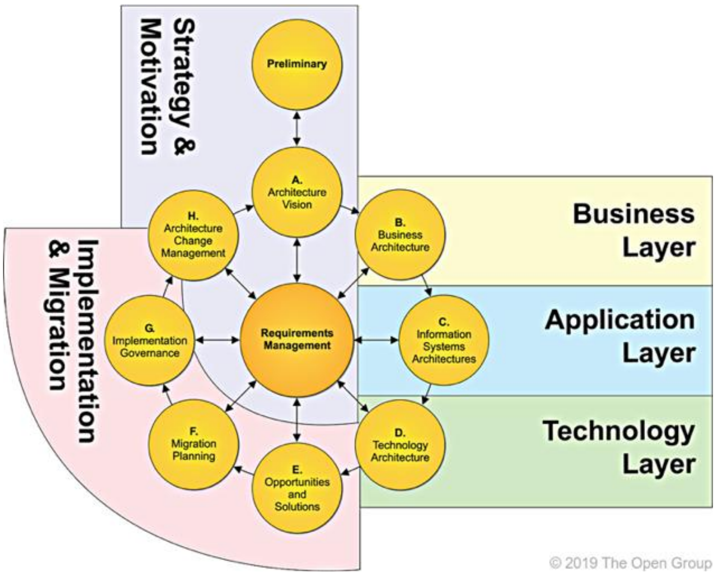

Figure 4 The correlation between the ArchiMate Language and the TOGAF ADM (The Open Group, 2019)

Furthermore, the correlation between EA and reference model is that an EA-based reference model provides a standardised and structured approach to describe and organise various aspects of an organisation's architecture, including its processes, systems, data, technology, and human resources. Meanwhile, ArchiMate is often employed as a means to illustrate and communicate the contents of the EA-based reference model.

The process of developing an EA-based reference model for structuring O&M strategies will be elaborated further in Chapter 4.

1.5.4. Design Science Research Methodology

Design science is "*the design and investigation of artifacts in context*" (Wieringa, 2014). Artifact is something made by people for some objective. Wieringa (2014) summarised design science as the investigation into designing an artifact to interact with a problem context, aiming to enhance that context. Design science is tailored for research endeavours primarily focusing on innovatively creating artifacts, including novel systems, models, processes, or methodologies.

The current design project adheres to the Design Science Research Methodology (DSRM) proposed by Wieringa (2014), which consists of four sequential phases as depicted in **Figure 5**: Problem Identification, Treatment Design, Treatment Validation, and Treatment Implementation. DSRM finds particular relevance in practical domains where the central aim is to develop real-world solutions. While frequently used in information systems, software engineering, and design research, the principles of DSRM can be adapted to diverse research domains.

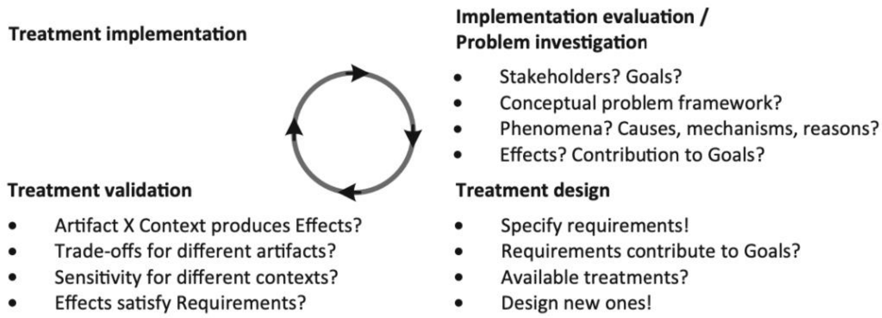

Figure 5: Design science engineering cycle (Wieringa, 2014)

To ascertain the artifact's relevance to the identified problem and context, validation of artifact becomes essential. This entails addressing either an unsolved issue or providing a more effective solution, contributing to new research. The design process involves three key segments: problem investigation, treatment design, and treatment validation, constituting the design cycle. Researchers often iterate these steps several times within a design science research project. Furthermore, the design cycle is just a part of a more extensive cycle known as the engineering cycle, encompassing the application and evaluation of the validated treatment in a real-world setting. Therefore, the scope of the Thesis is delineated as follows:

a. Problem Investigation

DSRM begins with the identification of a real-world problem that requires a solution. This problem is typically a complex and challenging issue within a specific domain. In this Thesis, the researcher observed the phenomena related to community-based PV microgrids on small islands and identifies the key stakeholders involved in O&M. Data collection is conducted to understand the underlying causes and contributing factors. A mixed-method approach is adopted to acquire comprehensive insights into the O&M aspects of community-based PV microgrids on small islands. A thorough understanding of the O&M challenges and opportunities within the context of community-based PV microgrids on small islands will be achieved by employing an observational case study and conducting a mix of these data collection methods. The research methods are as follows:

1. Literature Review (LR): The researcher reviewed academic papers, articles, and relevant publications to gather foundational knowledge, identify gaps in the current research and investigate O&M problem based on existing literature.
2. Site Observations: On-site observations have been carried out to closely examine the performance, conditions, and potential areas of improvement of the PV microgrid systems.
3. Households' Interviews: Interviews were conducted with households to understand households' energy access and the issues they faced in that regard.
4. Stakeholders' Interviews: Interviews were conducted with stakeholders at both provincial and district levels to understand their perspectives and insights regarding O&M strategies for PV microgrids on small islands. Direct interviews have also been conducted with operators working on-site to gain a real-time understanding of the operational conditions and challenges of PV microgrids.

The data collection protocol for this research has received approval from the Ethical Committee of Humanities & Social Sciences (HSS) the University of Twente. The outcomes of the data collection will be detailed further in Chapter 3.

b. Treatment Design

Treatment design encompasses the formulation of proposed solutions and the specification of requirements to address the identified issues.

In energy-related technology, O&M processes are inherently complex, involving numerous activities, systems, and stakeholders (Boruah & Chandel, 2023). In this phase, the design process is inspired by TOGAF ADM. In addition, there is a growing need for graphical visualisation and formalisation to plan, communicate, and manage O&M strategies effectively. In response to this demand, various visual modelling languages have emerged as valuable tools. Among the notable options like Unified Modelling Language (UML) and Business Process Model and Notation (BPMN), ArchiMate stands out as the preferred choice as a tool to design the proposed solution.

ArchiMate, with its abstraction capabilities, offers a powerful means to graphically depict and formalise O&M strategies, promoting optimal performance and transparency in complex O&M processes. In EA, abstraction refers to the process of simplifying complex systems, processes, or structures by focusing on the essential aspects while omitting unnecessary details. Abstraction is a critical concept in EA as it allows architects and stakeholders to understand, communicate, and manage the enterprise's complexity effectively. The process of developing an EA-based reference model for O&M strategies will be elaborated further on Chapter 4.

c. Treatment Validation

Treatment validation involves evaluating the effectiveness of the proposed solutions. The artifact is rigorously evaluated to ensure that it meets the defined objectives and requirements. The relevance of reference model is also evaluated in a case study. Given the focus of the research on proposing a conceptual model for O&M strategy, expert opinion emerges as the most appropriate method assess and validate models. Expert opinion is valuable in the early stages to identify and eliminate flawed designs, contributing significantly to the refinement and improvement of the proposed model (Wieringa, 2014).

The treatment implementation and implementation evaluation are out of the scope of this research due to time constraints.

1.6.Summary of Chapter 1

In summary, Chapter 1 is structured as follows:

Section 1.1 Background introduces the research background and the importance of the study.

Section 1.2 Problem Statement emphasises the existing research gap surrounding the O&M topics of community-based PV microgrids, especially within the unique context of small islands, where Enterprise Architecture (EA) models remain notably underutilised.

Section 1.3 Research Questions and Objectives outlines the key questions and objectives of the study.

Section 1.4 Research Scope provides the boundaries and areas covered in this Thesis.

Section 1.5 Definitions and Research Methodology provides the definition of primary terms that are used in this research and outlines the steps of methodology from Design Science Research Methodology by Wieringa (2014). Several data collection methods have been chosen to explore O&M aspects in community-based PV microgrids comprehensively.

Chapter 2 will present the theoretical background providing a robust foundation for the study.

CHAPTER 2:
THEORETICAL BACKGROUND

2. Theoretical Background

This chapter is to provide an extensive insight into the existing state-of-the-art in PV microgrids. This includes exploring previous research to elucidate the diverse of PV microgrids categorisations, the essential components, the sustainability metrics, and research gap in the context of O&M of PV microgrids.

2.1. Classification of PV Microgrids

In Section 1.5.1, the definition of PV microgrids has already been established. Furthermore, PV microgrids are outlined in the guidebook from the Ministry of Energy and Mineral Resources of Indonesia (2020), classifying them based on three key aspects: operation mode, installation positions, and system design, delineated as follows:

a. Operation mode
   - On-grid PV microgrids (connected to primary grid):
     These systems generate electric power from solar radiation by converting photovoltaic cells, with the electrical system connected to the main electrical grid. Typically, such systems do not include a battery bank. The system diagram for on-grid PV microgrids is shown in **Figure 6**.

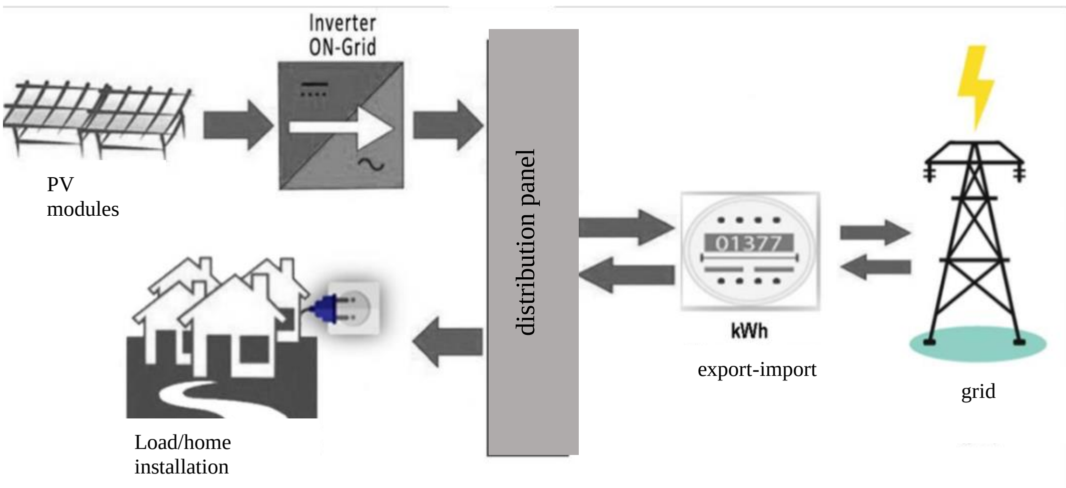

Figure 6: System diagram of on-grid PV microgrids. (Photo by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in Ministry of Energy and Mineral Resources, 2020)

   - Off-grid PV microgrids (not connected to a main grid):
     In this context, they refer to systems not connected to the main electrical grid (standalone). They generate electric power from solar radiation through the conversion of photovoltaic cells and are usually equipped with a battery bank for energy storage.

     There are two primary configurations of off-grid PV mini-grid: direct current (DC)-coupling and alternating current (AC)-coupling systems. In DC-coupling, the PV array connects directly to the DC side of the system, which is the battery. In AC coupling, the connection is made to the AC side of the system with the battery serving as a backup. Excess power, not consumed by the load, is converted back to

DC through an inverter and stored in the battery (Ramadhani et al., 2019). Both configurations share similar components, except for using a charge controller in DC-coupling systems, which is replaced by a grid inverter in AC-coupling systems. See **Figure 7** below for both component functionality, respectively.

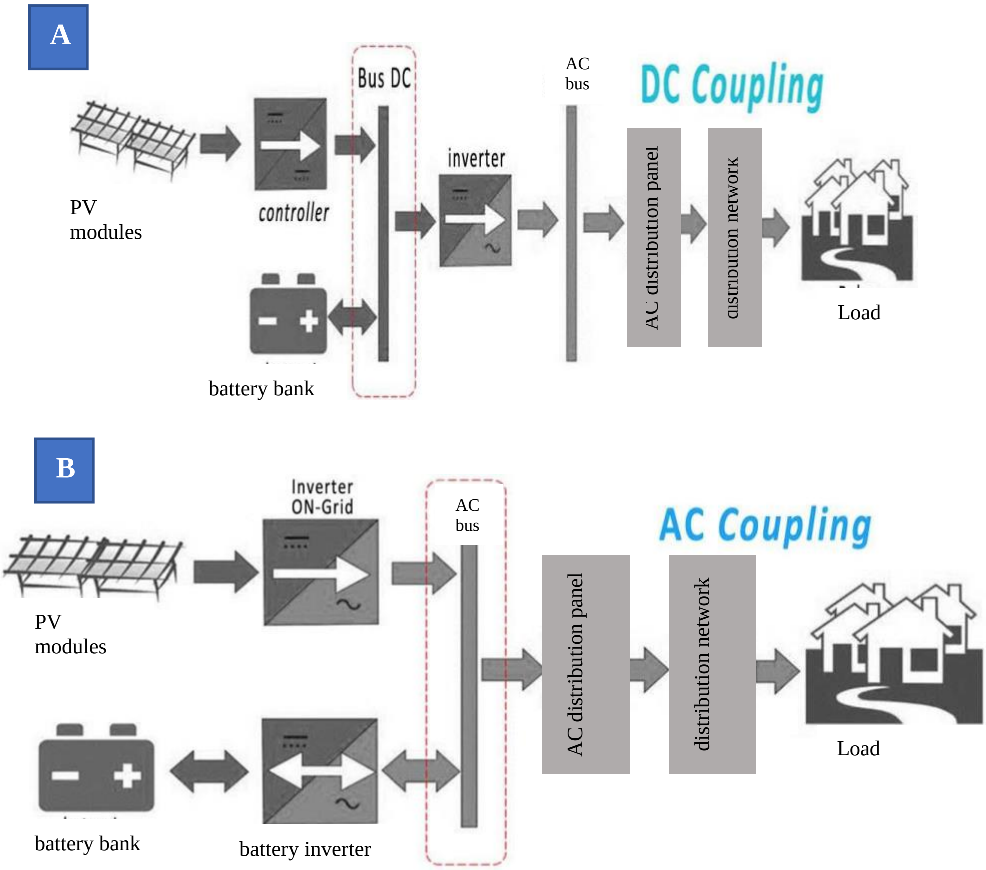

Figure 7: Off-grid PV microgrids with A). DC-coupling systems and B). AC-coupling (Photo by Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in Ministry of Energy and Mineral Resources, 2020)

b. Installation positions

- Rooftop PV microgrids
  This configuration involves the placement of solar panels on the rooftops of various structures, including residential homes, commercial buildings, and other suitable surfaces (**Figure 8**). Rooftop PV microgrids are commonly deployed in urban settings, using available rooftop space effectively.

Figure 8: Rooftop PV microgrids (Ministry of Energy and Mineral Resources, 2020)

- Ground-mounted PV microgrids
  Ground-mounted PV microgrids are characterised by the installation of solar panels on the ground, independent of existing structures (See **Figure 9**). They are often found in open areas with ample land space for solar energy generation.

Figure 9: A ground-mounted PV microgrid (Personal Documentation)

- Floating PV microgrids

  In this setup, solar panels are positioned on the surfaces of bodies of water, such as lakes, reservoirs, or ponds (See **Figure 10**). Floating PV microgrids are advantageous as they harness water surfaces for solar power generation without impacting land usage.

Figure 10: Floating PV microgrids (Ministry of Energy and Mineral Resources, 2020)

c. System design
   - Centralised PV microgrids
     Centralised PV microgrids are PV systems where the photovoltaic modules are centrally located in one area. These systems incorporate a distribution network to deliver electrical power to the intended load efficiently.

   - Distributed PV microgrids
     In contrast, distributed PV microgrids are PV systems where photovoltaic modules are dispersed, typically without the presence of a distribution network. In such configurations, each customer possesses their individual PV system.

In summary, the classification of PV microgrids can be observed in **Figure 11**, and the scope of the Thesis is indicated with a blue colour highlight.

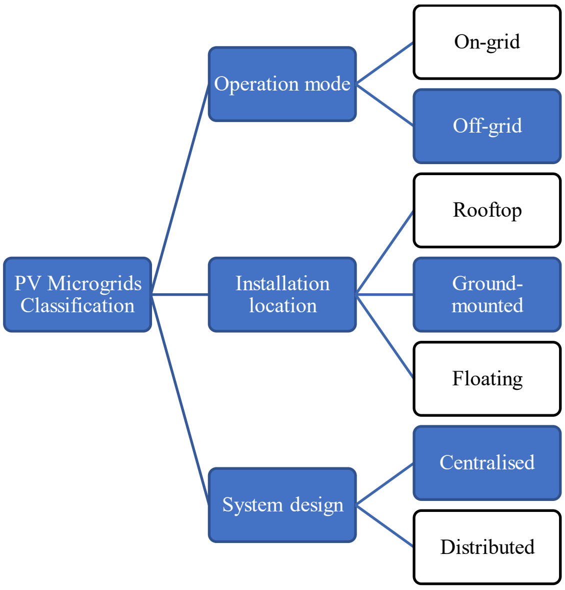

Figure 11: PV microgrids classification and the scope of the Thesis highlighted by blue boxes

2.2. Components of PV Microgrids

Off-grid PV systems usually include the following primary components:

a. PV Modules: These are devices formed by combining multiple solar cells, and they play a pivotal role in converting solar energy into electrical power. Solar modules serve as the primary component of off-grid PV systems. Without these modules, the generation of electrical energy is not possible.

b. Controllers: Controllers are hardware devices responsible for regulating the flow of electric current during battery charging and discharging processes. They are often integrated into a battery terminal box.

c. Inverters: Inverters are electrical equipment designed to convert DC into AC. These devices are found in various types of electronic equipment. Without inverters, the DC generated by solar modules cannot be directly utilised by electronic devices, which commonly rely on AC as their primary power source.

d. Batteries: Batteries are devices comprising one or more cells that convert chemical energy into electrical energy. They function as an energy storage system. In the absence of a battery, solar energy can only be utilised when there is sunlight, as there is no mechanism for energy storage.

In addition to these core components, there are several supporting elements, which can be found in **Figure 12**.

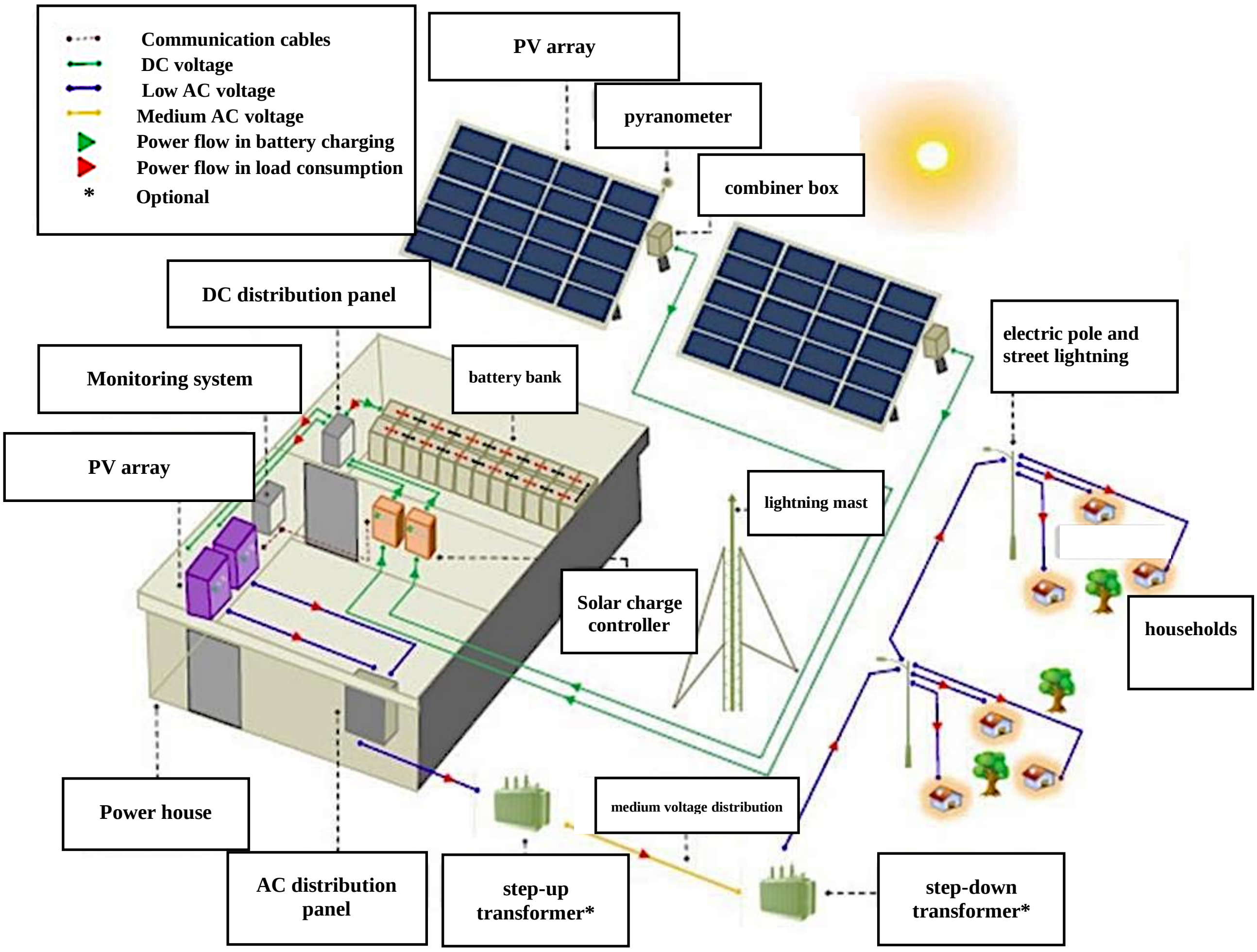

Figure 12: Block diagram of PV microgrid system.
(Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH in Ministry of Energy and Mineral Resources (2020))

2.3. Operation and Maintenance (O&M) Activities

The development of PV microgrids follows a series of stages: Inception (pre-construction) and design, construction, O&M, and decommission (Wijeratne et al., 2019) as shown in **Figure 13**. The life cycle stages of a Solar PV project, including O&M, entail the exchange of technical and economic information and knowledge within intricate networks of stakeholders. These stages involve numerous interactions among various specialists and professionals (Wijeratne et al., 2019). Within this progression, O&M constitutes an integral part of the microgrid's development stages. In addition, O&M system is crucial for maintaining the high technical and economic performance of the PV system throughout its lifespan (Solar Power Europe O&M Task Force (2018) in IRENA (2019)). The O&M phase, often spanning 20–35 years, constitutes the lengthiest period in a PV project's lifecycle. Consequently, ensuring the quality of O&M services becomes critical to avert potential risks (IRENA, 2019).

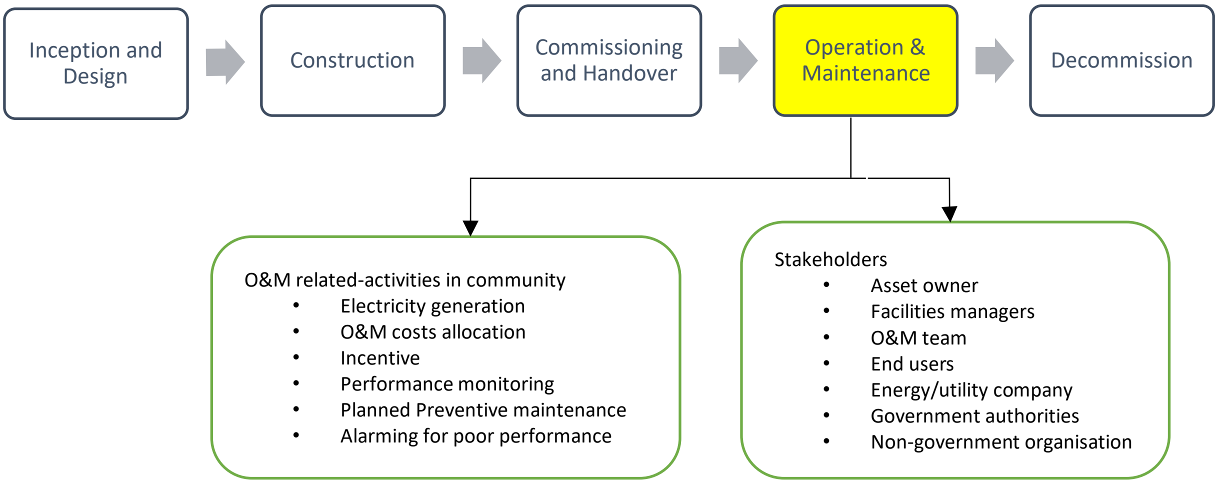

Figure 13: O&M as an integral part of PV microgrids development stages (Wijeratne et al., 2019).

On O&M stage, it is divided into two parts: operation and maintenance as follows.

a. Operation

Operation of system is defined as "the combination of all technical and administrative actions intended to enable an item to perform a required function" (British Standards Institution BSI (2010) in Keisang et al., (2021)). Referring to guidebook of standalone PV microgrids (Ministry of Energy and Mineral Resources, 2017b), the routine operation activities include activating off-grid PV microgrids, monitoring battery charge levels in the morning and evening. In emergency situation, ensuring the proper shutdown of off-grid PV microgrids and reactivating by ensuring safety by comprehending electrical hazards and using personal protective equipment. It includes an initial assessment by referencing wiring diagrams and inspecting grounding, PV arrays, inverters, and batteries, followed by voltage output confirmation. Furthermore, the functioning of solar PV microgrids also involves essential procedures such as monitoring (remote or onsite), supervision and control, and planning and coordinating maintenance strategies (Keisang et al., 2021). These procedures cooperate to maintain the system effectively, ensure consistent power supply, enhance system efficiency, and reduce maintenance expenses.

b. Maintenance Strategies

Maintenance strategies for PV microgrids can be broadly categorised into three distinct approaches: corrective maintenance, preventive maintenance, and predictive maintenance (Deli and Noel, 2020; and Epri, 2010; as cited in Keisang et al., 2021). These approaches play a vital role in ensuring the reliability, performance, and longevity of PV microgrid systems.

1) Corrective Maintenance
   In response to anomalies or failures detected through operational monitoring, corrective maintenance intervenes. This approach is also known as reactive maintenance and it involves prompt repairs and interventions by skilled technicians to address identified issues. During corrective maintenance, malfunctions are analysed, faulty components

replaced, and normal operation restored, minimising downtime and ensuring consistent energy provision.

2) Preventive Maintenance
Taking a proactive approach, preventive maintenance involves planned inspections, routine servicing, and component replacements at predefined intervals. Adhering to a predetermined maintenance schedule allows early detection and resolution of potential problems, leading to improved reliability and prolonged system longevity.

3) Predictive Maintenance
Leveraging advanced data analytics and predictive algorithms, predictive maintenance offers a forward-looking approach to PV microgrid upkeep. By analysing historical performance data and identifying patterns, potential equipment failures can be anticipated. This foresight enables strategic planning for maintenance activities, minimising unplanned downtime and maximising operational efficiency.

Given that O&M is a deeply technical facet of solar PV technology, its execution is heavily contingent upon factors like system size, precise design, and contextual location (Keisang et al., 2021). These intricacies result in differing approaches to maintenance protocols across diverse locations and installations. Consequently, the establishment of a maintenance management framework becomes crucial to promptly apply corrective measures as required, thereby preventing disruptions and prolonging the effective lifespan of the entire system. The pivotal elements for formulating a comprehensive O&M are depicted in **Figure 14**.

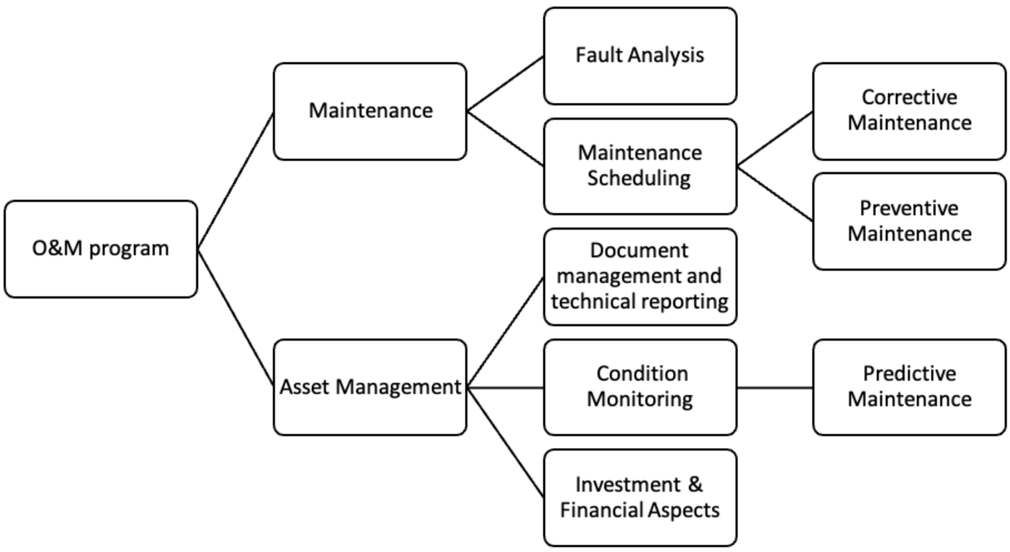

Figure 14: Diagram outlining the fundamental elements of a maintenance program (Eltawil and Zhao (2010) & Hirsch et al., (2018) in Keisang et al., 2021)

2.4. Stakeholders in O&M Activities

Stakeholders involved in O&M for community-based PV microgrids play crucial roles in ensuring the effective and sustainable functioning of these energy systems. These stakeholders encompass a diverse group of individuals, organisations, and entities with vested interests and responsibilities in the microgrid's operation and maintenance. The relevant stakeholders in O&M as identified in the literature are presented in Table 1 provided here.

Table 1 The relevant stakeholders in O&M

No.	Stakeholders	Role(s)
1.	Mini/microgrids owner	To provide operational and maintenance services
2.	Mini/microgrid operator	To be responsible for the daily management, maintenance, and overall operation of the system.
3.	Local Technicians/Engineers	• To ensure the system's proper functioning • To Promptly address any technical challenges that arise • Upgrading and repairing an improper installation.
4.	Government and Regulatory Authorities	• To set policies, standards, and regulations that govern the installation, operation, and maintenance of PV microgrids. • To provide incentive relates to O&M activities • To monitor and evaluate the government-initiated microgrid programs
5.	Contractor	In a third-party scheme, contractor has roles in O&M to do: • Preventive maintenance • Regular Monitoring and Inspection • Timely Repairs and Problem Resolution • Data Collection and Reporting
6.	Equipment Supplier	• To supply PV modules, inverters, batteries, and other equipment used in the microgrid are stakeholders with a vested interest in the system's reliable operation. • To provide manual books related to O&M of equipments in the local language, especially in certain regions, as mandated by the regulations.
7.	Non-governmental organisations (NGOs) and Development Organisations	To provide technical assistance, capacity-building programs, and leveraging financial support to enhance O&M practices and promote sustainability.
8.	Community members	Community members can have several positions as follow. • Community committee ensure user access and collected payments • Users/community members are involved in O&M activities and ensuring the microgrid meets the community's energy needs.

References: (Canziani & Melgarejo, 2018; Canziani et al., 2021; Derks & Romijn, 2019; Saire et al., 2021; Schnitzer et al., 2014; Xu et al., 2016; Ramadhani et al., 2019)

Here is an explanation of the key stakeholders involved in O&M for community-based PV microgrids, but this may differ for each community:

1. Microgrids owner
   The ownership of community-based microgrids can vary depending on the specific project and its context. For instance, in many cases, the local community that benefits from the microgrid may collectively own and manage it. This ownership model encourages community engagement. However, in some regions, government entities or established utility companies may own and operate community-based microgrids. Sometimes, community-based microgrids are owned through partnerships between local governments and private companies or NGOs, this model is known as Public-Private Partnership.

2. Microgrids operator
   This stakeholder oversees the technical aspects, ensures energy delivery, and manages routine O&M activities. They collaborate with other stakeholders, such as local technicians and community members, to address maintenance issues, monitor system performance, and implement improvements.

3. Technician/engineer
   Local technicians or maintenance teams are essential stakeholders with specialised technical expertise in handling PV systems. They have role in upgrading and repairing installations, particularly when they are hired or have a contractual agreement to do so. In that case, technicians ensure the system's proper functioning and promptly address any technical challenges that arise.

4. Government and Regulatory Authorities
   Government and regulatory authorities are important stakeholders who set policies, standards, and regulations related to the installation, operation, and maintenance of PV microgrids. They play a role in issuing licenses, incentive policy, and ensuring compliance with safety and environmental regulations. The study by Derks & Romijn (2019) delves into the involvement of central and local governments in government-initiated microgrid programs in Indonesia. Although there is a budget allocated for monitoring and evaluation, the challenges arise in defining clear responsibilities for funding O&M activities.

5. Contractor
   In case of using a third party for O&M, government agencies often utilise a competitive bidding process to select contractors for constructing and sometimes also maintaining microgrids (Schnitzer et al., 2014). Third-party contractor for O&M can do regular inspections, monitoring, and preventive maintenance. In addition, in the Indonesian context, following commissioning, there is a specified warranty period outlined in the contract, during which the contractor maintains responsibility for the O&M of the system.

6. Equipment Supplier
   Suppliers of PV modules, inverters, batteries, and other equipment used in the microgrid are stakeholders with a vested interest in the system's reliable operation. Collaboration with equipment suppliers ensures access to genuine spare parts, technical support, and warranty services, thus contributing to the longevity and performance of the microgrids. In the case of Indonesia, as per the regulations in the Electronic Procurement Service (LPSE), suppliers are required to furnish manual books related to O&M of the equipment in the Indonesian language.

7. Community members
   The local community is a fundamental stakeholder as they are the primary beneficiaries and users of the electricity provided by the PV microgrid. Community members play an important role in supporting and participating in O&M activities, especially in community-based microgrids where they often have direct ownership and decision-making authority. Their engagement is critical for reporting issues and ensuring the microgrid meets the community's energy needs.

8. NGOs and Development Organisations
   NGOs and development organisations often support the implementation and maintenance of community-based PV microgrids. They may provide technical assistance, capacity-building programs, and financial support to enhance O&M practices and promote sustainability (Ubilla et al., 2014). Some examples of organisations in Indonesia active in the renewable energy sector include Institute for Essential Services Reform (IESR) and Masyarakat Energi Terbarukan Indonesia (METI). Additionally, Mercy Corps Indonesia collaborates on development assistance programs such as the New Zealand – Maluku Access to Renewable Energy Support (NZMATES) program, funded by the New Zealand Ministry of Foreign Affairs and Trade (MFAT) (Mercy Corps Indonesia, 2021). The implementation of the NZMATES program is undertaken by New Zealand-based renewable energy company Infratec Ltd, which partners with Mercy Corps Indonesia for the joint execution of this five-year initiative.

2.5. Sustainable Isolated Microgrids

A sustainable isolated microgrid is characterised by its ability to maintain a harmonious balance between energy production and consumption while minimising any adverse environmental impacts. Furthermore, its operation should not hinder the economic and social activities of the community in which it is deployed (Rahmann et al., 2016). This definition encompasses four essential criteria:

1. Technological Sustainability: The microgrid project should be feasible using existing technologies, ensuring the reliable operation of critical components.
2. Economic Sustainability: Implementation of the microgrid project should be carried out to promotes efficient energy use, enabling both the community and the microgrid itself to remain economically viable over the long period.
3. Social Sustainability: The microgrid project must gain acceptance and support from the local community, fostering its social development and active participation.
4. Environmental Sustainability: The microgrid project should yield more significant environmental benefits compared to traditional electrification alternatives, such as diesel-based systems, thereby contributing to a more environmentally friendly solution.

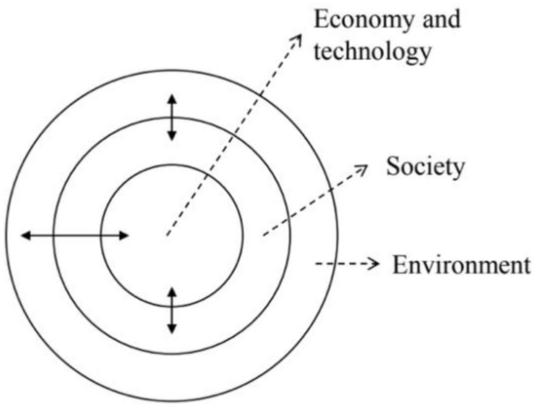

Figure 15 Approach to Sustainability Factors (Rahmann et al., 2016)

According to Rahmann et al., (2016), economic and technological elements are intertwined with society, as they are contained within the society circle (**Figure 15**). Furthermore, the dynamics of the environment are influenced by economic, technological, and societal factors.

2.6. Technology Recommendation for O&M

The technology recommendation for PV microgrids includes several advanced microgrid technologies suggested to enhance efficiency, reliability, and autonomous operation, ensuring sustainable energy supply in PV microgrids. By incorporating these cutting-edge solutions, the challenges associated with O&M can be effectively mitigated, supporting the long-term viability of photovoltaic microgrid systems. However, the application of these technologies is contingent upon factors such as PV microgrid system design, size, and contextual location.

The summary of technology recommendation, its function and application are presented in **Table 2**.

Table 2 Technology Recommendation for O&M

No.	Technology	Function	Application	References
1.	Battery Management System	Battery state-of-health (SoH) estimation	Operation and Maintenance	(Abbas et al., 2016; Mumtaz & Bayram, 2017; Girbau-Llistuella et al., 2015)
2.	PV inverters technology (micro inverters and direct current (DC) optimizers)	Maximizing energy yield	Operation	(Raya-Armenta et al., 2021; Simatupang et al., 2021)
3.	Online Monitoring System & Fault Analysis	• Performance monitoring • Remote control	Operation and Preventive Maintenance	(Rao et al., 2016; Sun et al., 2019)
4.	Drone for Intelligent Monitoring	Broad surveillance and monitoring capabilities	Operation and Preventive Maintenance	(IRENA, 2019; Simatupang et al., 2021)
5.	IoT techniques	• Real-time monitoring • Fault detection & Diagnostics • Data Storage & Historical Analysis	Operation, Remote Control, Preventive Maintenance	(Aljafari et al., 2022)
6.	Artificial Intelligence Applications	• Predictive maintenance • Energy Forecasting • Data Analytics	Predictive Maintenance	(Saire et al., 2021; Talaat et al., 2023)

Below is a brief explanation for each technology mentioned:

a. Battery Management System (BMS)

Energy storage devices are integral in effectively managing intermittent renewable energy sources (Mumtaz & Bayram, 2017), particularly batteries. Batteries play a pivotal role within microgrids. Beyond panel degradation, faulty batteries are a primary contributor to the premature failure of microgrid systems (Sulaeman et al., 2021). In both solar PV and wind energy configurations, battery storage systems are frequently incorporated to balance power generation and reserve electricity for consumption during periods of peak demand. In a study by Abbas et al., 2016 , an optimal capacity size and BMS operation for a hypothetical scenario in a remote microgrid were proposed by closely monitoring individual battery cells and considering the load mode extensively. In contrast, a conventional BMS focuses on task scheduling based on the overall discharge traits of a battery pack and does not factor in the specific load mode the battery serves. However, a smart BMS ensures optimal battery usage while also managing mode-switching challenges.

Furthermore, the battery's capacity diminishes over time and as it undergoes cycles. When the battery nears its cycle limit, it necessitates replacement with a new one. The cell that ages the most in the battery nearing its cycle limit triggers the requirement for replacement. Therefore, detecting the most aged cell and its operation within the battery signifies the conclusion of battery life, as proposed by Abbas et al. (2016).

While for the energy management system, Girbau-Llistuella et al. (2015) suggested a method to optimize the cost of energy procurement throughout the day while also regulating the status of batteries and determining the set point for photovoltaic generators.

b. PV inverters technology (micro inverters and direct current (DC) optimizers)

Upgrading to advanced PV inverter technology, including micro inverters and DC optimizers, can improve the reliability and performance of photovoltaic systems. These technologies enable real-time monitoring and optimization of solar energy production, helping to identify and address issues promptly (Simatupang et al., 2021).

Regarding the optimization of energy management in islanded microgrids, it revolves around six fundamental aspects: framework, temporal considerations, strategies for handling uncertainty, optimization techniques, definition of objective functions, and imposition of constraints (Raya-Armenta et al., 2021).

c. Online remote monitoring & Fault Analysis

In recent times, there has been a gradual integration of analytical control in small-scale PV systems. The significance of monitoring has been underscored as a crucial factor contributing to the success of rural electrification initiatives. This emphasis on monitoring contributes to prolonging the system's lifespan, mitigating PV system malfunctions, and bolstering users' trust in the system. Given the challenging conditions of the island's environment and its remote location, there is a need to establish an island microgrid monitoring system that is highly efficient and reliable, enabling remote monitoring and operation of microgrids (Sun et al., 2019).

Through data sourced from monitoring devices, the preventive maintenance approach with a reliability-centred perspective can be implemented. Rao et al. (2016) proposed a strategy for fault diagnosis in a solar microgrid with battery backup. The authors conduct an extensive analysis of potential faults in a PV microgrid, identifies crucial diagnostic parameters, and advocates for the use of a minimal set of sensors and data acquisition for effective Reliability Centred Maintenance in a PV-based microgrid. It is demonstrated that four sensors—measuring voltage, current, environmental conditions irradiance and temperature—are adequate for detecting, diagnosing, and categorising faults.

d. Intelligent Monitoring using Drone

Drones have become increasingly applicable in the solar industry due to their broad surveillance and monitoring capabilities, enabling long-range inspection and effortless control than human inspections (IRENA, 2019; Simatupang et al., 2021). Further enhancing their functionality, drones efficiently gather vital data through sensory elements and swiftly transmit this information to the cloud for quicker and more accurate analysis (Kumar et al., 2018 in (IRENA, 2019)).

e. **IoT techniques**

In rural areas with internet connectivity, leveraging Internet of Things (IoT) techniques can revolutionize O&M in microgrids. According to Aljafari et al. (2022),IoT technology plays a crucial role in facilitating the instant exchange of data gathered by PV sensors. It also enables remote control of solar unit functions for diagnosing failures and faults, as well as predicting and preventing maintenance issues. Moreover, IoT infrastructure can support real-time communication essential for synchronizing unpredictable energy storage systems and solar energy production at a grid scale. The uncertainties primarily revolve around assessing solar resources and the performance of PV systems.

f. Artificial Intelligence Applications

AI-based solutions can play a pivotal role in O&M by analysing vast amounts of data to detect anomalies and predict system failures. Machine learning algorithms can continuously improve their accuracy in identifying maintenance needs (predictive maintenance), helping microgrid operators make informed decisions and optimize O&M strategies. A case study in Peru, a data science methodology is employed to analyse energy resource data, including solar irradiance, wind speed, and energy demand (Saire et al., 2021).

The study conducted by Talaat et al. (2023) focuses on investigating the uses of artificial intelligence (AI) in the integration and management of hybrid renewable energy sources within microgrids. This research delves into the innovative ways AI can be leveraged to enhance the efficiency, reliability, and sustainability of microgrid systems that incorporate various renewable energy sources such as solar, wind, and battery storage.

To sum up, the mentioned technologies have a substantial impact on the functionality and performance of PV microgrids and become promising solutions in addressing various O&M challenges. Furthermore, advancements in technology such as IoT and AI play a vital role in enhancing preventive and predictive maintenance strategies for these microgrids. These technological aspects collectively contribute to the efficiency and reliability of PV microgrid operations. However, it's important to consider specific requirements based on the unique situation and geographical conditions of each microgrid.

2.7. Previous Research on O&M Models and ArchiMate in Microgrids Context

Through the conducted search, several studies about O&M models and ArchiMate within the context of microgrids were identified. In total, four relevant papers were discovered.

One of the identified papers by Ubilla et al. (2014) proposed O&M business model based on the community's characteristics as summarised below.

a. Cooperative structure

Ubilla et al. (2014) proposed that in cooperative structure model, a cooperative manages the microgrid's administration, decision-making, and daily operations. The community (represented by the cooperative) is responsible for overseeing the financial resources needed for microgrid O&M. To fund O&M, a fee-for-service collection mechanism is suggested, with the tariff being established through community consultation. It's crucial that the community comprehends the significance of their contributions, their role in system management, and that the fees are both meaningful and affordable. Ubilla et al. (2014) proposed four alternative charging programs for consideration.

1) "Charging by consumption": Users pay based on their actual electricity consumption, with a fixed cost per kilowatt-hour (Pay-as-you-go).

2) "Fixed Fee": Users pay a fixed fee at regular intervals, regardless of their electricity consumption. (Flat-rate tariff).

3) "Differentiated consumption fee": Users are charged different rates for their electricity consumption, depending on their usage levels (Tiered consumption fee).

4) "Fee per quote": Users are assigned a set electricity consumption quota at a certain rate, and consumption exceeding this quota incurs a higher charge (Quota-based fee).

b. Hybrid structure

The hybrid model involves community input in energy system decisions, with a public/private entity handling O&M in exchange for a fee. The presence of economic incentives is crucial in case of private party involvement. This model is suitable in cases where the community lacks project experience and weak social cohesion. Then, an additional administrative structure may be established.

Additional services for private parties:

1) Commercial incentives: In commercial incentives, governments may provide tax breaks and import duty exemptions for companies, often during a grace period of 2 to 3 years. These incentives can also include tax-free repatriation of earnings and contracts for state energy programs. Private companies, in particular, find these incentives attractive. Tendering processes can favour companies willing to finance a significant portion of the investment, with the remaining costs covered by public sector electrification funds.

2) Service payment: In this scenario, the company overseeing the O&M charges a fee. This fee, distinct from what a community cooperative might charge, incorporates an added profit for the company and covers the O&M expenses.

This paper has limitations; it does not discuss the O&M execution models specifically for PV microgrids. Meanwhile, a paper by (Keisang et al., 2021) filled the gaps and delved into the review of O&M execution models. The O&M execution models encompass the utilisation of either a third-party O&M company or an in-house (internal) team. The third-party model involves employing an external entity for O&M activities. In contrast, the in-house team model signifies that the responsibility for ensuring optimal system performance lies with the institution that owns or hosts the system. **Table 3** below delineates the differences in the implementation models of O&M conducted by an internal team versus a third-party O&M company.

Table 3 O&M Execution Model (Keisang et al., 2021)

In-house	Third-party
Description	
O&M's responsibility for maintaining optimal performance lies with the institution that owns or hosts the system.	• Known as outsourcing to an external contractor • A contractor is responsible for meeting the client's requirements for an uninterrupted and reliable electricity supply. • The contractor handles all maintenance and system upkeep tasks, including managing warranty claims when necessary.
Advantages	
• Enhanced personnel and equipment monitoring • Elevated quality control • Utilisation of existing utility assets • Employee training, • Proficient control of the solar PV O&M process is achieved.	• Reduced initial expenses • Increased flexibility • Minimised initial risks • Decreased demand on the utility labour force is experienced.
Disadvantages	
• Greater initial expenditures • Elevated risk levels • the need for workforce knowledge and resource ramp-up are encountered.	• Absence of engagement results in no transfer of knowledge or skills • Potentially leading to inflated costs and dependence on external contractors.

From **Table 3**, it is clear that each option has its own advantages and disadvantages, requiring careful decision-making based on factors like risk, costs, and expertise. For organisations with existing O&M resources, in-house management can be beneficial. Outsourcing may cut costs but could lead to quality issues and a lack of transparency in system monitoring. Additionally, installer-related challenges may arise if they go out of business, impacting warranty claims and post-installation service.

The mentioned paper has certain limitations. It does not address the intricacies of strategy design and economic sustainability for O&M specifically in a community-based context on small islands. Moreover, the paper does not provide an exhaustive discussion regarding the roles of stakeholders in the realm of O&M.

The third paper authored by Simatupang et al., (2021) examines the challenges encountered across the planning, design, and O&M phases, as well as the technological perspectives for addressing O&M issues in PV microgrids within Maluku province and North Maluku Province (MMU), Indonesia, which comprises small islands. The paper offers an initial insight into the sustainability challenges on these small islands. Nevertheless, it does not provide a detailed approach to designing optimal O&M strategies for small islands. In addition, the study, conducted in 2021, could be enhanced with an updated or renewed examination.

Furthermore, in light of implementation of ArchiMate in the context of microgrids, Valja et al. (2014) proposed extended ArchiMate metamodel to analyse microgrid architectures. The extended ArchiMate metamodel is instrumental in constructing the analysis model, primarily employing behaviour and active structure elements. However, the utilisation of ArchiMate in the realm of microgrids, especially concerning O&M, has not been addressed within existing literature. Hence, research utilising ArchiMate in the context of microgrids holds promise not only for microgrid operation and maintenance but also for advancing theoretical knowledge in the field of EA.

In summary, the execution models for O&M can generally be categorised into two types: those carried out by a third-party entity or an internal team within the organisation. When it comes to O&M business models within a community setting, they often adopt either a cooperative structure or a hybrid structure. The objective is to establish a sustainable O&M approach that best fits the unique needs and circumstances of the community-based PV microgrid.

In identifying research gaps, it is evident that there is a notable absence of discussions regarding the O&M aspects concerning community-based PV microgrids in the specific context of small islands, particularly utilising EA models. The summary of the gap and proposed research for Master Thesis can be seen in Table 4.

Table 4 Research Gap Summary and Thesis Research Scope

No.	Paper	Summary	Research Method	Research Gaps	Thesis Research Scope
1.	(Ubilla et al., 2014)	The paper explores smart microgrids as an answer for rural electrification by guaranteeing sustainable longevity via cadastre and business approaches.	Case study in Chile	This paper has limitations, it does not discuss the O&M execution models specifically for small islands.	To bridge this research gap, this Master's Thesis provides analysis of O&M activities. Thoroughly analyse O&M activities encompassing both existing practices and ideal conditions, particularly tailored to the unique context of small islands using EA models.
2.	(Keisang et al., 2021)	The paper provides a comprehensive review of both O&M activities, as well as the various models associated with solar PV microgrids	Literature review	It does not address the intricacies of strategy design for O&M specifically in a community-based context on small islands. Moreover, the paper does not provide an exhaustive discussion regarding the roles of stakeholders in the realm of O&M.	To bridge this research gap, the proposed O&M models in this Master's Thesis presents stakeholder engagement assessment matrix and maps stakeholders' role in EA models.
3.	(Simatupang et al., 2021)	The paper delves into challenges experienced during the planning, design, and O&M stages and the technology outlook to solve O&M problem of PV microgrids in Maluku province and North Maluku Province, Indonesia.	Case study in Indonesia	The paper does not delve into the optimal O&M design for small islands. This study was conducted in 2021 and would benefit from an update or a renewal.	To address this research gap, various data collection methods has been conducted in this Thesis. They involve interviews with stakeholders from local governments, interviewing operators to understand their energy usage, and assessing the actual performance of PV microgrids through on-site observations on small islands. Furthermore, the research focuses on O&M model design for small islands by leveraging a case study approach.
4.	(Valja et al., 2014)	This paper demonstrates the integration of enterprise architecture modelling into the domain of embedded systems, using microgrids as an example. It showcases the design of a control architecture for microgrids utilising ArchiMate.	Literature review, Analysis & Design by ArchiMate	The utilisation of ArchiMate was limited to microgrids components. The O&M design of microgrids has not been addressed in the paper.	To close this research gap, the Thesis proposes a reference model of O&M strategies utilising an EA modelling language such as ArchiMate.

2.8. Summary of Chapter 2

Chapter 2 serves to address sub questions #1 and #2, regarding the current state-of-the-art of PV microgrids which consisted of 7 (seven) sections as follows:

Section 2.1: Classification of PV microgrids distinguishes and categorises the different types of PV microgrids, highlighting their distinct characteristics and variations in design, deployment, and operational functionality.

Section 2.2: Components of PV Microgrids explores the essential components forming PV microgrid systems, providing an insight into the crucial elements contributing to their operations and functionality.

Section 2.3: Operation and Maintenance (O&M) activities investigates the diverse tasks and procedures involved in the upkeep and management of PV microgrid systems.

Section 2.4: Stakeholders in O&M Activities identifies and elaborates on the various parties involved in operating and maintaining PV microgrids, elucidating their roles and contributions within these systems.

Section 2.5: Sustainable Isolated Microgrids discusses sustainability concepts within isolated microgrids, focusing on environmental, social, and economic facets, emphasising the importance of sustainability for long-term viability.

Section 2.6: Technology Recommendation for O&M focuses on providing recommendations regarding technology to optimize O&M practices within the studied PV microgrids. It suggests specific technological solutions or tools that could enhance the efficiency, reliability, or ease of managing and maintaining these systems.

Section 2.7: Previous Research on O&M Models and EA in Microgrids Context provides an overview of present research concerning O&M models in microgrids, particularly addressing the application and pertinence of ArchiMate in this context, highlighting current knowledge and research gaps in this field.

Chapter 3 will delve into the problem investigation concerning O&M within the context of PV microgrids. This section will encompass an in-depth analysis, combining insights from previous studies in the field with observations drawn from a newly conducted observational case study, conducted by the researcher.

CHAPTER 3:

PROBLEM INVESTIGATION

3. Problem Investigation

As per Wieringa (2014), problem investigation entails examining real-world issues in preparation for designing a solution for the problem. Its purpose is to learn stakeholder objectives and comprehend the problem that requires addressing (**Figure 16**). Besides referencing problem investigation from existing literature, another research method for problem investigation involves observational case studies.

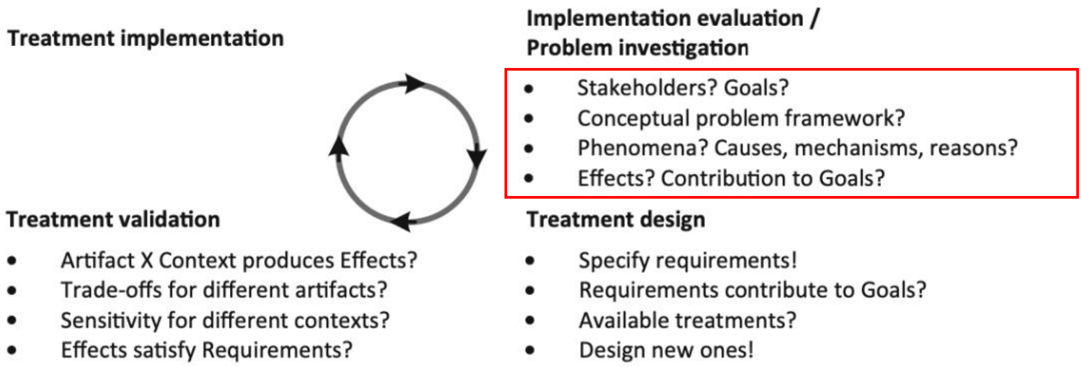

Figure 16 Problem Investigation part in design cycle

3.1. Problem Investigation based on Literature Review

Research focusing on microgrid O&M has highlighted various challenges that need careful attention. Previous studies have found important O&M problems like insufficient money, technical issues, insufficient skilled workers, and not involving the community appropriately. These difficulties can make it hard for microgrids to last long and work well, affecting how people can get energy.

The study by Schnitzer et al. (2014), based on seven case studies of microgrids in India, identifies several determinants dictating the prosperity or downfall of microgrids, encompassing cost recovery via tariffs, reliability of energy services, and maintenance practices. Schnitzer et al. (2014) introduced two cycle types of microgrid operation: the "virtuous" and "vicious" cycle, as shown in **Figure 17.** Within the realm of microgrid O&M, a virtuous cycle signifies a positive feedback loop that fosters the sustained functioning of the microgrid. In contrast, a vicious cycle embodies a negative feedback loop that precipitates microgrid failure. Conversely, an O&M virtuous cycle necessitates a commitment to undertake both preventive and corrective maintenance.

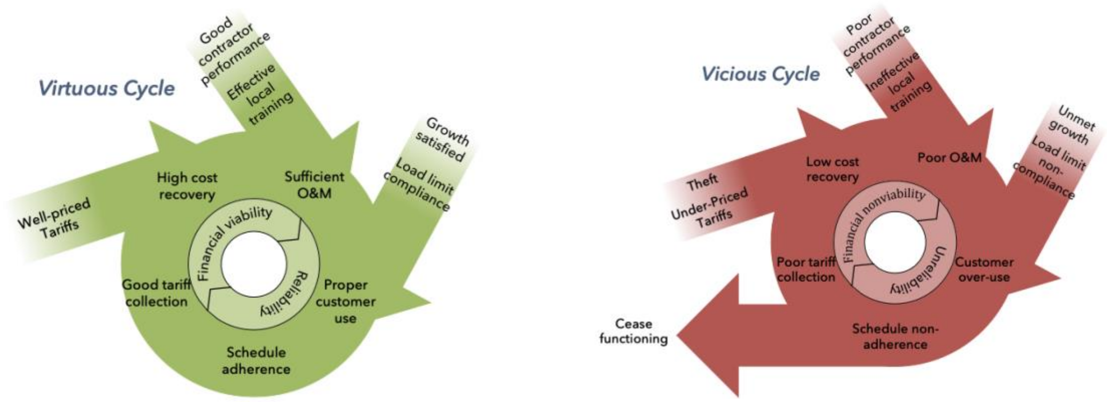

Figure 17 The Microgrid Operations "Virtuous" Cycle vs "Vicious" Cycle (Schnitzer et al., 2014)

In Indonesia, the long-term reliability of PV microgrids has been a concern. PV microgrids funded by the Ministry of Energy and Mineral Resources (MEMR) have a shorter lifetime, around four years, compared to typical PV systems that last approximately seven years (Simatupang et al., 2021).In addition, Derks & Romijn (2019) analysed incentives and motives contributing to the early failures of microgrids in Indonesia. Factors such as inadequate O&M and the absence of clearly defined roles and responsibilities among stakeholders were identified, as highlighted in the red box in **Figure 18**.

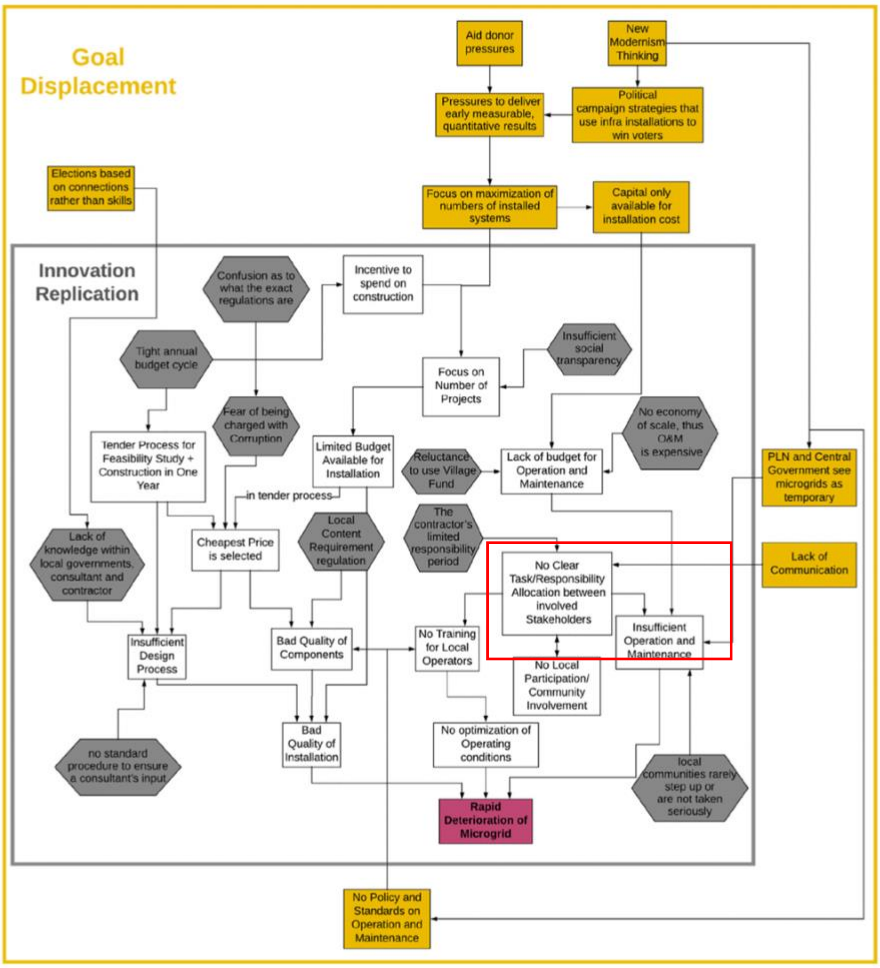

Figure 18: Causes of rapid failure of microgrids (Derks & Romijn (2019)

3.2. Problem Investigation based on Observational Case Study

Observational case studies are beneficial for problem investigation as they offer insights into the fundamental mechanisms governing real-world occurrences. As mentioned in **Section 1.5.1,** the selection criteria of small islands as the research location are defined by specific characteristics, including a small population with limited density, physical remoteness or isolation, limited infrastructure, especially electricity infrastructure, and lower economic activities compared to more developed areas. In Indonesia, these small populated islands are targeted for accelerated electrification, as outlined in the regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia, number 38 of 2016.

3.2.1. Contextual Overview of Case Study Location

Maluku Province, situated in the southern part of the Maluku Islands in Indonesia, is bordered by the Seram Sea to the North, the Indian Ocean and the Arafura Sea to the South, Papua to the East, and Sulawesi to the West (Kembauw, 2017). Its primary capital is Ambon City. The province ranks 28th in Indonesia in terms of population, with an estimated population of 1,900,914 people by mid-2023 (Ministry of Internal Affairs, Republic of Indonesia, 2023). Comprising 9 districts and 2 cities, the province consists of numerous small islands, including the Tanimbar Islands District, situated in its south-eastern region, as shown in **Figure 19**.

Tanimbar Islands District is categorised as part of the ‘3T’ area (Frontier, Remote, and Disadvantaged Region), positioned as one of Indonesia's outermost regions, adjacent to Australia. Travelling from Ambon to Saumlaki, the Tanimbar Islands District's main city, takes approximately 1.5 hours by plane or one night by ferry. Several community-based PV microgrids have been established in this region, with two recently revitalised. Consequently, the researcher identified the Tanimbar Islands District as meeting these criteria, making it a fitting subject for conducting observational case study and data collection in this study.

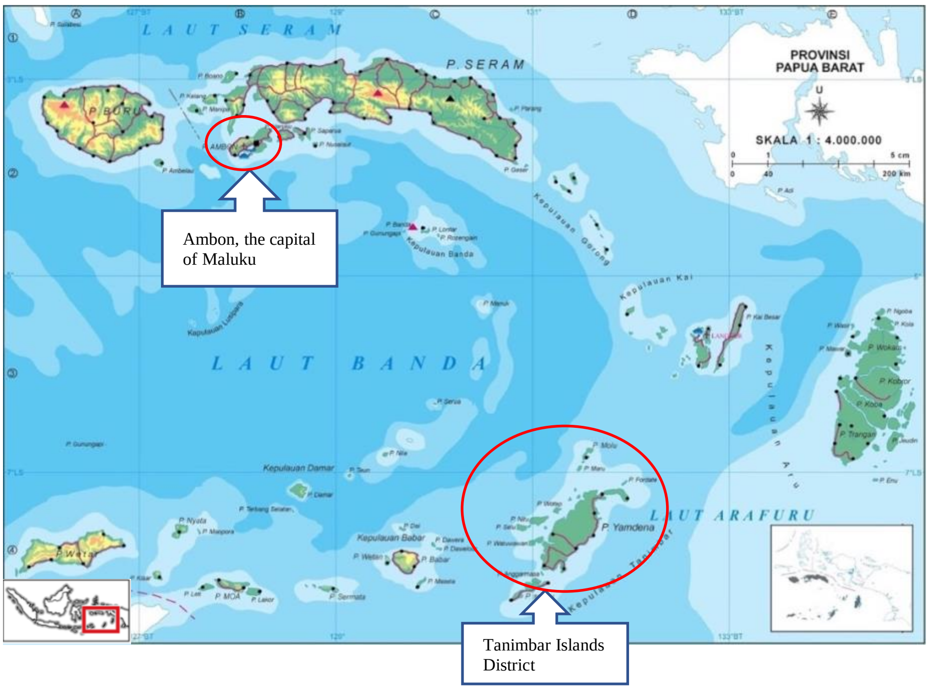

Figure 19: Geographical map of Maluku Province and location of Tanimbar Islands District (BPK Maluku Province, (2003) in Astor et. al)

3.2.2. Data Collection Protocol

As this research involved the direct involvement of human participants through surveys and interviews with individuals and organisations, therefore this study upheld ethical considerations. The research protocol underwent scrutiny and approval by the Ethical Committee within the Faculty of Behavioural, Management, and Social Sciences (BMS) or the domain of Humanities and Social Sciences at the University of Twente with application number 230549.

To ensure ethical compliance and participant safety during the research procedures, the following precautions have been instituted:

- The Informed Consent form was applied. Informed Participation is a pivotal process, ensuring participants are fully apprised of all aspects of the research, thereby enabling them to make a voluntary and informed decision regarding their involvement (University of Twente, n.d.). Ethical standards during surveys and interviews are observed, involving obtaining consent for audio recordings, photography, and video recordings used explicitly for research purposes.
- Courteous conduct was demonstrated by adhering to norms throughout the data collection process.
- Confidentiality is safeguarded by protecting the identities of interviewees and respondents, ensuring anonymity in research reports where potential risks are identified.
- Ethical protocols are adhered to during the data analysis process by maintaining strict confidentiality of research data.

3.2.3. Data Collection Techniques & Results

Besides the literature review, additional data collection methods were utilised, including:

a. Site observation
b. Interview with households
c. Interview with stakeholders

Here is a detailed overview of each method:

a. Site Observations

The primary aim of conducting these observations is to inspect the actual condition, operational functionality, and efficiency of the PV microgrid systems, identifying any potential problems or challenges that could impact their overall performance. The four villages selected as case studies are each equipped with their respective PV microgrids. Each village hosts its own PV microgrid, with specific geographic coordinates provided for these setups as shown in **Figure 20-23.**

Figure 20. PV Microgrid A in Village A

Figure 21. PV Microgrid B in Village B

Figure 22. PV Microgrid C in Village C

Figure 23. PV Microgrid D in Village D

Below are the conditions of each site derived from site observations and interviews with the operators about O&M activities:

1) PV Microgrid A

PV Microgrid A with capacity of 100 kWp was initially constructed in 2016 with an operational lifespan of approximately one year, intended to function in collaboration with PLN (National utility company). The funder of this site was the Indonesian MEMR and the asset was transferred to district's government. The PV microgrid is situated in close proximity to the local PLN office, approximately 300 meters away, and just 20 meters from the utility grid. Unfortunately, technical complications arose when the AC distribution panel malfunctioned, prompting PLN to cease operations (see **Figure 24**). However, no subsequent actions were taken, as the ownership rested with the local government. The situation deteriorated during the 2020 pandemic, leading to the abandonment of the site. Neglected maintenance resulted in uncontrolled vegetation growth over the PV panels (see **Figure 25**). Additionally, incidents of theft and vandalism targeted the critical components such as PV panels, battery bank, and grounding system, further exacerbating the site's condition (see **Figure 26** and **Figure 27**).

Figure 24. Malfunctioned AC distribution panel

Figure 25. Uncontrolled vegetation and vandalism

Figure 26. Theft towards battery bank

Figure 27. Overall view of PV Microgrid A

2) PV Microgrid B

PV Microgrid B, established in 2016 and funded by the Indonesian MEMR, was initially designed as an on-grid installation with a capacity of 250 kWp. It was designed for operation in hybrid mode alongside a diesel system, supported by evidence indicating the absence of a battery bank within the powerhouse and the presence of two transformers on-site (refer to **Figure 28**). Positioned behind the former diesel power plant (PLTD) office, the microgrid faced a challenge when the diesel equipment was relocated to PLN office in Saumlaki, rendering the site without any available diesel machinery. Consequently, the microgrid was never operational due to the absence of the necessary diesel engine. Unfortunately, there has been no follow-up or attention from local authorities as the official owner, resulting in the neglect of this asset.

The current state of PV Microgrid B reflects a condition of abandonment since its commissioning, with uncontrolled vegetation encroaching upon the microgrid components and its surrounding area (See **Figure 29**). Additionally, several other components remain non-functional, contributing to the overall state of disrepair.

Figure 28. Abandoned PV-site

Figure 29. Uncontrolled vegetation on PV-panels

3) PV Microgrid C

PV Microgrid C hosts an off-grid system with a capacity of 75 kWp, comprised of three PV arrays, each rated at 25 kWp. Initially installed in 2017 and funded by the Indonesian MEMR, the system encountered damage in 2018. Following this setback, the microgrid underwent revitalisation in 2022, sponsored once again by the MEMR, and have subsequently been transferred to the regional administration of Tanimbar Islands District.

Accessing this location necessitates crossing the island via sea, as no land access is available, typically accomplished by fishing boat (see **Figure 30**). Located in an area where PLN service is accessible, most households are connected to the PLN grids and simultaneously to microgrids, establishing a dual electricity system (see **Figure 31**).

Current conditions at PV Microgrid C exhibit several noteworthy aspects. The area appears dusty, with the Remote Monitoring System (RMS) non-operational due to a lack of network availability. Additionally, several streetlights are reported to be out of service, reducing illumination in some regions of the area.

An evident aspect contributing to the site's operational challenges is the need for more operator training, which may hinder effective management and maintenance of the microgrid infrastructure. Furthermore, the payment structure entails a fee of IDR 10,000 (approximately 0.6 euros) per month for three lamps and one electricity socket, indicating a specific tariff setup for lighting services.

However, the site faces difficulties in the collection of tariffs due to some customers are not willing/late to pay, which may affect the sustainability of its operations, as reflected by poor tariff and poor collection practices. Based on an interview with the PV microgrid committee on PV Microgrid C, the current payment method, involving the PV microgrid committee going from house to house, has been deemed time-consuming, taking at least one day to cover the village.

Furthermore, as part of the revitalisation efforts, a significant update has been made in the form of the battery bank. The prior zinc-air batteries have been substituted with lead-acid batteries (refer to **Figure 32** for details). Nevertheless, another pertinent concern is the need for more government attention to waste management, particularly concerning waste batteries from prior microgrid projects, requiring special attention for proper disposal and environmental responsibility (refer to **Figure 33**).

Figure 30. Access to PV Microgrid C by fishing boat

Figure 31. Dual electricity system (PLN grid and PV microgrid)

Figure 32. New battery bank

Figure 33. Neglected battery waste from previous project

4) PV Microgrid D

PV Microgrid D comprises an off-grid system with a 15 kWp capacity for 176 households. Initially established in 2017, this microgrid underwent revitalisation in 2022 under the sponsorship of the MEMR before being handed over to the district government of Tanimbar Islands alongside PV Microgrid C. Situated approximately 220 km from the district's capital, the site is accessible solely via speedboat due to its isolated location. Residents of Village D primarily rely on microgrid and possess own diesel generators as an alternative power source.

The 15 kWp system consists of 40 PV modules, each with a capacity of 390 Wp, arranged into four strings. The system operates using two hybrid inverters and three battery banks, with two Maximum Power Point Tracking (MPPT) units in each inverter (refer to **Figure 34-36**).

However, PV Microgrid D encounters several challenges. The PV panels suffer from the accumulation of thick dust, hampering their energy output (**Figure 37**). Additionally, there are limitations in providing adequate training for operators due to financial constraints. Two street lights on the site are non-functional, impacting lighting provisions. Moreover, there are issues with customer payments, with a fee of IDR 5000 (approximately 0.3 euros) per household each month for two lamps, leading to delays or reluctance in payments by some customers.

Figure 34. PV Microgrid D

Figure 35. Three battery banks on PV Microgrid D

Figure 36. Hybrid Inverters

Figure 37. PV-panels of PV Microgrid D

The findings of site observations are summarised in Table 5 while O&M problems are summarised in Table 6.

Table 5 Summary of Site Observations

PV Microgrid Name	Type	Capacity (kWp)	Year of Construction	Microgrids Owner	Status	Management	Distance to Closest City	Access to Location
PV Microgrid A	hybrid	100	2016	Government of Tanimbar Islands District	Not operational since 2017	Joint-operational with PLN (hybrid)	11 km from capital city	Car/motorcycle
PV Microgrid B	hybrid; on-grid	250	2016	Government of Tanimbar Islands District	Not operational since 2016	Never operational, supposed to be PLN	97 km from capital city	Car/motorcycle
PV Microgrid C	off-grid	75	2017; revitalisation October 2022	Government of Tanimbar Islands District	Operational since Dec 2022	Informal committee of 5 people	155 km from capital city (5 km from port)	Longboat
PV Microgrid D	off-grid	15	2017; revitalisation October 2022	Government of Tanimbar Islands District	Operational since Dec 2022	Informal committee of two operators	70 km from PV Microgrid C (+-220 km from capital city)	Speedboat

Table 6 Summary of O&M Problems found on fields

Site Name & Capacity	Failures/Disturbance	O&M Problems	Resolution from operator/management
PV Microgrid A (100 kWp)	• PV microgrid components are out of service • Uncontrolled vegetation • Theft & Vandalism	Both PV Microgrids A and B have the same problems: • Technical problems (PV microgrids components are out of service and burned AC distribution panel (PV Microgrid A only) • No proper maintenance from microgrids owner and no dedicated/mandated institution in energy sector in district level (Institutional problem) • There is no follow up action of Joint-Operational Cooperation between Local Gov. and PLN (Institutional problem) • Waste management issues	• The operator tried to repair but failed
PV Microgrid B (250 kWp)	• PV microgrid components are out of service • Uncontrolled vegetation		• No resolution yet • The village government does not know how contact the relevant department in district government
PV Microgrid C (75 kWp)	• Remote monitoring system is not working due to unavailability of local network • Some customers are not willing/late to pay	Both PV Microgrids C and D have the same following problems: • Lack of awareness from microgrid owner about O&M (Institutional problem) • Irregular maintenance such as irregular cleaning PV schedule • Financial problems due to poor tariff collection (Insufficient O&M costs) • No formality and clear status of microgrid management (Institutional problems) • Lack of operator training • Waste management issues	• Keep in touch with the contractor • Disconnection by removing lamps for disobedient community member
PV Microgrid D (15 kWp)	• Dusty areas cause lower output • Some customers are not willing/late to pay		• Cleaning microgrids • Keep in touch with the contractor • No punishment yet for disobedient community member

b. Interview with Households

The researcher conducted interviews with households in four villages where the PV microgrids are situated. The objectives of these interviews were to ascertain the characteristics of energy access and identify any associated problems. A total of 48 interviews were conducted from 17 to 21 October 2023, as illustrated in **Table 7** below.

Table 7. Households' Interview

Village Name	Households interviewed (people)	Interview Date
Village A	13	17-18 October 2023
Village B	12	19 October 2023
Village C	13	20 October 2023
Village D	10	21 October 2023

The researcher structured using an interview sheet prepared in advance, as shown in Appendix A. The interview questions were adapted from The Living Standards Measurement Study (LSMS) guidebook for Measuring Energy Access (World Bank and the World Health Organization, 2021). The core questions concerning households' energy usage revolve around availability, reliability, quality, affordability, formality, and health and safety. Below is a summary of the findings.

As presented in **Figure 38**, the interviewees comprised 53% women and 48% men. Around 58% of the participants were aged between 36 and 50 years old, with nearly a quarter aged 20-35, and the remainder above 51, indicating the majority being adults. The occupation of the interviewees varied among the villages. Most villagers in Village A were either employees or self-employed, likely due to their proximity to the government's capital city. In contrast, most residents in Village B worked as farmers, while those in Villages C and D mainly worked as farmers and fishermen (**Figure 39**).

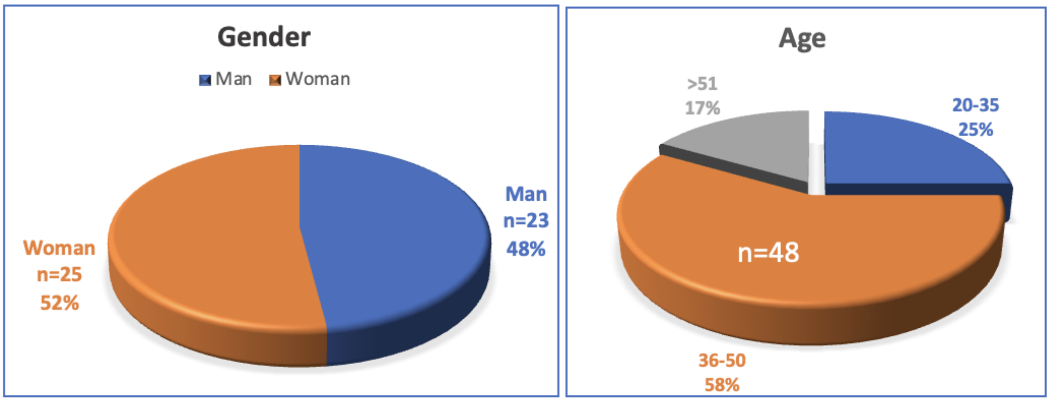

Figure 38. Age and Gender Distribution of Interviewees

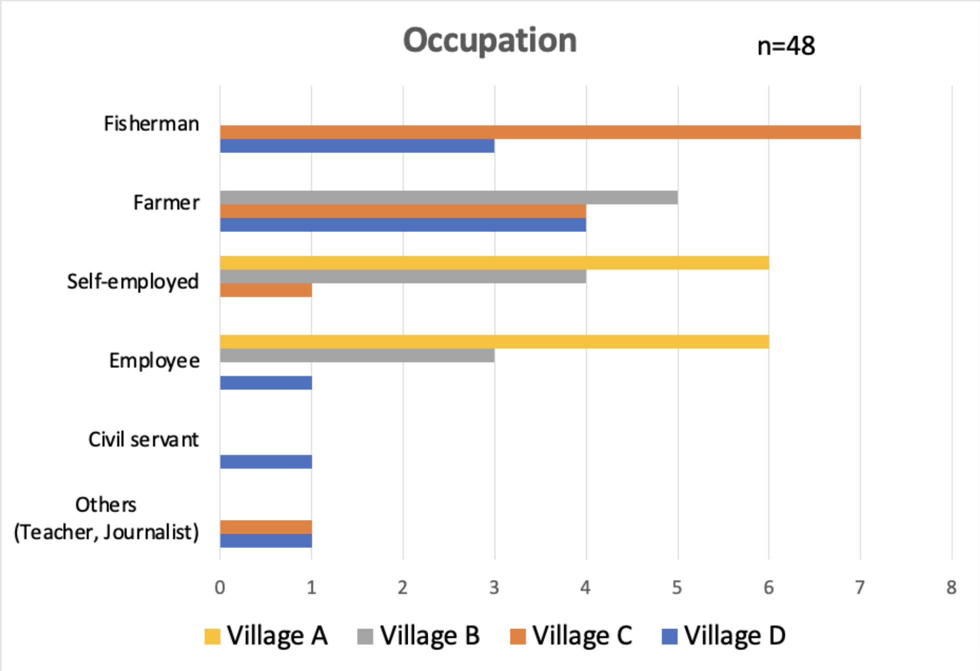

Figure 39 Diverse Occupations within Households

According to **Table 8**, electricity is available in all villages. Villages A and B source their electricity from PLN, Village C has dual electricity from PLN and solar microgrids, and Village D relies on solar microgrid and own diesel gensets. PLN has provided electricity between 2015 and 2017, while solar microgrids began operating in 2022. PLN is the main electricity source for Villages A, B, and C, available 24 hours, whereas the solar microgrids predominantly serve Village D for only 8 hours, indicating lower system output. Villagers from Village D mostly own diesel gensets as backup and use them occasionally. Village B experienced an unscheduled outage lasting 44 hours within the past 7 days, likely due to an issue at the diesel power plant owned by PLN.

Table 8. Household Energy Characteristics

Category							
Village Name	**Electricity Availability**	**Source of Electricity (HE2)**	**Year of Service**	**Main source of Electricity (HE3)**	**Availability of HE3 (max. 24 hours)**	**Reliability**	
						Number of unscheduled outages in last 7 days (in time)*	**Duration of unscheduled outage in last 7 days (in hours)***
Village A	Yes	PLN	2015	PLN	24	0	0
Village B	Yes	PLN	2015	PLN	24	1	44
Village C	Yes	PLN	2017	PLN	24	0	0
		Solar microgrid	2022				
Village D	Yes	Solar microgrid	2017	Solar microgrids	**8**	0	0
		Own diesel generator	2022				

Regarding quality, despite 100% electricity availability, there are reports in Villages B, C, and D of household appliances being damaged due to voltage fluctuations, as shown in **Table 9**. Commonly reported damaged appliances include TVs, refrigerators, blenders, and amplifiers.

Affordability varies, with no connection fee for Villages A and D, subsidised by the government. The connection fee is the initial payment made by consumers for installation of a new electricity supply infrastructure and/or an upgrade of an existing one. Village B charges between IDR 700k and IDR 1500k for connection fees, while Village C's fees are almost double, ranging between IDR 2-3 million due to its remoteness. Furthermore, monthly electricity tariffs range from IDR 50k-400k in Villages A, B, and C. At the same time, monthly operational costs for personal diesel genset fuel are almost IDR 2 million, indicating the high cost of this technology.

Table 9. Quality and Affordability Aspects of Household Energy Use

Category	Indicator	Village A	Village B	Village C	Village D
Quality	In the last 12 months, did any of this household's appliances get damaged because the voltage?	No	Yes (lamp, TV, amplifier)	Yes (lamp, TV, blender)	Yes (TV, refrigerator)
Affordability	Fee for the first connection	0 (grant from local gov)	IDR 700k-1500k	IDR 2-3 million	IDR0 (grant from local government)
	Fee for the electricity monthly tariff	IDR 50k-400k	IDR 100k	IDR 10k for PV microgrid and IDR 100k for PLN	IDR 5k for PV microgrid; IDR 1,8-2 million for diesel genset fuel costs

In terms of formality, residents in Villages A, B, and C pay for their electricity through pre-paid meters from PLN and the PV microgrid committee in the community for the service of PV microgrids. Lastly, there is no record of injury or mortality due to electricity from the main source, indicating good health and safety practices, as presented in **Table 10**.

Table 10. Formality and Health and Safety Aspects in Household Energy Usage

Category	Question	Statement/Indicator	Village A	Village B	Village C	Village D
Formality	To whom does this household currently pay for [electricity system from HE3]?	PLN	-	-	-	-
		Pre-paid meter	✓	✓	✓	-
		Community/village	-	-	✓	✓
		Cooperative/BUMD	-	-	-	-
		No one	-	-	-	-
Health and Safety	In the last 12 months, did anyone using electricty from [electricity system from HE3] injured?	Injury due to electricity from HE3 in the last 12 months	No	No	No	No
	In the last 12 months, did anyone using electricty from [electricity system from HE3] die or have permanent limb (bodily injury) damage?	Mortality or permanent limb (bodily injury) damage due to electricity from HE3 in the last 12 months	No	No	No	No

c. Interviews with Stakeholders

Every project encompasses individuals or groups with vested interests, known as stakeholders. In the case of a medium to mega-project, such as the construction of community-based PV microgrids within infrastructure development, the involvement of stakeholders can be extensive, involving a vast array of individual stakeholders and stakeholder groups. This becomes even more pronounced if the project has national implications or is part of a larger program.

Understanding the stakeholders associated with a project, their respective roles, and interrelations is pivotal for ensuring the success of the program and its long-term sustainability. This becomes particularly significant for influential and highly engaged stakeholders. To this end, a series of interviews were conducted with various stakeholders. The primary aim of these interviews was to acquire understanding of stakeholders' functions in the O&M of community-based PV microgrids. These interviews aimed to capture insights based on their direct experiences and perspectives.

Another objective of these interviews was to gather insights into the stakeholders' roles within the O&M of community-based PV microgrids, drawing from their first-hand experiences and viewpoints. The interviews took place face-to-face in two distinct cities: Ambon, serving as the provincial capital, and Saumlaki, as the capital city of the Tanimbar Islands District. Totally, there are sixteen (16) interviewees representing fourteen (14) institutions, spanning from the provincial to district levels, were engaged as shown in **Table 11**. Their inclusion was driven by their involvement and association with energy-related matters, particularly concerning community-based PV microgrids within Maluku Province. The following is the list of interview sessions conducted, including details of the stakeholders involved:

Table 11 Interview Information Details

No.	Interview Date	Position	Institution Name	No. of Interviewee (person)
1.	2023-10-10	Managerial & Staff	PLN (National Utility) Unit for Maluku and North Maluku Region	3
2.	2023-10-10	Managerial	Pattimura University	1
3.	2023-10-11	Managerial	Village Community Empowerment Agency (BPMD) of Maluku Province	1
4.	2023-10-11	Managerial	Vocational Training Centre (BPVP) Ambon	1
5.	2023-10-11	Managerial	NZMATES (New Zealand-Maluku Access to Renewable Energy Support)	1
6.	2023-10-12	Managerial	BPKAD Maluku Province	1
7.	2023-10-13	Managerial	Ambon State University	1
8.	2023-10-16	Managerial	Department of Energy and Mineral Resources (ESDM) Maluku Province	1
9.	2023-10-17	Managerial	Regional Development Agency (BAPPEDA) Tanimbar Islands district	1
10.	2023-10-17	Managerial	BPKAD Tanimbar Islands District	1
11.	2023-10-17	Managerial	PLN UP3 Saumlaki	1
12.	2023-10-23	Managerial	Village Community Empowerment Agency (BPMD) of Tanimbar Islands District	1

No.	Interview Date	Position	Institution Name	No. of Interviewee (person)
13.	2023-10-23	Managerial	Human Settlement Agency of Tanimbar Islands District (Dinas Cipta Karya, KPUPR)	1
14.	2023-10-23	Managerial	Regional Development Agency (BAPPEDA) Maluku Prov.	1
	Total Participants			16

The interview findings facilitated the identification of institutional stakeholders and their respective roles in the O&M as presented in **Table 12**.

Table 12 Stakeholders in case study & key findings from the interviews

No.	Role	Stakeholders in Case Study	Key findings
1.	PV microgrids owner	Asset Bureau, Government of Tanimbar Islands District	The Asset Bureau operates as the administrative entity responsible for overseeing assets within the Tanimbar Islands District. As per available data, Sites A, B, C, and D have been officially transferred from the MEMR to the Asset Bureau, make it is the official owner of the mentioned sites. However, during interview regarding its role in O&M the Head of the Asset Bureau displayed a lack of awareness regarding these assets and mentioned intentions to seek information from the respective staff. Consequently, the session yielded limited information regarding the stakeholders' roles.
2.	National Utility company	PLN Maluku and North Maluku Region	PLN, a national utility company engaged in electricity generation, transmission, and distribution, has its representation serving the Maluku and North Maluku regions, including a dedicated presence in the Tanimbar Islands District. Specifically managed by PLN UP3 Saumlaki, the Tanimbar Islands District operates with diesel-based power. PLN UP3 Saumlaki collaborated as a partner with the owner of the PV microgrids at Site A to operate the PV hybrid system. It's worth noting that without cooperation from the microgrid owner, PLN will refrain from operating the PV microgrids, considering it lies beyond PLN's scope of engagement.
3.		PLN UP3 Saumlaki	
4.	Government and Regulatory Authorities	Department of Energy & Mineral Resources (EMR) in Provincial Level	Department of EMR in provincial level has role as monitor & evaluator of energy programs in the provincial level.
5.		BPMD Province	Formulator, monitor & evaluator on policies in the field of community and village empowerment in provincial level
6.		BPMD in District level	Formulator, monitor & evaluator on policies in the field of community and village empowerment in district level.
7.		BAPPEDA Province	Provincial-level program planning agency.
8.		BAPPEDA District	District-level program planning agency.
9.		BPKAD Province	Entity managing provincial assets.
10.		Human Settlement Agency of Tanimbar Islands District	District-level infrastructure program agency.

No.	Role	Stakeholders in Case Study	Key findings
11.	International Technical Assistance Program	NZMATES	Technical assistance provider on RE development in Maluku province;
12.	Education Institution	Pattimura University;	Institution providing education, research, training, and community service on solar mini grids and electrical engineering.
13.		State Polytechnic of Ambon;	Institution providing education, research, training, and community service on solar mini grids and electrical engineering.
14.		BPVP	Provider of training and certification for PV microgrid operators.

Upon data collection, the researcher sought to identify stakeholders who hold significant influence and engagement in this project. To achieve this, the researcher employed a Stakeholder Engagement Assessment Matrix, following the guidelines outlined in The Project Management Institute (PMI)'s A Guide of Project Management Body of Knowledge (PMBOK® Guide, 6th ed., ch.13.2.2.5).

This matrix compares between the stakeholders' current engagement levels and the desired engagement levels necessary for successful project delivery, as suggested by PMI's classification:

- Unaware. Lacking awareness regarding the project and its potential effects.
- Resistant. Recognizing the project and potential impacts but displaying resistance towards any alterations that might arise due to the project's execution or its results. Stakeholders in this category are unsupportive of the project's work or outcomes.
- Neutral. Acknowledging the project's existence but maintaining a stance that is neither supportive nor unsupportive.
- Supportive. Acknowledging the project and its potential impacts and showing support for the project's work and anticipated outcomes.
- Leading. Aware of the project and the possibility of its impacts, actively participating to ensure the project's success.

In alignment with PMI's classification, the current engagement level is denoted with a "C," while the desired level is indicated with a "D." First step, in developing the stakeholder engagement assessment matrix, such as in the process of 'planning stakeholder engagement,' the researcher referred the stakeholder engagement plan. This plan aimed to ascertain the anticipated or desired level of engagement, taking into account the primary tasks, functions, and roles that the entity should ideally fulfil.

Following this consideration, the identified desired level was symbolised as ("D") with blue colour and the identified current level was symbolised as ("C") with orange colour. Both of them are incorporated into the stakeholder engagement matrix in **Table 13**. Instances where the current and desired levels coincided were marked as ("DC") in green, signifying their alignment. Upon analysing this matrix, noticeable gaps emerged among certain stakeholders:

- The PV microgrids owner and funder could assume a more leading role.
- The current position of several government entities involved in village empowerment and energy-related matters is neutral, but there is potential for them to be more supportive.

- The current neutral position of educational institutions signifies the potential benefits that could arise from engaging in research collaborations or community service initiatives within the specified location.

These highlighted gaps indicate the need for improvements in stakeholder engagement management going forward. Nevertheless, there is a positive aspect observed where Parliament Members in the Energy Sector display proactive leadership and advocacy for electrification programs while demonstrating awareness of O&M issues.

Reasoning behind this allocation of the matrix is based on primary data from statements from stakeholder's interviews and field surveys, and from secondary data from government documents and reports as well as news regarding O&M PV microgrids at the case study location.

Table 13 Stakeholder Engagement Assessment Matrix on O&M of Community-based PV microgrids

No.	O&M Stakeholders in literature	Stakeholder in Case Study	Unaware	Resistant	Neutral	Supportive	Leading
1.	Community-based PV microgrids owner	Asset Bureau, Government of Tanimbar Islands District	C				D
2.	Utility company	PLN (Indonesian government-owned corporation)			C	D	
3.	PV Microgrid operator	Local operator				DC	
		PLN Officer			C	D	
4.	PV microgrid management committee	PV microgrid committee				C	D
5.	PV Microgrids Funder	Ministry of Energy and Mineral Resources, Republic of Indonesia				C	D
6.	Government and Regulatory Authorities	Parliament Members in Energy Sector					DC
		Department EMR in Provincial Level				DC	
		BPMD Province			C	D	
		BPMD in District level			C	D	
		BAPPEDA Province			C	D	
		BAPPEDA District			C	D	
		BPKAD Province			DC		
		Dinas Cipta Karya, KPUPR			C	D	
7.	Contractor	PT Surya Energi Indonesia			C	D	
		Centre for Survey and Testing of Electricity, New, Renewable Energy and Energy Conservation (P3TEK/BBSP KEBTKE)			C	D	
	Equipment Supplier	PT Zaitech Engineering			DC		
		Sankeindo			DC		
8.	End-user/Consumer	Community members in Village A, B, C, D			C	D	
9.	International Organisation	NZMATES				C	D
10.		Pattimura University			C	D	

No.	O&M Stakeholders in literature	Stakeholder in Case Study	Unaware	Resistant	Neutral	Supportive	Leading
	Education Institution	State Polytechnic of Ambon;			C	D	
		BPVP			C	D	

3.3. Summary of Chapter 3

Chapter 3 addresses sub question #3, presenting the contextual overview of the case study location and the actual performance of O&M activities, along with the functioning of PV microgrids on small islands. This chapter comprises following parts:

Section 3.1. Problem Investigation based on Literature Review explores the problem investigation process by delving into existing literature relevant to the subject matter. It aims to understand the challenges associated with O&M strategies for community-based photovoltaic microgrids, relying on information gathered from previously published works and scholarly articles.

Section 3.2. Problem Investigation based on Case Study focuses on investigating problems through case study analysis, entailing a thorough scrutiny of particular instances concerning O&M practices within photovoltaic microgrids located on small islands. The aim is to collect primary data, observations, and insights by directly examining these microgrid configurations, their operational and maintenance methods, as well as the encountered challenges. This approach offers a practical viewpoint on the identified issues.

Section 3.2.1. Contextual Overview of Case Study Location introduces the geographical context of the case study area, offering insights into its unique characteristics, challenges, and relevant background information.

Section 3.2.2: Data Collection Protocol outlines the methodology used for gathering information, entailing the specific procedures to collect data related to O&M activities and the performance of PV microgrids on small islands.

Section 3.2.3: Data Collection Techniques and Results includes subsections regarding the findings derived from on-site observations, providing data and observations related to the actual functioning of PV microgrids and O&M activities in the designated locations. Additionally, this section presents interviews conducted with stakeholders involved in the project, shedding light on their perspectives, experiences, and insights regarding the O&M for PV microgrids.

Chapter 4 will explore the design of proposed O&M strategies using Enterprise Architecture model.

CHAPTER 4:
REFERENCE MODEL DESIGN

4. Designing Reference Model of O&M Strategies for Community-based PV Microgrids

This chapter discusses how to design reference model on O&M strategies in context of community-based PV microgrids by specifying the requirements, approaches, and the methods as well as the tools to design O&M strategy. Strategy according to Oxford English Dictionary is “a plan, scheme, or course of action designed to achieve a particular objective, especially a long-term or overall aim”(Oxford University Press, 2023).

In Design Science Methodology, this is a second part of treatment design. The goal of treatment design is to formulate innovative and effective solutions or artifacts to address the identified problem. These solutions or artifacts are designed based on an in-depth understanding of the problem domain and are intended to achieve predefined objectives or goals within the context of the research (Wieringa, 2014).

4.1. O&M Strategies Concept for Community-based PV Microgrids

Based on the discussions in Section 2.3, the O&M strategies encompasses technical, financial, and human resource aspects. It involves considerations from O&M business and execution models, inspired by prior studies such as those by Ubilla (2014) and Eras-Almeida & Egido-Aguilera (2019). These studies identify diverse models like cooperatives and hybrid structures for O&M business, along with in-house and third-party models for execution. This collective insight informs the development of a conceptual O&M strategy tailored for community-based PV microgrids, depicted in **Figure 40**.

One important note that O&M strategy is contingent upon three factors: system size, specific design, and location context (Keisang et al., 2021). These elements contribute to distinct maintenance protocols across diverse locations and installations. Hence, validating this design through a case study becomes imperative.

.

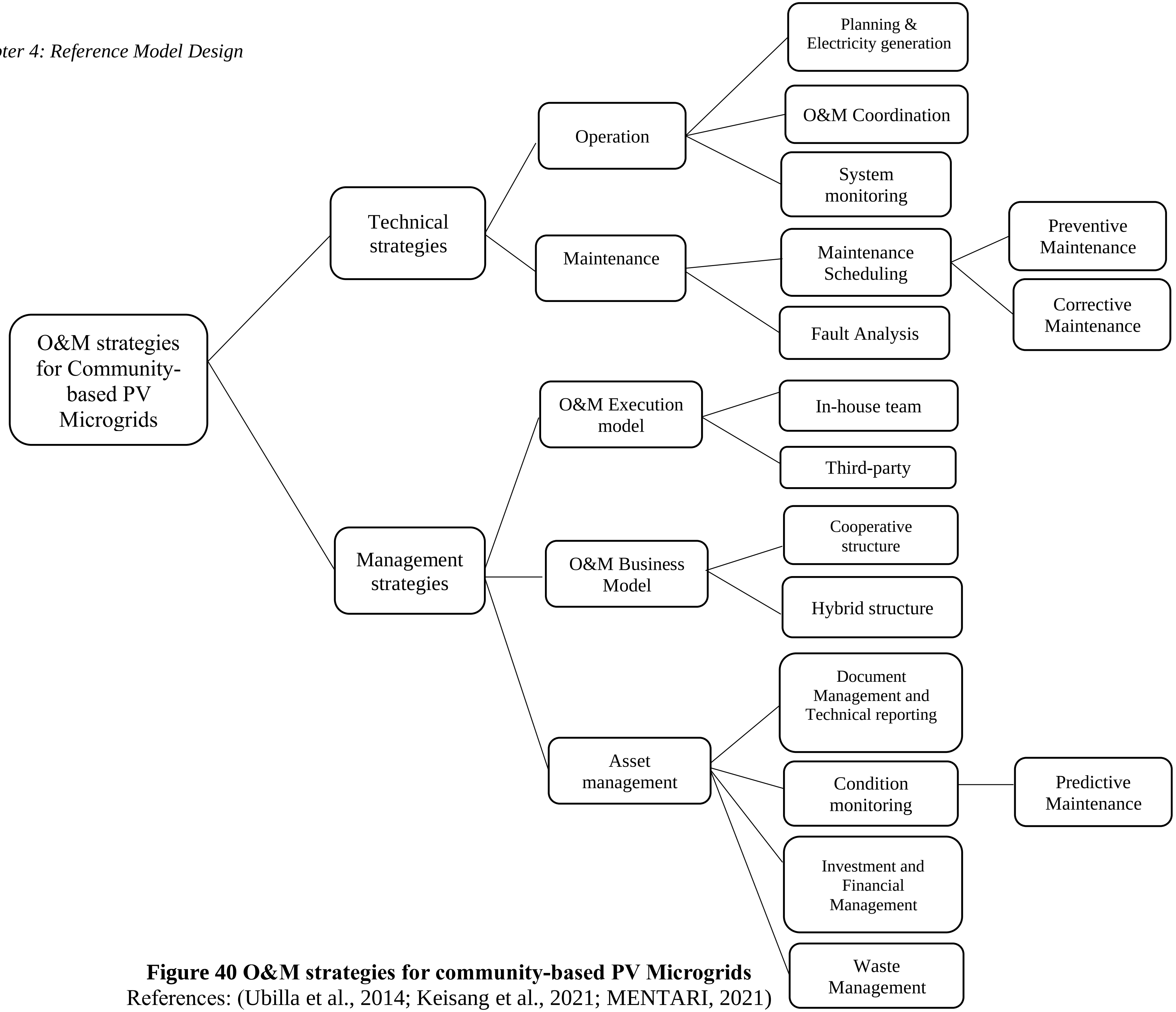

Figure 40 O&M strategies for community-based PV Microgrids
References: (Ubilla et al., 2014; Keisang et al., 2021; MENTARI, 2021)

4.2. Design Requirements and Reference Model

The conceptual O&M strategy depicted in Figure 40 above shows conventional diagram, hence, the researcher aims to enhance this by developing a specific reference model that incorporates essential inputs like requirements, motivations, and goals. The reference model framework draws inspiration from a comprehensive framework outlined by Candela et al. (2007), as previously discussed in Section 1.5.2. In designing reference model, the requirements should be defined. Therefore, this section is divided into three parts: Requirement Specification, Design Method and Modelling Tool, and Reference Model design as follows.

4.2.1. Requirement Specification

A requirement represents an attribute or characteristic of the treatment that a stakeholder intends to achieve, having invested resources (such as time and/or money) to attain this attribute (Wieringa, 2014). Essentially, it serves as a goal for the treatment that is being designed.

Functional requirements for designing reference model of O&M strategies using include:

a. Capability to Model O&M Processes: The reference model should facilitate the depiction and modelling of various O&M processes within the PV microgrid system.

b. Representation of O&M Components: The reference model should allow for the representation of different O&M components, such as monitoring systems, hardware.

c. Integration of Stakeholders and Roles: It should enable the modelling of various stakeholders involved in O&M, defining their roles, responsibilities, and interactions within the system.

d. Flexibility and Adaptability: The reference model should be adaptable to changes in the O&M strategy, allowing for updates, modifications, and additions to the strategy over time.

e. Visualisation: The model should provide visualisation tools of the O&M strategy.

While non-functional requirement is usability. It means the proposed reference model should be user-friendly, allowing stakeholders to easily navigate and comprehend the O&M strategies represented in the reference model. These requirements are derived from the research objectives, identified research gaps in Table 4 of Chapter 2, and the defined research scope.

4.2.2. Design Method and Modelling Tool

As previously mentioned in Section 1.5.3, that the methodology of developing reference model of O&M strategies for community-based PV microgrids is inspired by TOGAF ADM and the modelling tool that will be used is ArchiMate modelling language.

TOGAF provides a comprehensive framework and methodology guiding the entire enterprise architecture development process, while ArchiMate serves as a standardised graphical modelling language specifically for representing architecture within an enterprise.

In addition, as shown in **Figure 41**, ArchiMate comprises "Layers", the levels at which an enterprise can be modelled in ArchiMate (Motivation, Strategy, Business, Application, Technology, Implementation & Migration layers) and the "Aspects". The aspects of ArchiMate draw inspiration from natural language, where a sentence comprises a subject (active structure), a verb (behaviour), and an object (passive structure). This design choice makes the ArchiMate language more intuitive and accessible for both technical experts and non-technical stakeholders, resembling the familiar constructs found in their native languages, consequently enhancing the ease of learning and readability.

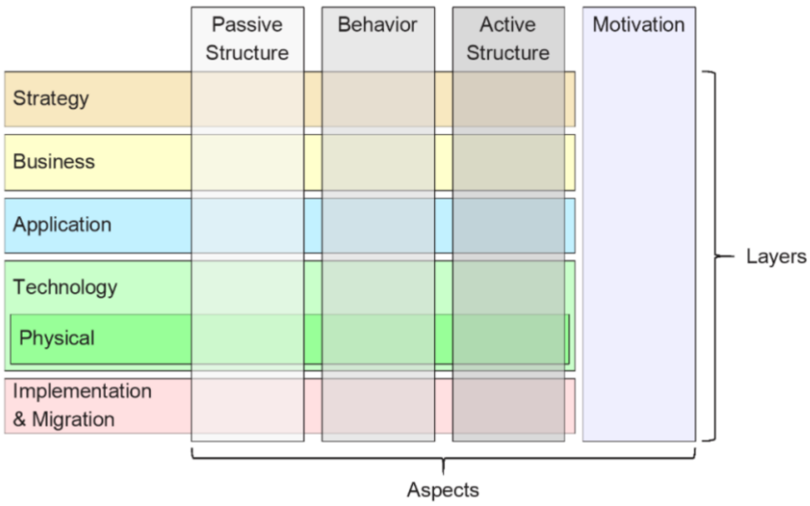

Figure 41 ArchiMate Full Framework

The concept definition of ArchiMate elements is shown in **Figure 42** and the conceptual application of ArchiMate metamodel by Hosiaisluoma (2021) is demonstrated in **Figure 43**. This metamodel comprises diverse layers and relationships, defining distinct facets within the organisation's architecture.

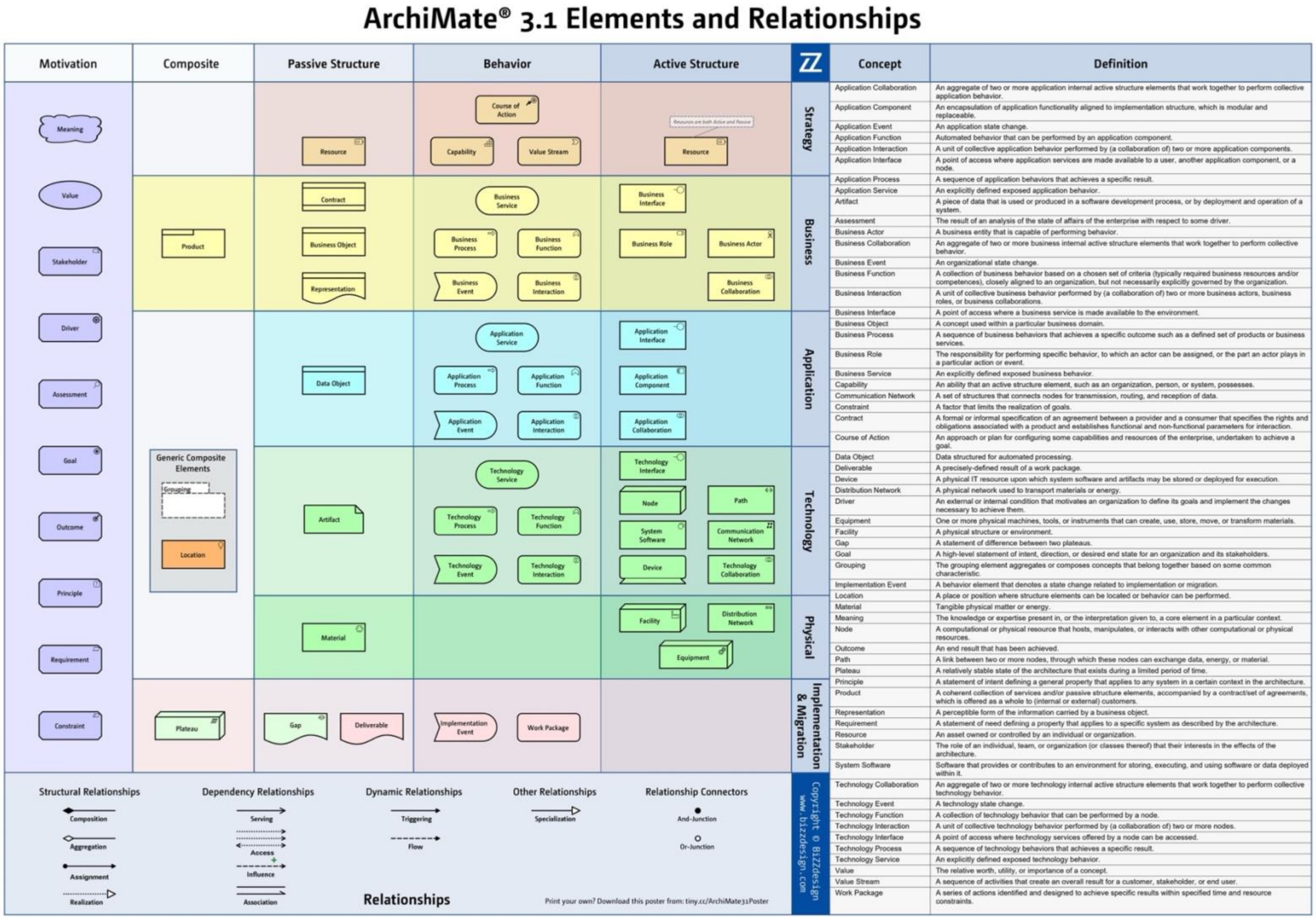

Figure 42 The concept definition of ArchiMate elements (Bizzdesign, n.d.)

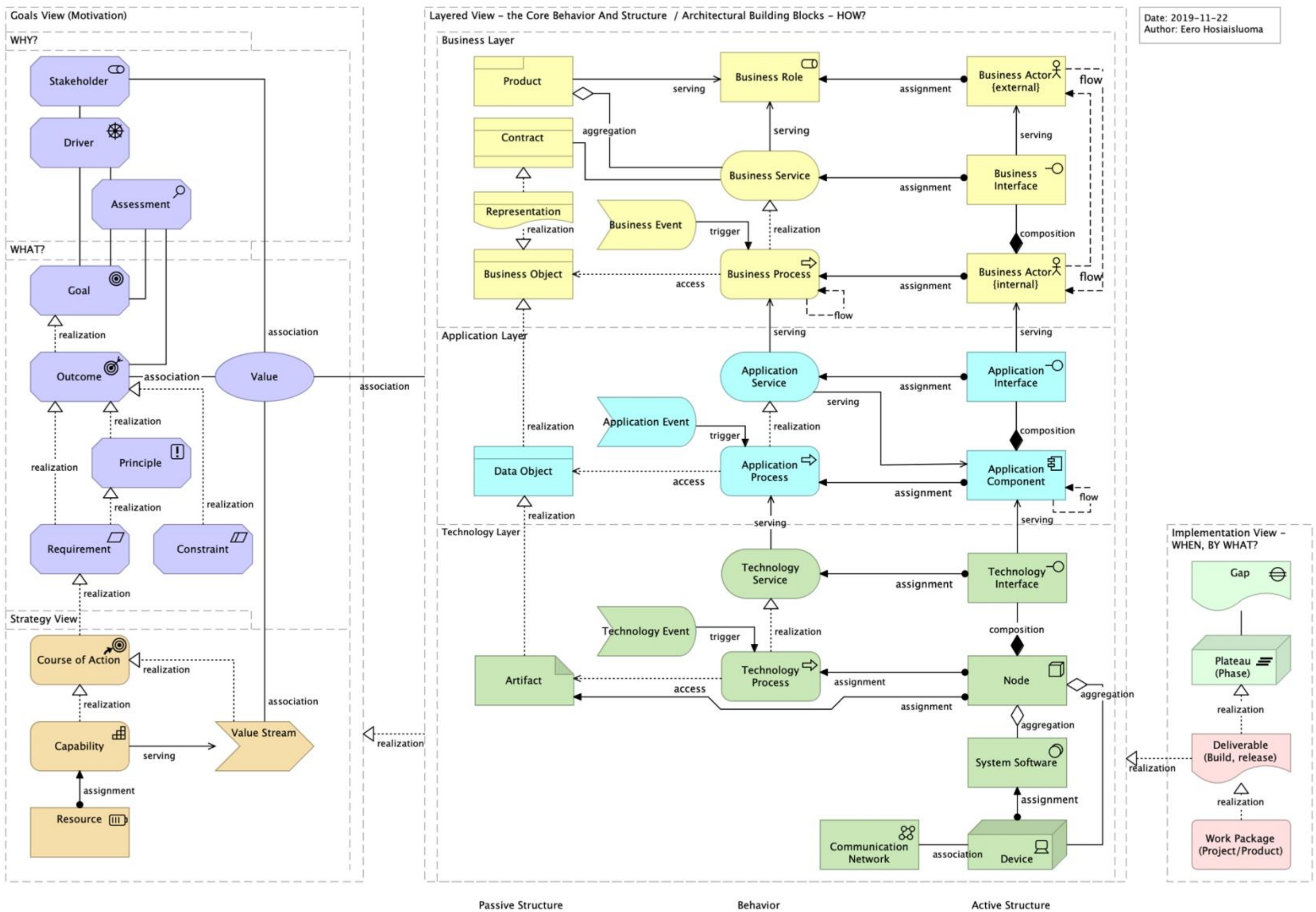

Figure 43 ArchiMate Metamodel with simplified relations (Hosiaisluoma, 2019)

4.2.3. Reference Model of O&M Strategies for Community-based PV microgrids

In this section, the reference model delivers various viewpoints that focus on specific aspects and layers. Viewpoints concentrate on encapsulating individual or multiple concerns. They allow a concern to be represented across multiple viewpoints. Viewpoint conventions encompass languages, notations, model types, design guidelines, and/or modelling methods (The Open Group, n.d.). The reference model of O&M strategies for community-based PV microgrids presents these following viewpoints:

1. Motivation Viewpoint
2. Strategy Viewpoint
3. Maintenance Strategies Viewpoints (Preventive, Corrective, and Predictive Maintenance)
4. Migration Planning Viewpoint

Detailed explanations of each viewpoint are provided below:

a. Motivation Viewpoint on O&M Strategies for Community-based PV Microgrids

The motivation viewpoint aims to create models of the involved stakeholders, their concerns, and assessment (covering strengths, weaknesses, opportunities, and threats) associated with these concerns. Additionally, it involves establishing connections to the primary high-level objectives aimed at addressing these concerns and assessments.

Objective of motivation viewpoint on O&M strategies of Community-based PV Microgrids is to identify the alignment between the O&M strategies and the overall objectives, goals, and aspirations of the involved stakeholders. It also establishes a clear linkage between the goals of the O&M strategies and the motivations driving the stakeholders to ensure successful implementation and adherence to the strategy.

To reach the goal, there are some requirements to be fulfilled to achieve each goal based on findings. Therefore, the drivers, goals, assessments, and requirements of microgrids sustainability can be identified and summarised on **Table 14**.

Table 14 Mapping sustainability factors into ArchiMate notation
(Derks & Romijn, 2019; Rahmann et al., 2016; Schnitzer et al., 2014; Sulaeman et al., 2021)

No.	**Microgrids Sustainability Factors (Drivers)**	**Weaknesses & Threats (Assessments)**	**Indicators of Sustainability (Goals)**	**Determinant factors (Requirements)**	
1.	Economic Sustainability	Theft	Financial viability	High-cost recovery	Well-priced tariffs
		Under-priced tariff			Good tariff collection
		No formality of for microgrids management		Sufficient O&M	Good contractor performance
		No allocation for O&M costs			Effective local training
2.	Technical/Technological Sustainability	Insufficient O&M	Reliability	Proper customer use	Growth satisfied
		Short operational lifetime of microgrids influenced by rapid failure of microgrids			Load limit compliance
		Lack of policy in O&M		Schedule adherence	Maintenance Scheduling
3.	Environmental Sustainability	Waste of PV microgrids components	Environmental Safety	Proper asset Management	Proper waste Management

Combining it with the drivers, goals, assessments, and requirements of microgrids sustainability from **Table 14**, ArchiMate can be effectively employed to map and illustrate their concerns within the framework as shown in **Figure 44**.

In previous Section 3.2.3 part c, an array of stakeholders in O&M has been identified. **Figure 44** shows a diagram, showing relevant stakeholders and three of them are leading stakeholders (the PV microgrids owner, government authorities, and community members as end-users) and their concerns, modelled as drivers. Sustainability is a shared concern of those stakeholders. Sustainability can be refined into more detailed concerns such as economic sustainability, technological sustainability, and environmental sustainability (referring to Section 2.5). In this study, the assessments of the drivers focus on identifying weaknesses and threats, reflecting the analysis of the contextual circumstances.

Each driver aligns with a sustainability indicator/goal. For instance, 'Reliability' corresponds to the 'Technical (Technological) Sustainability' goal, 'Financial viability' aligns with 'Economic Sustainability,' and 'Environmental Safety' is the goal linked with 'Environmental Sustainability.'

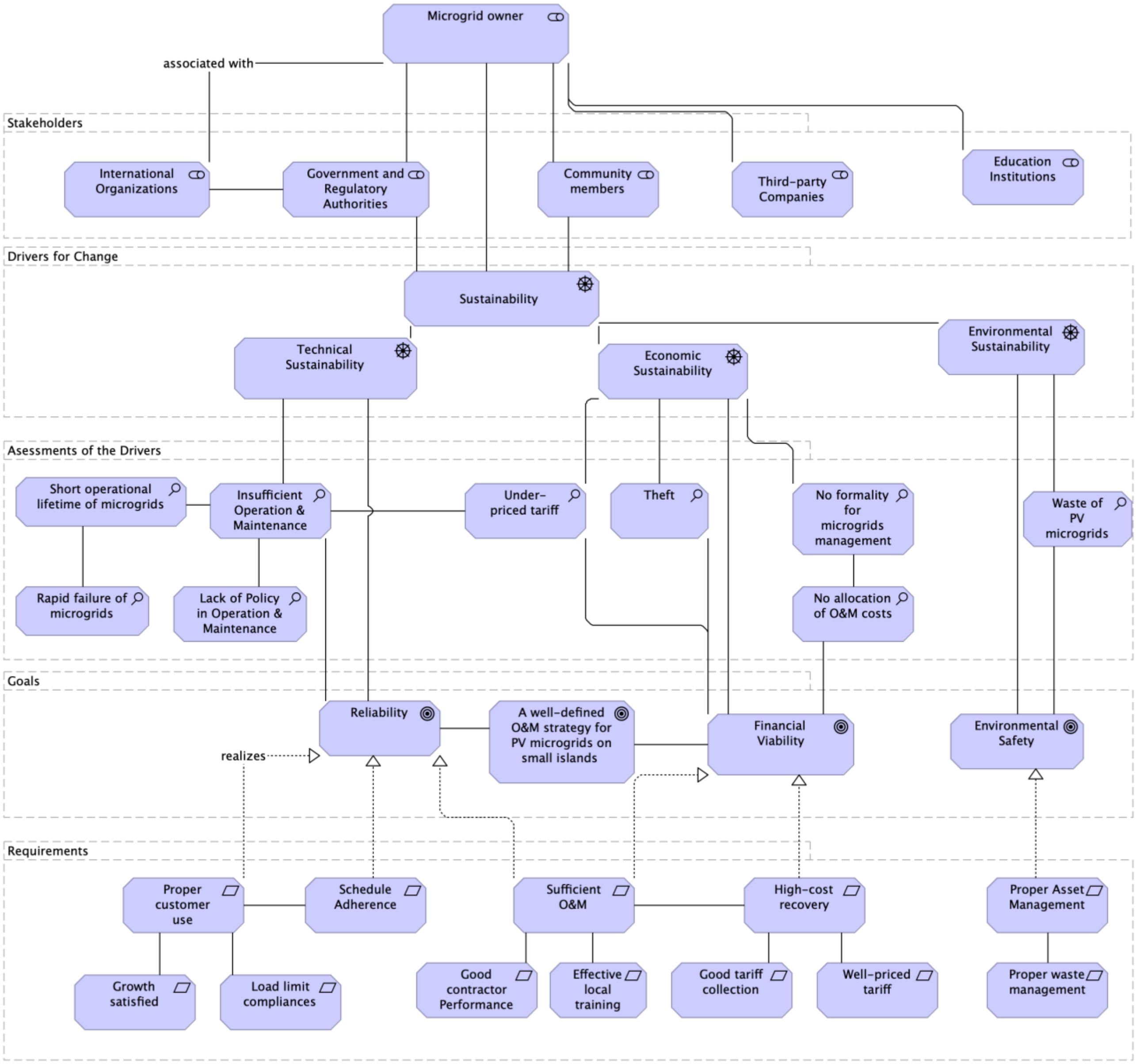

Figure 44 Motivation Viewpoint of O&M strategies for community-based PV microgrids

b. Strategy Viewpoint on O&M Strategies for Community-based PV Microgrids

The Strategy viewpoint, as illustrated in **Figure 45**, represents a segment of the O&M strategies derived from the conceptual O&M strategies framework. This viewpoint organises the strategy based on different aspects.

The O&M Strategies encompasses both technical and managerial facets, denoted by the symbol 'Course of Action,' indicating the plan or approach to be adopted. These courses of action are executed through various capabilities.

In the Strategy viewpoint, the O&M execution model include options such as "third party" or "in-house team." Meanwhile, the resources of the O&M business model within this viewpoint present choices such as "cooperative" or "hybrid structure".

As discussed in Section 2.7, in cooperative structure model, a cooperative manages the microgrid's administration, decision-making, and daily operations. While the hybrid model involves community input in energy system decisions, with a public/private entity handling O&M in exchange for a fee (Ubilla et al., 2014).

Asset management includes document management, technical reporting, investment and financial management, and condition monitoring to facilitate predictive maintenance. Waste management is also part of asset management because proper waste management procedures must be followed when components are replaced due to damage or routine replacement.

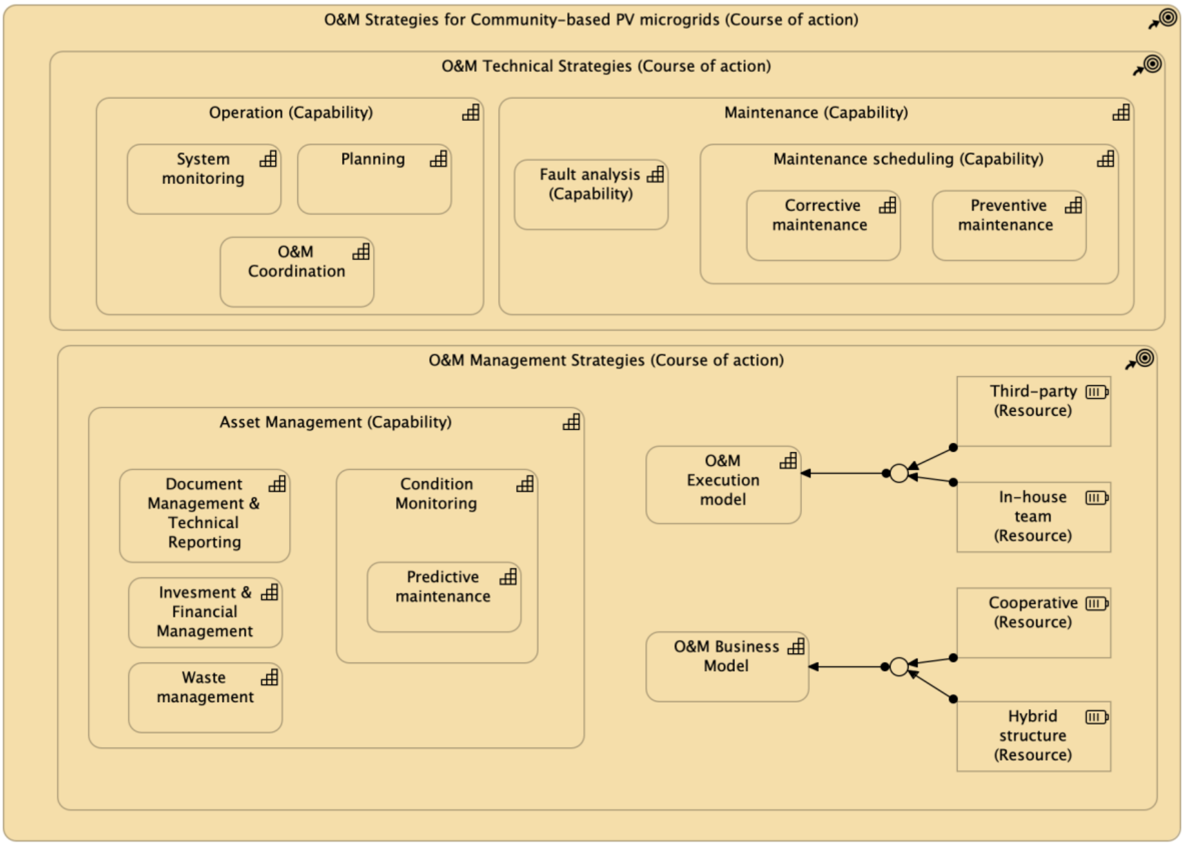

Figure 45 Strategy View of O&M Strategies

c. Maintenance Strategies

Maintenance has become a crucial element in improving service delivery across industries while prioritizing safety and reliability (Dhillon, 2002 as cited in Keisang et al., 2021). In Section 2.3, maintenance strategies have been introduced such as corrective, preventive, and predictive maintenance, emphasizing reliability, production, and system maintenance. The reference model below aims to visually represent the processes, steps, and essential aspects concerning these three strategies.

1) Preventive Maintenance Viewpoint

This viewpoint, as shown in **Figure 46**, deals with preventive maintenance strategies within the O&M framework. It outlines plans and procedures to prevent potential issues or breakdowns in the PV microgrid system. It encompasses regular inspections on system performance, routine upkeep follows manufacturer recommendations, and proactive measures to avoid or minimize equipment failures or system disruptions (Keisang et al., 2021). It's crucial to carefully determine maintenance intervals and actions under this strategy, considering variable, systematic, or condition-based approaches (Alam et al., 2015; Baklouti et al., 2020; in Keisang et al., 2021). Systematic preventive maintenance replaces aging or unfit components at set intervals, while condition-based maintenance responds to observed signs of failure or abnormal performance (Sharma and Chandel, 2013, in Keisang et al., 2021).

In this preventive maintenance, application that is essential is the monitoring system. The monitoring system configuration on microgrids can vary depending on the system design and size in a context.

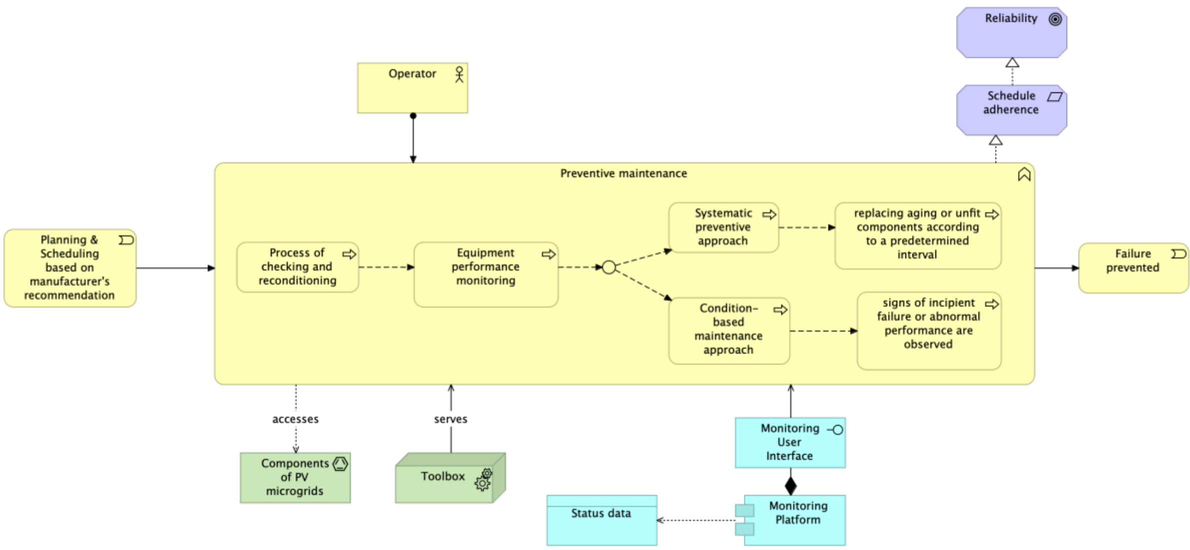

Figure 46. Preventive Maintenance

2) Corrective Maintenance Viewpoint

This corrective maintenance aims to ensure reliability. Effective operator training is crucial to swiftly restore normal operations using the tools on powerhouse. Repair procedures usually involve operational checks, diagnostic troubleshooting, and repair/replacement decisions based on component availability, lead time, cost, and repair complexity. Lack of operator expertise may escalate issues to technicians. **Figure 47** illustrates the process of corrective maintenance.

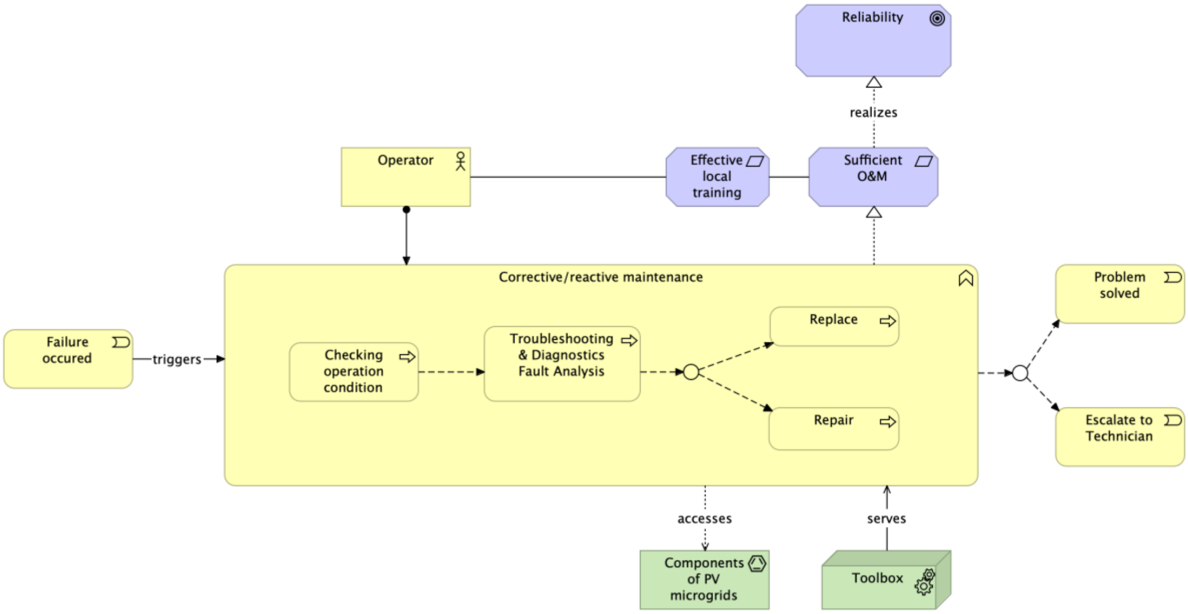

Figure 47. Total View of Corrective Maintenance

3) Predictive Maintenance Viewpoint

Predictive maintenance approach involves mitigation actions (repair or replacement) upon forecasting potential system failure. It relies on consistent monitoring, continuous supervision, forecasting, and analysing historical performance data and anomalies of the PV system (Bosman et al., 2020, in Keisang et al., 2021). Specialised skills such as machine learning and AI tools are essential for this method, necessitating collaboration between operator with skilled researchers or technicians for analysis. This data-driven approach will lead to determine next operation plan as depicted in **Figure 48**.

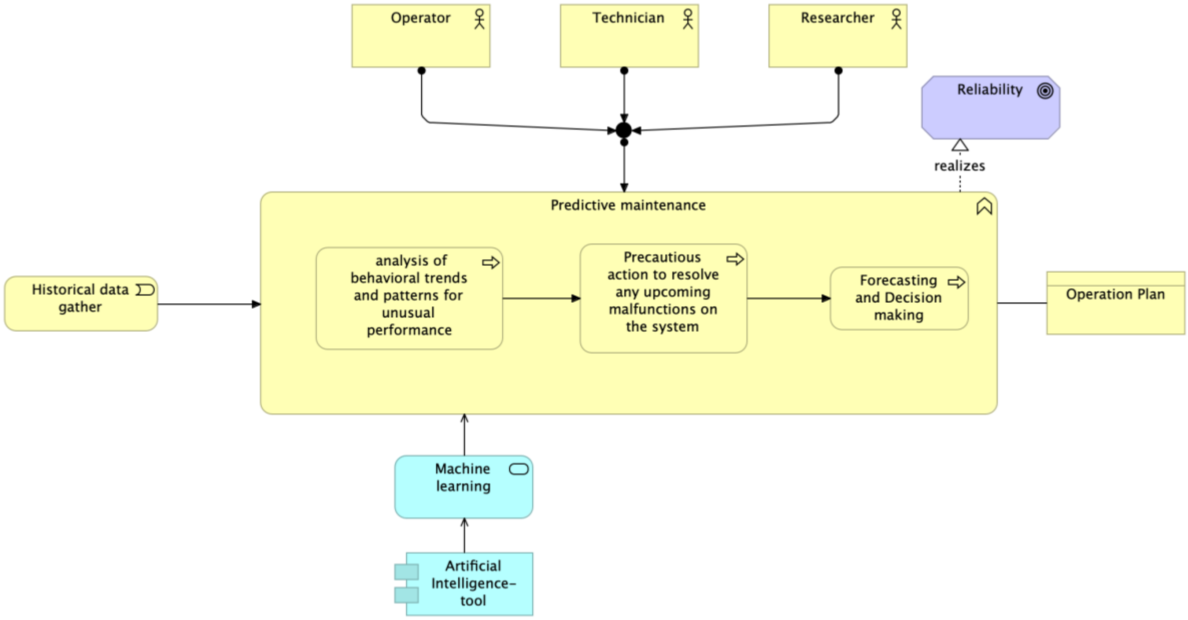

Figure 48. Total View of Predictive Maintenance

In essence, selecting the ideal maintenance strategy for a PV system is a complex decision. It demands a comprehensive understanding of various factors and the system's unique maintenance requirements. An effective maintenance approach often combines different strategies, chosen based on risk assessment and cost-benefit analysis to maximize benefits and minimize risks (Keisang et al., 2021).

d. Migration Planning Viewpoint

Migration Planning viewpoint within the EA-based reference model for structuring the O&M strategies for PV microgrids is a crucial stage. There is a plateau, a stage where the strategy has reached a stable state. Plateau refers to a phase wherein it becomes necessary to evaluate or adopt the strategy. **Figure 49** shows the first step in designing migration plan is evaluating the current state or the as-is condition, with a focus on O&M management strategy to achieve financial viability and identify any existing gaps. Subsequently, the transition from management strategy to the technical strategy aims to uncover obstacles hindering the strategy's implementation. Through this migration planning process, work packages and deliverables are identified, tailored to specific location needs. Thus, the reference model validation into a specific case study caters to the unique requirements of each location.

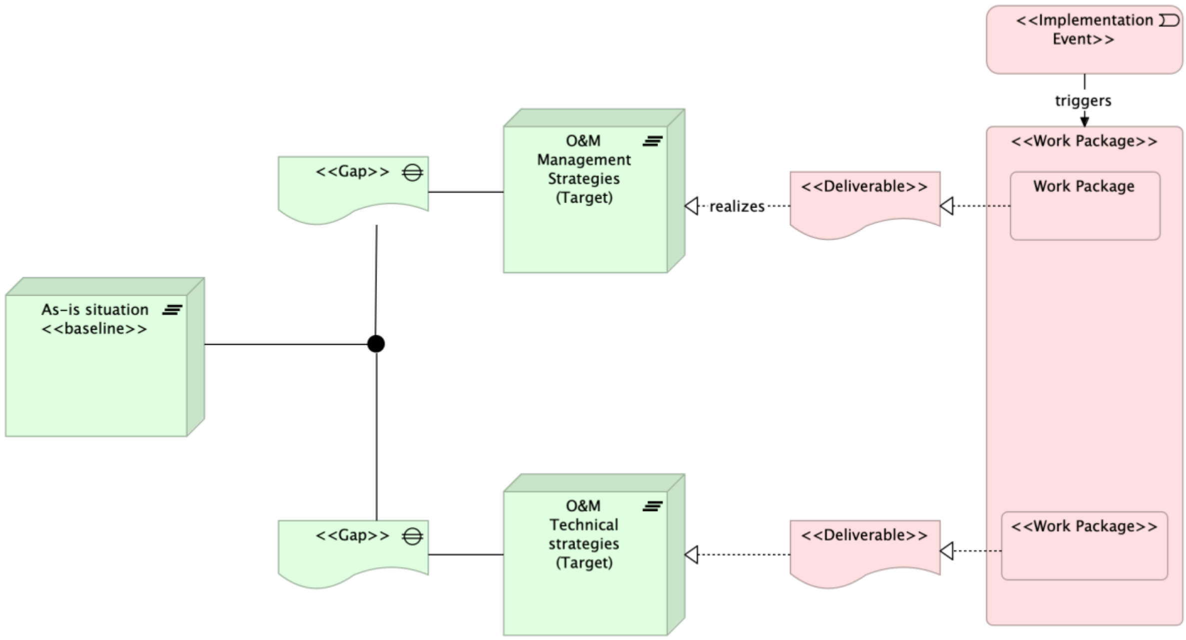

Figure 49. Migration planning viewpoint

4.3. Summary of Chapter 4

Section 4.1 O&M Strategies Concept for Community-based PV Microgrids provides the necessary criteria for structuring the reference model, leveraging insights obtained from scholarly works as a foundational guideline.

Section 4.2 Design Requirements and Reference Model focuses on outlining the specific requirements for the reference model while drawing insights from existing literature. The reference model for O&M strategies incorporates multiple viewpoints within the reference model framework to provide a structured approach to manage O&M activities.

The subsequent stage involves assessing the reference model in a particular case study, to be elaborated upon in Chapter 5.

CHAPTER 5

REFERENCE MODEL VALIDATION: A CASE STUDY

5. Validation of O&M Strategies Reference Model: A Case Study

The purpose of Chapter 5 is to operationalise the generic reference model as it pertains to O&M strategies, within a case study. This process provides further details on the factors that are essential for facilitating the implementation of an O&M reference model for community-based PV microgrids in the Tanimbar Islands District of Indonesia. This chapter is also to answer sub research question #4: *How can the reference model of the O&M strategies be operationalised to support community-based PV microgrids in a case study such as Tanimbar Islands District, Indonesia?*

5.1. Community-based PV Microgrids in Tanimbar Islands, Maluku Province

Contextual overview of case study has been introduced in Section 3.2. Tanimbar Islands District in Maluku Province, Indonesia, is chosen as a case study. There are four PV microgrids in four locations selected in Tanimbar Islands District, they are community-based PV microgrids (in short 'PV microgrids') A, B, C, and D as shown in **Figure 50**.

Figure 50 Four PV Microgrids locations in a case study

In Section 4.2, generic reference model for O&M has been proposed. In this part, the reference model will guide the application and assessment of O&M strategies in case study. Below are proposed steps for validating reference model of O&M strategies in case study:

1. Identify existing situation (as-is situation)
2. Refer to the proposed reference model
3. Identify the gaps between as-is situation and proposed to-be situation
4. Analyse the implementation and migration planning

5.2. Identification of Existing Situation

a. Existing situation of PV Microgrids A and B

Off-grid PV microgrid A, rated at 100 kWp, and on-grid PV microgrid B, rated at 250 kWp, have been assessed during on-site observations in Section 3.2. These systems, which were intended to be managed by PLN, are currently non-operational. Both sites exhibit components that are out of service, and there is no active management present. In addition, Village A and B households are presently receiving electricity from the PLN grid, powered by a diesel plant, providing 24-hour electricity service.

Due to these circumstances, these PV microgrids require revitalising or refurbishing the infrastructure in advance to implement O&M strategies and it will take substantial efforts and time, extending beyond the scope of the reference model outlined in this thesis. Consequently, the implementation of the O&M design reference model for PV microgrids A and B is not illustrated in this study.

b. Existing situation of PV Microgrids C and D

PV microgrid C (rated at 75 kWp) and D (rated at 15 kWp) underwent simultaneous revitalisation and became operational at the end of 2022. Both microgrids were part of a project funded by the Indonesian MEMR. **Figure 51** illustrates the project flow initiated by the Indonesian MEMR, employing a third-party contractor for construction, subsequent transfer of responsibility to the district government. However, due to their remote locations in villages far from the district's capital, these microgrids are informally managed by local individuals. An informal committee was established to oversee the microgrid operations, although their skills are limited. The contribution tariff set for these microgrids, as detailed in Section 3.2.3 part a, is inadequately low, does not cover the costs associated with O&M.

An analysis of the situation reveals at least four critical issues with PV microgrids C and D:

1) Inadequate engagement of the PV microgrid owner.
2) Absence of formal management structures.
3) Operations managed by local villagers lacking electrical engineering expertise.
4) Contribution tariff set below actual O&M costs, reflecting the absence of a clear O&M business model.

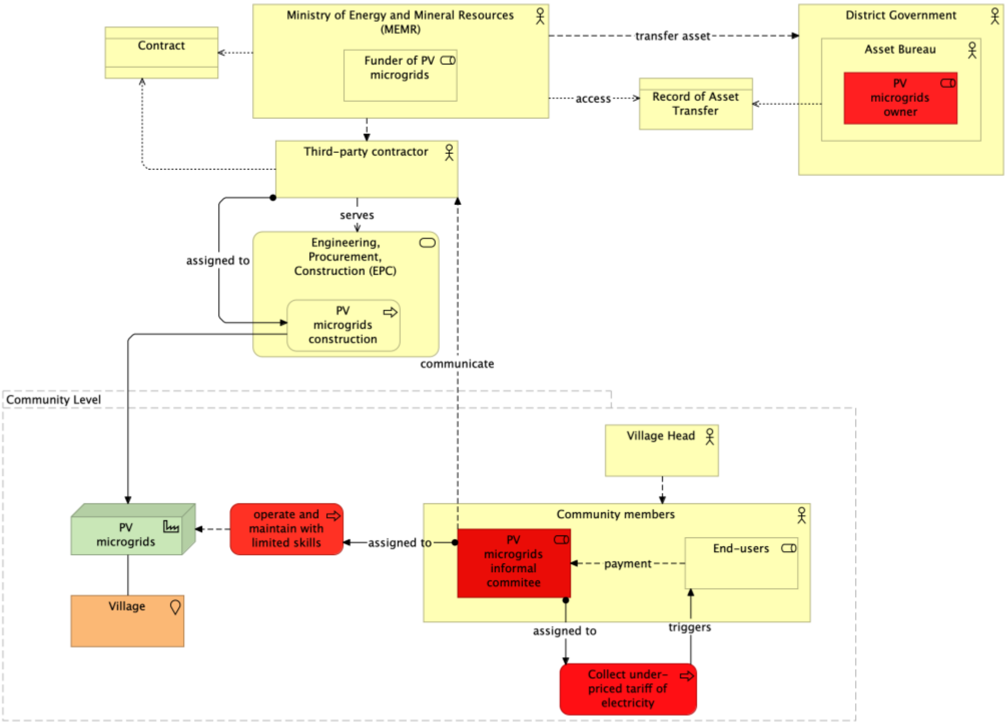

Figure 51 Illustration of as-is situation at Village C and D, issues are highlighted by red color

5.3. Assessment of the Reference Model in the Case Study

a. Motivation Viewpoint on Community-based PV Microgrids in Tanimbar Islands

The motivation viewpoint from reference model aligns with the perspectives highlighted in the case study. It captures the motivations and underlying principles driving the implementation of community-based PV microgrids within the Tanimbar Islands.

b. Proposed O&M Business Model in the Case Study (Target)

The investigation in Section 5.2 revealed that PV microgrids C and D lack a clear O&M business model. Drawing reference from Ubilla (2014), various potential models come to light, including cooperative and hybrid structures. The hybrid model involves active community engagement in energy system decisions, partnering with public or private entities for O&M tasks against a fee. Specifically, the hybrid structure observable in Indonesia encompasses Social Enterprises, such as District-owned Enterprise (BUMD) or Village-owned Enterprise (BUM Desa / BUMDes).

Village-owned Enterprise is a social enterprise established by the village to harness all economic potential, economic institutions, and the natural and human resources available to enhance the welfare of village communities (Indonesian Regulation No. 6 of 2014). It stands as a key priority program under the Ministry of Villages, Development of Disadvantaged Regions and Transmigration, Republic of Indonesia. Each village is entitled to establish one Village-owned Enterprise. In Indonesia, numerous PV microgrids are owned and managed by these enterprises, demonstrating their effectiveness in operation, as detailed in **Table 15**.

For instance, the Government of Kubu Raya District has transferred the ownership of PV microgrid to three villages, granting them the autonomy to manage the microgrid. However, the status of operational is unknown yet and needs more information to know the current status.

An exemplary case is observed in Muara Enggelam Village, East Borneo Province, where the Community-based PV microgrid has been successfully operational for eight years under the management of BUMDes. They regulate tariff rates, manage payments, and allocate O&M costs. The electricity tariff is set at IDR 100,000, which is equivalent to EUR 6 (10 times higher than the tariff in Village C). Similarly, in Mata Redi, East Nusa Tenggara, the PV microgrid is owned and managed by BUMDes.

Table 15 Case studies from other regions

Village Name	Region name (Indonesia)	Microgrid capacity (kWp)	Year of Construction	Operational Status	Ownership & Management	Reference
1. Sumber Agung, 2. Muara Tiga 3. Sungai Kerawang	Kec. Batu Ampar, Kubu Raya District, Kalimantan Barat (West Borneo Province)	100	2017; hand-over asset in 2018 to district gov.; hand-over asset in 2021 to village level	Need more information	BUMDes	(Kubu Raya District Government, 2021)
Muara Enggelam	Kecamatan Muara Wis, Kutai Kartanegara District, Kalimantan Timur (East Borneo Province)	30	2015	Still operational well (8 years up to now)	BUMDes (Tariff, payment collection, O&M costs)	(Barsei & Saptohadi, 2023; MONGABAY, 2023)
Mata Redi	Kecamatan Katikutana, Kabupaten Sumba Tengah, NTT (East Nusa Tenggara)	95	2022	Still operational well	BUMDes (Tariff, payment collection, O&M costs)	(MENTARI, 2022)

In light of this, the researcher advocates for adopting BUMDes as the O&M business model for Tanimbar Islands District. The structure of BUMDes is delineated in **Figure *52***, illustrating the establishment of BUMDes by the community forum discussion, signifying its authority, and includes a unit manager responsible for PV microgrids within the structure, alongside other business entities. This structured approach formalises and legitimises the management of PV microgrids. In remote islands, BUMDes could facilitate electricity management and forge business collaborations with third parties.

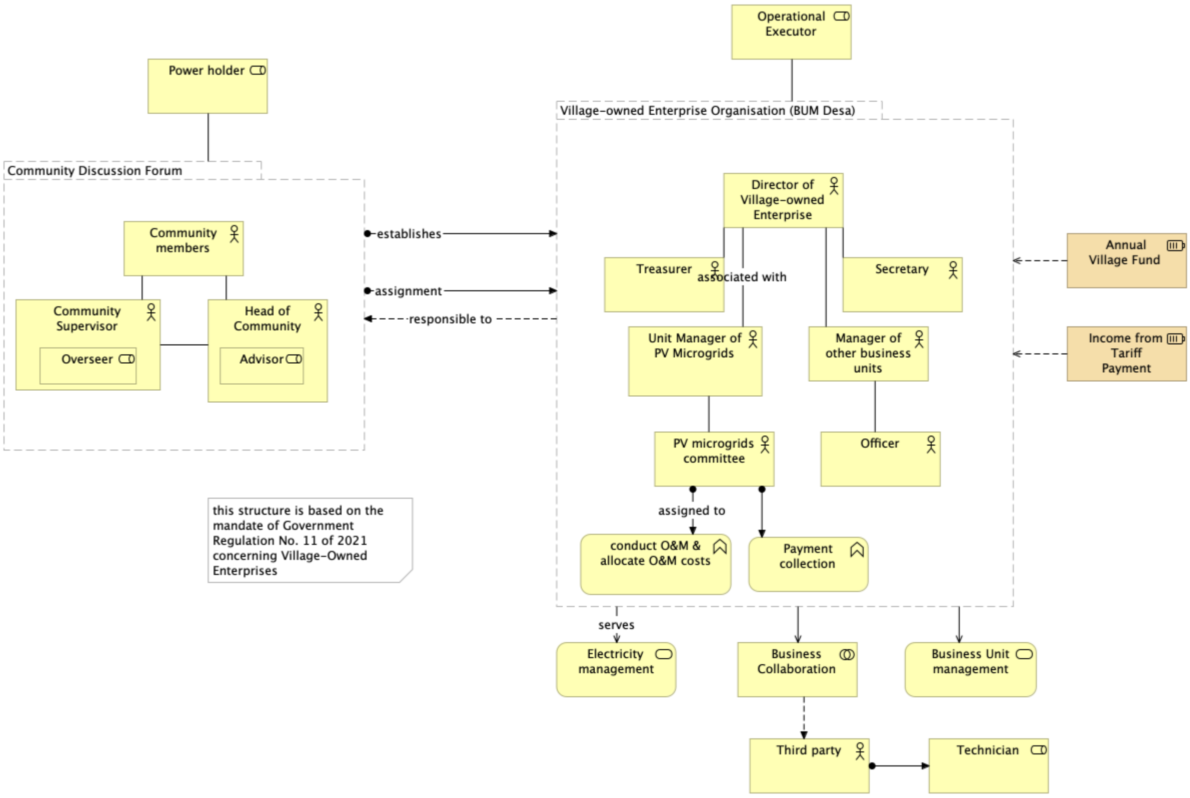

Figure 52 Village-owned Enterprise (BUMDes) structure as proposed O&M business model in the case study

c. Proposed O&M Technical Strategies in the Case Study (Target)

Proposed O&M technical strategies in case study offer target (to-be) situations in specific case study for Tanimbar Islands District. These target situations are developed based on reference model and make adjustment based on the context location.

The optimal scenario for preventive maintenance refers to reference model about Preventive Maintenance Viewpoint. In this case study, the desired situation elaborates more on detailed components in the application layer and technology layer as shown in **Figure 53**. The proposed situation envisions operators being able to conduct preventive maintenance by monitoring the status data of equipment performance. This is achieved through a monitoring interface available on a monitoring platform. The data can be retrieved from devices such as computers, controllers, or inverters interconnected within a network. This streamlined process enhances efficient monitoring and enables the implementation of proactive maintenance measures.

Moreover, the target situations for corrective maintenance and predictive maintenance in this case study align with those depicted in the reference model in Section 4.2.3 part c. This alignment signifies that these situations accurately mirror the desired conditions in the case study.

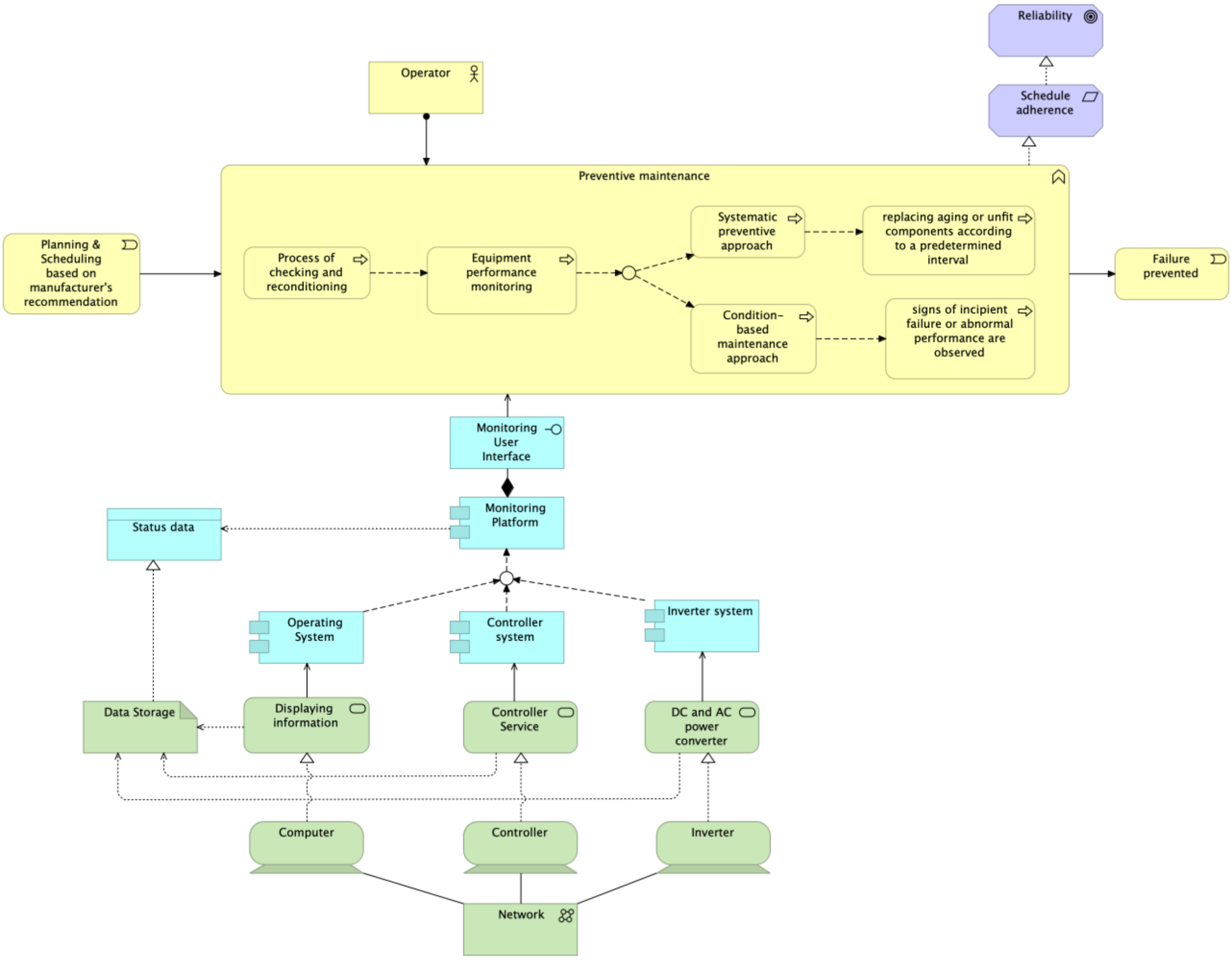

Figure 53 Preventive Maintenance (Target)

d. Gap Analysis

1) Gap Analysis: Preventive Maintenance

The gap in addressing the implementation of preventive technology, an observation was conducted on the existing technology in the case study area and compared to the ideal preventive maintenance. While most components are available, a noticeable gap emerges in the network infrastructure as highlighted in **Figure 54**. Upon further investigation, the absence of a network is attributed to the lack of allocated budget specifically for network infrastructure due to insufficient tariff rates in the region. The lack of network connection can hamper the remote monitoring. However, this gap is relatively minor; for preventive maintenance in case study, the data can be retrieved directly offline either from a computer, controller or inverter.

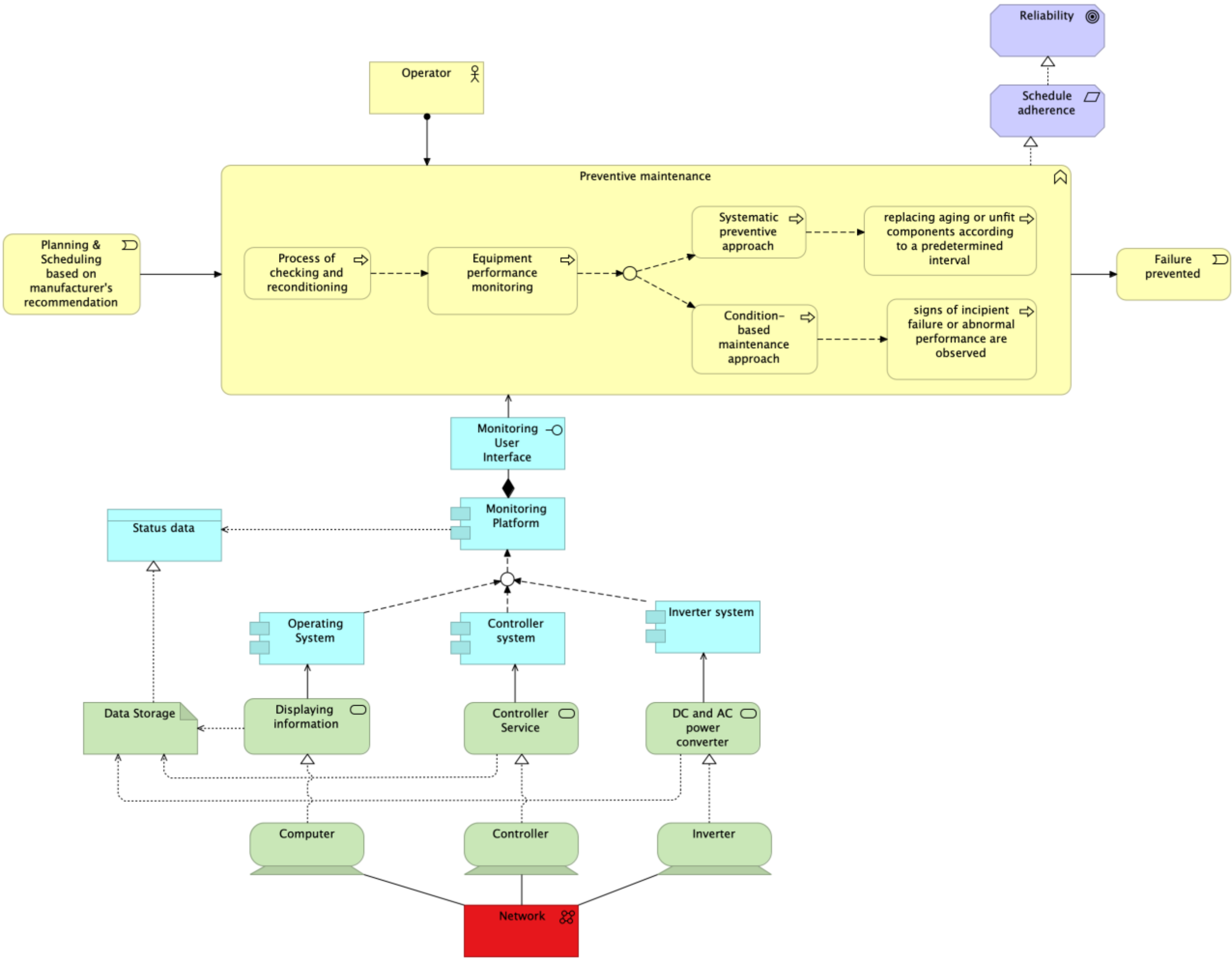

Figure 54. The technology gap in preventive maintenance within the case study is represented by the red colour

2) Gap Analysis: Predictive Maintenance

The gap analysis is found in the realm of predictive maintenance as shown in **Figure** *55*. The gap analysis conducted in this domain revealed a critical shortage in the case study context: there is a notable absence of technicians trained in predictive maintenance techniques, compounded by the lack of support from researchers. This shortage significantly limits the available skill set necessary for effective predictive maintenance analysis within the case study.

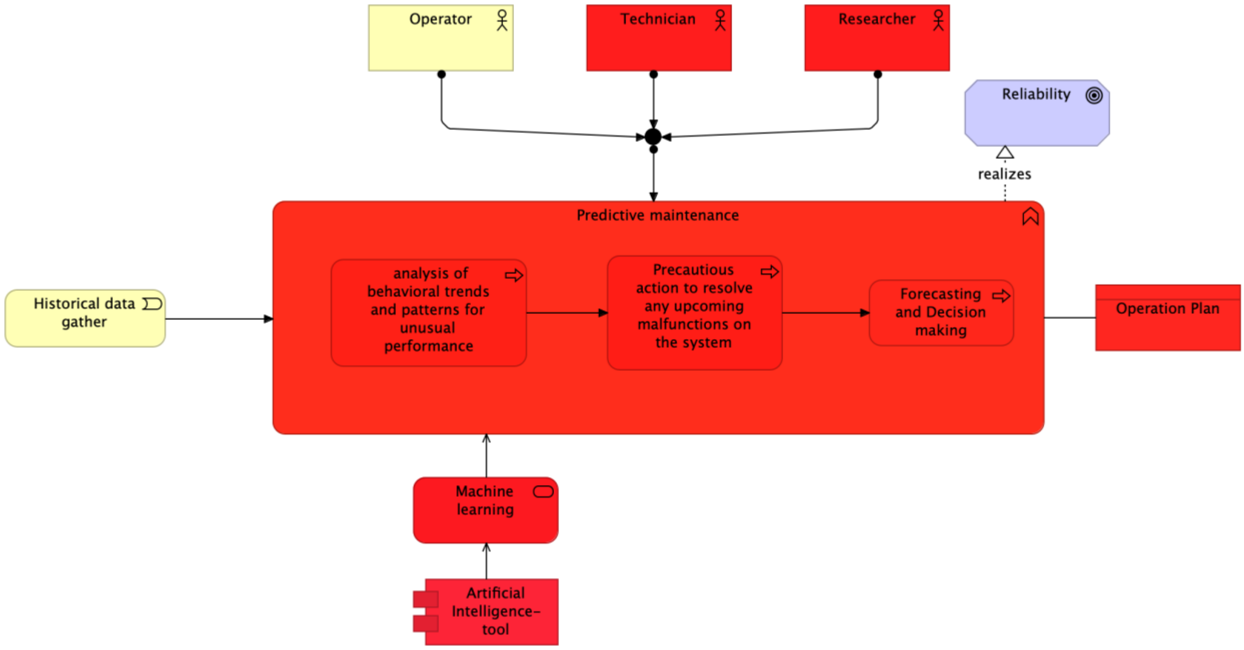

Figure 55. The technology and human resource gap in preventive maintenance within the case study are represented by the red colour

e. Proposed Migration Planning for O&M Strategies Initiation in the Case Study

The proposed migration plan delineates the steps necessary to transition from the current situation (as-is condition) to the desired state (to-be situation), encompassing three plateaus: the existing condition, O&M management strategies, and O&M technical strategies. These strategies can be executed concurrently to expedite the process.

Initiating the O&M management strategies takes precedence over the technical strategies, focusing on establishing a clear business model and effective tariff mechanisms. A coherent business model is pivotal, enabling the allocation of O&M costs and funds for potential repairs or replacements. Without a well-defined business model, akin to the current situation, any unexpected failures may result in unallocated recovery costs.

To transition between plateaus, several work projects should be undertaken. Addressing the gaps identified within the O&M management strategies reveals two key areas: the ownership gap concerning assets and the lack of O&M cost allocation due to the absence of a business model. Particularly in PV Microgrid C and D, the initial step involves transferring asset ownership from the district level to the village level, laying the groundwork for a business model fully managed by the village. Subsequently, establishing a PV microgrid committee within a formal organisation, such as BUMDes, is imperative, clarifying their roles, rights, and responsibilities in a documented agreement. Additionally, formulating a tariff agreement and defining O&M cost allocations are pivotal components of this strategy.

On the other side, O&M technical strategies aim to address electrical engineering competency and technology gaps. Implementing these strategies necessitates technical support and human capacity development, achievable through operator training and certification initiatives. Fulfilling these outlined steps ensures the successful implementation of the O&M strategies. The proposed migration planning for O&M strategies initiation in the case study is illustrated in **Figure 56**.

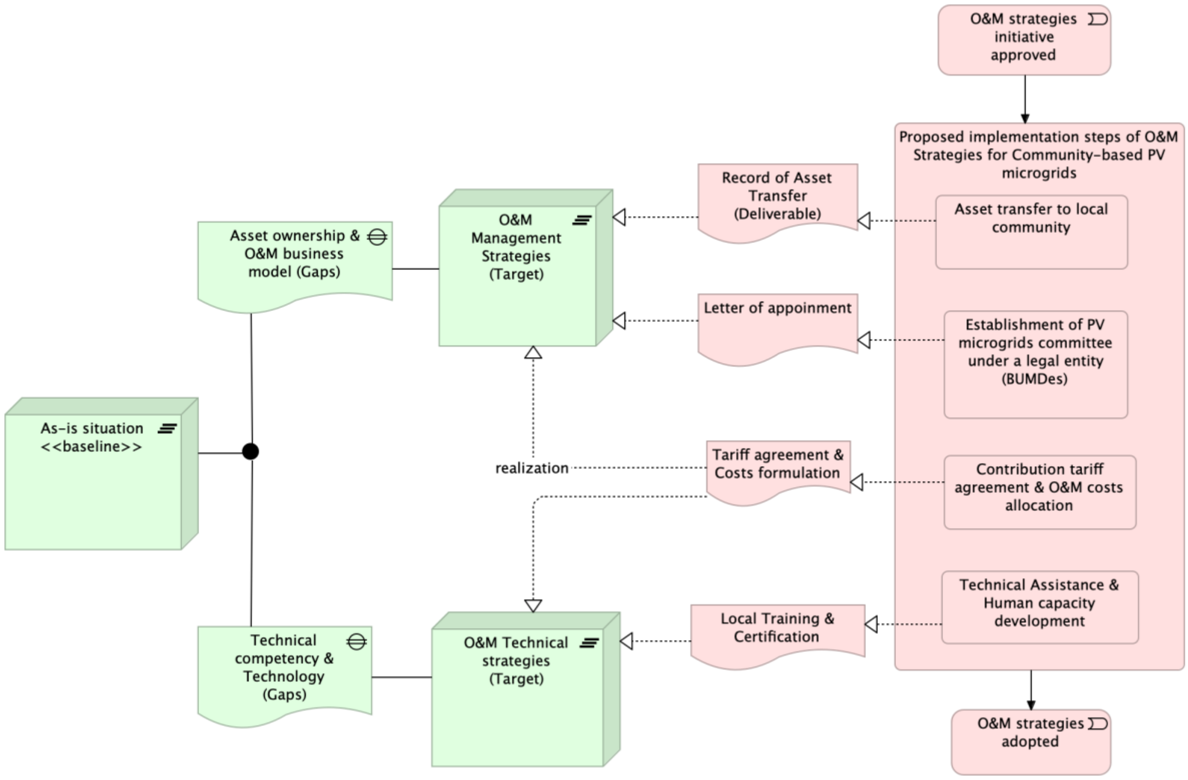

Figure 56 Proposed Migration and Planning in the Case Study

The researcher suggests that a collaborative effort of stakeholders is essential in migration and implementation planning, including PV microgrid owners, government entities, and development organisations. PV microgrid owners, being responsible for the assets, have the choice to manage them internally or delegate to another party. In the case study, considering the distance of PV microgrid owners from the site, transferring ownership to the village government can be a viable option.

Both the central government and district government play vital roles in providing policies for O&M and incentives to support financial viability. Development organisations such as NGO, can contribute through technical assistance, providing training on O&M, and seeking donors to support the initiatives. In summary, migration and implementation planning can be effectively conducted simultaneously with the coordinated efforts of various stakeholders.

5.4. Summary of Chapter 5

In essence, this chapter involves the validation of the reference model applied within the case study, focusing on proposing business model, ideal situation of O&M strategies, identifying any gaps and suggesting subsequent implementation steps for potential adoption of the model. It also presents a reflective analysis highlighting areas requiring improvement within the case study. Primarily, the challenges identified encompass aspects such as asset ownership, the need for an effective O&M business model, technical competency gaps, and technological shortcomings. In summary, the reference model demonstrates its capability to guide the application of O&M strategies in a specific context location following the outlined model.

CHAPTER 6

REFERENCE MODEL VALIDATION: EXPERT OPINION

6. Validation of O&M Strategies Reference Model: Expert Opinion

This chapter is part of treatment validation in design cycle and it explores the validation procedure of the previously outlined solution in Chapter 4 and 5. This chapter is also to answer sub research question #5: *What is the feedback from experts on the proposed reference model for O&M strategies in community-based PV microgrids?*

6.1. Validation Participants and Validation Protocol

The validation session was conducted from 10 December 2023 to 12 January 2024. There are five validation participants as follows:

1. Participant A: A renewable energy technical officer from NZMATES, holding an educational background in Physics Engineering.
2. Participant B: A leader in a Demonstration Project associated with the UK-Indonesia low carbon energy partnership program, called Towards Indonesia's Low Carbon Energy Transition "MENTARI". He possesses 15 years of professional expertise acquired across private, government, and development sectors, with nearly a decade dedicated to small-scale renewable energy initiatives.
3. Participant C: The Head of the Mechanical Engineering Department at the State Polytechnic of Ambon in Maluku Province, Indonesia.
4. Participant D: An Indonesian researcher based in Australia with 7 years of professional expertise in renewable energy, focusing on climate and energy access research.
5. Participant E: An official of Directorate General of New, Renewable Energy and Energy Conservation, Ministry of Energy and Mineral Resources, Republic of Indonesia.

The protocol involved the researcher arranging video conferences with each participant according to availability. During these sessions, the researcher presented an overview of the research, encompassing the general reference model and the specific model utilised in the case study. Following the initial presentation, a short questionnaire was provided to obtain the participants' opinions, coupled with the distribution of a questionnaire via an online form. The entirety of the validation interview session was completed within a time frame of approximately one hour.

The selection criteria for the validation participants centred on their specialised expertise in renewable energy, particularly in the domain of PV microgrids within the context of Maluku Province. These individuals were chosen based on their profound knowledge and practical experience in this field, enabling them to effectively assess the reference model presented and evaluate its alignment with the real-world scenario reflected in the case study. Their extensive familiarity with PV microgrid systems in the Maluku Province equipped them with the capability to critically evaluate the applicability, relevance, and suitability of the reference model in comparison to the practical context outlined in the case study.

Table 16 presents each question within the themes sought scores and opinions, except for the theme "Adoption of Reference Model", where the researcher exclusively sought participants' opinions. This deviation was due to the fact that the participants were not decision-makers responsible for the adoption of the model.

Table 16 Validation Criteria Derived from Reference Model Requirements

Theme (Reference Model Requirements)	Questions	Remark
Capability to Model O&M Processes & O&M Components	How well does the reference model support the modelling of diverse O&M activities and O&M components within the system?	Score (Likert scale) 1= Very Poor 5= Very well
Integration of Stakeholders and Roles	How well does the reference model enable the modelling of various stakeholders involved in O&M, defining their roles, responsibilities, and interactions?	1= Very Poor 5= Very well
Flexibility and Adaptability	To what extent does the model allow for updates, modifications, and additions to the strategy over time?	1= Not at all 5= To a Great Extent
Visualisation & Usability	To what extent do the visualisation tools aid in comprehending the O&M strategies within the reference model?	1= Not at all 5= To a Great Extent
Supporting high-level goal achievability	To what extent does this reference model support the sustainability (technical, economic, and environmental sustainability) of community-based PV microgrids?	1= Not at all 5= To a Great Extent
Adoption of Reference Model	If these strategies will be adopted, what aspects that hinders this adoption?	Open question

6.2.Validation Results and Analysis

The analysis of the interview results begins with an overview of the questionnaire findings. This section primarily focuses on two statistical measures: the average (mean) and the standard deviation. The outcomes, as outlined in **Table 17**, indicate an average score between 4.0 and 4.8 out of 5, for each question. Additionally, the standard deviation recorded is below 1. Typically, a standard deviation of 0 suggests a consensus among respondents, while a value exceeding 1 indicates considerable diversity in their responses. In this case, the relatively low standard deviation implies a high level of agreement among the participants regarding their satisfaction with the requirements of reference model.

Table 17 Validation Results

Validation Theme (Reference Model Requirements)	Score from Participant					Average	Standard Deviation
	A	B	C	D	E		
Capability to Model O&M Processes & O&M Components	4	5	5	4	5	4.60	0.55
Integration of Stakeholders and Roles	4	4	5	3	4	4.00	0.71
Flexibility and Adaptability	4	4	5	3	4	4.00	0.71
Visualisation & Usability	4	5	5	5	4	4.60	0.55
Supporting high-level goal achievability	4	5	5	5	5	4.80	0.45

The comprehensive transcript derived from the interview sessions, detailed in Appendix B, encapsulates the key findings garnered from these discussions. Participants have provided their assessment justifications, as outlined below:

a. Capability to Model O&M Processes & O&M Components

Participants A, D, E acknowledged the reference model's structured nature, facilitating immediate comprehension. Participant B proposed to add warranty management in the reference model. Participant D suggests that in addition to local operator training, there should be an empowerment of local service providers. According to them, one of the sustainability factors is having access to long-term local providers. This can be accomplished by identifying local enterprises such as repair shops, limited partnerships (CV), and involving them in O&M training. The idea is that in the future, these entities can evolve into potential local service providers.

b. Integration of Stakeholders and Roles

All participants agreed on the reference model's ability to integrate stakeholders and their respective roles, offering a clear representation. Participant B reminded the researcher to check the regulation and policy of each stakeholder involved.

c. Flexibility and Adaptability

Participant A noted potential adaptability in O&M management, Participant C expressed optimism about potential applications in the Maluku region due to the model's structuring capabilities, and Participant B mentioned that adaptability depends on the context location. However, Participant D expressed concern about the importance of social aspects, which are not covered in this study.

d. Visualisation & Usability

Participant A found the reference model's graphical representation superior to traditional descriptive text, indicating easier understanding. Similarly, Participant C agreed, emphasizing the ease of comprehension through visualisation. Participant D also highlighted that the reference model, with its use of colours, is easy to understand. This model has the potential to be highly beneficial if effectively communicated to operators.

e. High-level goal achievability

Both Participant A and C acknowledged the reference model's support for sustainability in the future, especially if the three maintenance strategies can be implemented by the local community. In addition, Participant D expressed that the reference model has the potential to contribute to sustainability if effectively translated and communicated to stakeholders, particularly to community operators. At a higher level, specifically for the Indonesian MEMR, the reference model can serve as a pivotal point and reflection, especially in planning and budgeting, aiming for improved projects in the future. Moreover, Participant B suggested that current PV microgrids still require incentives from government due to an inadequate business model in those areas.

f. Adoption of Reference Model

Participants A and C identified competency difficulties among local operators as a potential obstacle, while Participant B expressed concerns about local energy management, and Participant E highlighted potential technical aspect considerations hampering national-level adoption.

In summary, the validation process uncovered key insights on the efficacy of the reference model and the potential difficulties that may arise during its deployment. The model clearly illustrates the O&M procedures, however, there are worries about the competency of operators, particularly among non-experts. The beneficial parts of stakeholder integration and role representation were widely acknowledged. Although the model demonstrated adaptability and potential for local application, precisely capturing real-world situations could pose difficulties. The visual depiction improved usability, despite certain observed and anticipated effects. The challenges in adopting the approach included operator proficiency, financial limitations, and the constraints related to the primary duties and functions of sub-governmental institutions. These disclosures highlight the model's advantages while identifying key areas for improvement and addressing obstacles to ensure its effective implementation.

CHAPTER 7

CONCLUSIONS & RECOMMENDATIONS

7. Conclusions and Recommendations

This chapter encompasses the reflection of research questions, a conclusion, highlighting contributions, outlining limitations, and proposing future research directions.

7.1. Reflection of Research Questions

In essence, this research has addressed the main research question of improving O&M practices for community-based PV microgrids by designing a reference model for O&M strategies that supports the sustainability of these microgrids throughout their lifetime. Furthermore, below is the reflection of how the sub-research questions are answered.

SQ#1*: What is the state-of-art of O&M for community-based PV microgrids?*

The first sub-research question delved into understanding the theoretical background of O&M practices in these microgrids. The literature review was performed in this process, providing valuable insights into existing knowledge and practices within this domain.

SQ#2*: What is the contextual overview of the case study location, and how do the actual O&M activities and PV microgrids perform on small islands?*

The second sub-research question focused on establishing the contextual overview of the case study location and assessing the actual O&M activities and performance of PV microgrids on small islands. This was achieved through an in-depth analysis presented in Chapter 3. It offers a detailed understanding of the challenges and nuances in the studied context and draws insights from a meticulous analysis conducted through on-site observations and stakeholders interviews.

SQ#3*: How can the reference model of O&M strategies for community-based PV microgrids be specified?*

The third sub-research question was centred on specifying the reference model of the O&M strategies. Chapter 4 provides the conceptual framework and requirements for designing the reference model, outlining the necessary components and considerations needed to create an effective strategy. ArchiMate modelling language has been used in designing the reference model with an enterprise architecture approach.

SQ#4: *How can the reference model of the O&M strategies be operationalised to support community-based PV microgrids in a case study, such as Tanimbar Islands District, Indonesia?*

Moving on to the fourth sub-research question, Chapter 5 elaborated on how the reference model of the O&M strategies could be operationalised to support community-based PV microgrids in Tanimbar Islands District, Indonesia. It provided the picture of current situation, target situation, gap analysis and practical steps for implementing the designed strategies within the identified context.

SQ#5*: What is the feedback from experts on the proposed reference model for O&M strategies in community-based PV microgrids?*

Lastly, the fifth sub-research question sought expert feedback on the proposed reference model. Chapter 6 discussed the insights gained from expert evaluation to validate the proposed model based on expert opinion through one-on-one interview and an online questionnaire.

Collectively, this research comprehensively addressed the main research question and its sub-questions, offering a multi-faceted approach towards enhancing O&M practices for community-based PV microgrids. The findings put forth in each chapter contribute to the understanding and improvement of sustainable O&M strategies within this specific context.

7.2. Conclusion

In summary, this study has introduced a specialised reference model tailored for structuring the O&M strategies in community-based PV microgrids situated on small islands. The reference model as the artifact of this study incorporates conceptual framework of O&M strategies and multiple viewpoints, including motivation, strategy, maintenance strategies (preventive, corrective, and predictive maintenance) and migration planning for managing O&M practices in such contexts. Leveraging the ArchiMate modelling language, this model allows the mapping of O&M processes, PV microgrid components, stakeholder roles, and gap analysis. Moreover, the reference model, with standardised notation, functions as a means of communication to convey concepts, processes, plans regarding O&M strategies to experts and non-experts.

To ensure relevance and suitability to the specific context of remote islands, this reference model underwent a case study validation. Another validation also involved experts in energy domain, offering feedback and validating the design decisions of the reference model. Validation activities involving expert opinion underscored the significance of this framework in ensuring the efficient and sustainable operation of PV microgrids on small islands. The validation participants identified several benefits, such as the usability of the reference model, the effectiveness of visualisation compared to traditional text-based approaches, and adaptability to diverse settings. However, validation interviews also identified potential barriers to O&M strategies adoption, such as budget constraints, local operator competency, local energy management, and the rigidity of procedural tasks and bureaucratic system at governmental institutions.

7.3. Contributions

The contribution of this research encompasses two significant aspects: academic and practical contributions.

a. Academic Contribution:

The academic significance of this research lies in its unique and innovative approach to addressing the complexities of O&M strategies in community-based PV microgrids, particularly in remote island environments. By establishing a reference model for O&M strategies, this study contributes to the theoretical framework within the field of energy management and microgrid sustainability. The utilisation of a real-world case study in in specific geographic context and primary data collection techniques also enriches the existing academic knowledge base by offering empirical evidence and practical insights. Additionally, this research provides a structured and systematic approach for future academic studies in similar contexts, thereby fostering the development of more effective O&M strategies for sustainable PV microgrids in remote and island communities.

b. Practical Contribution:

This research aims to address real-world challenge, specifically regarding O&M within small island contexts. It leverages primary data obtained directly from fieldwork in Tanimbar Islands District, Maluku Province, Indonesia, providing crucial insights into O&M practices within community-based PV microgrids. Moreover, the research offers practical recommendations in the form of reference model, serving as a guideline for adopting of O&M strategies. A set of reference model is designed to be practical and actionable, offering specific considerations and key factors to contemplate when implementing O&M strategies within similar settings. A practical next step will involve sharing and presenting the results of this study with the stakeholders in Indonesia.

7.4. Limitations

It is important to acknowledge the limitations faced during this research study as follow:

1. **Limited Time for Data Collection:** The constrained time for data collection suggests the potential for increased participant involvement to enhance data reliability.
2. **Focus on Higher-Level O&M Strategy:** The study's limitation lies in its focus on the higher-level O&M strategy, prioritizing essential aspects like maintenance strategies and the O&M business model while abstracting technical components. Moreover, this study also refrains from delving into the analysis of the dynamic aspects of the social dimension. It may impact the precision and depth of the reference model's design.
3. **Limitation in Design Cycle Steps**: This research is confined to three steps of the design cycle by Wieringa (2014), specifically concentrating on problem investigation, treatment design, and treatment validation. Notably, it excludes the treatment implementation phase and implementation evaluation from its scope.
4. **Absence of Instantiation:** Another limitation is the absence of instantiation and deployment of the reference model into the actual implementation of a system or a project.

7.5. Future Research Recommendations

The recommendation for future research pathways could explore these following areas:

1. **Implementation of Concrete Technical Components:** To bring the currently more abstract technical components to a more concrete approach in real-world projects or scenarios.
2. **Stakeholders' Perspective Analysis**: To conduct a comprehensive content analysis of the stakeholders’ perspective towards O&M for PV microgrids on small islands.
3. **Cost-Effective Maintenance Approaches:** To investigate cost-effective maintenance approaches tailored to the limited resources characteristic of small island communities.
4. **Integration of Emerging Technologies**: To explore the integration of emerging technologies like data science, artificial intelligence, Internet of Things (IoT), smart BMS, and intelligent monitoring into O&M strategies for more efficient and cost-effective solutions.

5. **Validation Through Case Studies**: Given the substantial impact of technical factors such as system size, design, and contextual differences on the O&M strategy, validating the approach through case studies in various locations is highly recommended.

In summary, ongoing research efforts could continue refining existing frameworks while exploring innovative methods to address challenges encountered by community-based PV microgrids on small islands.

REFERENCES

References

Abbas, M., Kim, E., Kim, S., & Kim, Y. (2016). Comparative Analysis of Battery Behavior with Different Modes of Discharge for Optimal Capacity Sizing and BMS Operation. *Energies*, *9*(10), 812. https://doi.org/10.3390/en9100812

Aljafari, B., Vasantharaj, S., Indragandhi, V., & Vaibhav, R. (2022). Optimization of DC, AC, and Hybrid AC/DC Microgrid-Based IoT Systems: A Review. *Energies*, *15*(18), 6813. https://doi.org/10.3390/en15186813

Asian Development Bank. (2014). *Attaining sustainable energy access for all: Third Asia-Pacific dialogue on clean energy governance, policy, law, and regulation*. https://www.adb.org/sites/default/files/publication/42468/attaining-sustainable-energy-access-all.pdf

Asia-Pacific Economic Cooperation (APEC) Policy Support Unit. (2018). *Development and Integration of Remote Areas in the APEC Region*. https://www.apec.org/docs/default-source/Publications/2018/11/Development-and-Integration-of-Remote-Areas-in-the-APEC-Region/218_PSU_Remote-areas-development.pdf

Barsei, A. N., & Saptohadi, J. (2023). Analisis Pemangku Kepentingan dalam Pengembangan Energi Terbarukan: Studi Kasus Pembangkit Listrik Tenaga Surya (PLTS) Desa Muara Enggelam. *Inovasi*, *20*(1), 41–54. https://doi.org/10.33626/inovasi.v20i1.641

Bizzdesign. (n.d.). *ArchiMate concepts downloads*.

Boruah, D., & Chandel, S. S. (2023). Challenges in the operational performance of six 15-19kWp photovoltaic mini-grid power plants in the Jharkhand State of India. *Energy for Sustainable Development*, *73*, 326–339. https://doi.org/10.1016/j.esd.2023.02.013

Candela, L. & C. D. & F. N. & I. Y. & K. G. & M. C. & P. P. & R. S. & S. D. & A. M. & D.-M. M. & K. V. & S. Heiko. (2007). *The DELOS Digital Library Reference Model - Foundations for Digital Libraries.* .

Canziani, F., & Melgarejo, Ó. (2018). Design and implementation of rural microgrids. In *Microgrids Design and Implementation* (pp. 477–504). https://doi.org/10.1007/978-3-319-98687-6_17

Chowdhury, S., Chowdhury, S. P., & Crossley, P. (2009). Microgrids and active distribution networks. In *Microgrids and Active Distribution Networks*. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85013036572&partnerID=40&md5=7e72d024a16b4acb7c99c518dd293c58

Derks, M., & Romijn, H. (2019). Sustainable performance challenges of rural microgrids: Analysis of incentives and policy framework in Indonesia. *Energy for Sustainable Development*, *53*, 57–70. https://doi.org/10.1016/j.esd.2019.08.003

Energy Sector Management Assistance Program (ESMAP). (2022). *Mini Grids for Half a Billion People: Market Outlook and Handbook for Decision Makers.* . World Bank. https://www.esmap.org/mini_grids_for_half_a_billion_people_the_report

Girbau-Llistuella, F., Sumper, A., Gallart-Fernandez, R., & Buehner, V. (2015). Operation of rural distribution grids with intermittent generation in connected and island mode using the open source EMS solver SCIP. *2015 International Conference on Renewable Energy Research and Applications, ICRERA 2015*, 983–988. https://doi.org/10.1109/ICRERA.2015.7418557

Hosiaisluoma, E. (2019). *ArchiMate Metamodel For Enterprise Development*. https://www.hosiaisluoma.fi/blog/archimate-metamodel/

IRENA. (2019). *Future of Solar Photovoltaic: Deployment, investment, technology, grid integration and socio-economic aspects (A Global Energy Transformation: paper)*. https://www.irena.org/publications/2019/Nov/Future-of-Solar-Photovoltaic

Keisang, K., Bader, T., & Samikannu, R. (2021a). Review of Operation and Maintenance Methodologies for Solar Photovoltaic Microgrids. In *Frontiers in Energy Research* (Vol. 9). Frontiers Media S.A. https://doi.org/10.3389/fenrg.2021.730230

Kembauw, E. S. A. M. ; S. L. J. (2017). *Pembangunan Perekonomian Maluku*. https://books.google.co.id/books?id=--FeDwAAQBAJ&printsec=frontcover

KontraS. (2019). *Pulau Kecil Dan Hak Asasi Manusia Catatan Situasi HAM Di Tiga Pulau Kecil (Pulau Bangka, Pulau Sunut, Pulau Romang)* . https://kontras.org/wp-content/uploads/2019/11/cetak_pulau-kecil.pdf

Kubu Raya District Government. (2021). *Tiga Desa Terjauh Terima Hibah PLTS, Senilai Rp26 M, Dikelola Bumdes (Three Farthest Villages Receive PLTS Grants, Worth IDR 26 billions, Managed by Bumdes)*. https://kuburayakab.go.id/seputar-kuburaya/berita/tiga-desa-terjauh-terima-hibah-plts-senilai-rp26-dikelola-bumdes

Lankhorst, M. (2009). *Enterprise Architecture at Work*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-01310-2

MENTARI. (2022, August). *MENTARI Kerjasama Inggris – Indonesia pada sektor Energi Rendah Karbon, Peresmian PLTS 95kWp dan baterai milik masyarakat di Sumba Tengah (MENTARI UK – Indonesia Cooperation in the Low Carbon Energy sector, Inauguration of 95kWp PLTS and community owned batteries in Central Sumba)*. https://mentari.info/id/2022/08/24/mentari-kerjasama-inggris-indonesia-pada-sektor-energi-rendah-karbon-peresmian-plts-95kwp-dan-baterai-milik-masyarakat-di-sumba-tengah/

Mercy Corps Indonesia. (2021). *Renewable Energy Technical Specialist (Rets) – Nzmates*. https://www.mercycorps.or.id/peluang/renewable-energy-technical-specialist-rets-nzmates

Ministry of Energy and Mineral Resources. (2017a). *KEBIJAKAN, REGULASI DAN INISIATIF PENGEMBANGAN ENERGI SURYA DI INDONESIA (POLICIES, REGULATIONS AND DEVELOPMENT INITIATIVES SOLAR ENERGY IN INDONESIA)*. https://iesr.or.id/wp-content/uploads/2019/10/2019-10-10-Bahan-Paparan-Akselerasi-PLTS-Mencapai-65-GW-pada-2025-IESR.pdf

Ministry of Energy and Mineral Resources, R. of I. (2017b). *Panduan Pengoperasian dan Pemeliharaan PLTS Off-grid (Off-grid Solar Power Plant Operation and Maintenance Guide)*. https://ebtke.esdm.go.id/post/2018/01/31/1870/buku.panduan.pengoperasian.dan.pemeliharaan.pembangkit.listrik.tenaga.surya.plts.off-grid

Ministry of Energy and Mineral Resources, R. of I. (2020). *PANDUAN PENGELOLAAN LINGKUNGAN PEMBANGKIT LISTRIK TENAGA SURYA (PLTS) (SOLAR POWER PLANT (PLTS) ENVIRONMENTAL MANAGEMENT GUIDE)*. https://ebtke.esdm.go.id/post/2021/02/22/2806/buku.panduan.pengelola.lingkungan.plts

Ministry of Internal Affairs Republic of Indonesia. (2023). *Population Data Visualization (Visualisasi Data Kependudukan)*. https://gis.dukcapil.kemendagri.go.id/peta/

MONGABAY. (2023). *Muara Enggelam, Desa "Role Model" PLTS Komunal di Kalimantan Timur (Muara Enggelam, "Role Model" Village of Communal PV microgrids in East Kalimantan)*. https://www.mongabay.co.id/2023/08/16/muara-enggelam-desa-role-model-plts-komunal-di-kalimantan-timur/

Mumtaz, F., & Bayram, I. S. (2017). Planning, Operation, and Protection of Microgrids: An Overview. *Energy Procedia*, *107*, 94–100. https://doi.org/10.1016/j.egypro.2016.12.137

OASIS. (2006). *Reference Model for Service Oriented Architecture 1.0 (2006)*.

OASIS SOA Technical Committee. (n.d.). *OASIS SOA Reference Model*. Retrieved December 7, 2023, from https://www.oasis-open.org/committees/soa-rm/faq.php

Oxford University Press. (2023). *Oxford English Dictionay*. https://www.oed.com/search/dictionary/?scope=Entries&q=strategy

Rahmann, C., Núñez, O., Valencia, F., Arrechea, S., Sager, J., & Kammen, D. (2016). Methodology for monitoring sustainable development of isolated microgrids in rural communities. *Sustainability (Switzerland)*, *8*(11). https://doi.org/10.3390/su8111163

Ramadhani, B., Suryani, A., Fadhillah, Atiek. P., Saichu, P., Mubarok, M. H., Wibowo, C., Askolani, I., Broemling, G. J., & Lechman, I. (2019). *PV Mini-Grid Installation: Dos and Don'ts*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH . https://endev.info/wp-content/uploads/2021/06/PV-Mini-Grid-Dos-and-Donts.pdf

Rao, K. U., Parvatikar, A. G., Gokul S., Nitish N., & Rao, P. (2016). A novel fault diagnostic strategy for PV micro grid to achieve Reliability Centered Maintenance. *2016 IEEE 1st International Conference on Power Electronics, Intelligent Control and Energy Systems (ICPEICES)*, 1–4. https://doi.org/10.1109/ICPEICES.2016.7853546

Raya-Armenta, J. M., Bazmohammadi, N., Avina-Cervantes, J. G., Sáez, D., Vasquez, J. C., & Guerrero, J. M. (2021). Energy management system optimization in islanded microgrids: An overview and future trends. *Renewable and Sustainable Energy Reviews*, *149*. https://doi.org/10.1016/j.rser.2021.111327

Saire, J. E. C., Gastelo-Roque, J. A., & Canziani, F. (2021). Study of a hybrid photovoltaic-wind smart microgrid using data science approach. *2021 IEEE PES Innovative Smart Grid Technologies Conference - Latin America, ISGT Latin America 2021*. https://doi.org/10.1109/ISGTLatinAmerica52371.2021.9543064

Savitri, D. A. (2023). *Design and implementation of velocity in risk assessment with enterprise architecture modeling*. http://essay.utwente.nl/96135/

Schnitzer, D., Carvallo, J., Lounsbury, D., Deshmukh, R., Apt, J., & Kammen, D. (2014). *Microgrids for Rural Electrification: A critical review of best practices based on seven case studies*. https://doi.org/10.13140/RG.2.1.1399.9600

Simatupang, D., Sulaeman, I., Moonen, N., Maulana, R., Baharuddin, S., Suryani, A., Popovic, J., & Leferink, F. (2021). Remote Microgrids for Energy Access in Indonesia—Part II: PV Microgrids and a Technology Outlook. *Energies*, *14*(21), 6901. https://doi.org/10.3390/en14216901

Sulaeman, I., Simatupang, D. P., Noya, B. K., Suryani, A., Moonen, N., Popovic, J., & Leferink, F. (2021). Remote microgrids for energy access in indonesia—part i: Scaling and sustainability challenges and a technology outlook. *Energies*, *14*(20). https://doi.org/10.3390/en14206643

Sun, D., Tang, Y., Yang, B., Feng, X., Wang, Y., & Li, H. (2019). Research on Preventive-Emergency Control Method Based on Multi-communications in Island Microgrid. *2018 International Conference on Power System Technology, POWERCON 2018 - Proceedings*, 1579–1585. https://doi.org/10.1109/POWERCON.2018.8602043

Talaat, M., Elkholy, M. H., Alblawi, A., & Said, T. (2023). Artificial intelligence applications for microgrids integration and management of hybrid renewable energy sources. *Artificial Intelligence Review*, *56*(9), 10557–10611. https://doi.org/10.1007/s10462-023-10410-w

Teras Maluku. (2022, October 3). *Belasan Aset PLTS di Maluku Rusak, Nzmates : Ada Risiko yang Cukup Tinggi (Dozens of Microgrids assets in Maluku damaged, Nzmates: There is quite a high risk)*. https://terasmaluku.com/headline/2022/10/03/belasan-aset-plts-di-maluku-rusak-nzmates-ada-risiko-yang-cukup-tinggi/

The Ministry of Energy and Mineral Resources of the Republic of Indonesia. (2023, January 30). *2023, Indonesia timur jadi target Kejar Rasio Elektrifikasi (2023, Eastern Indonesia Becomes Target to Pursue Electrification Ratio*. https://www.esdm.go.id/id/media-center/arsip-berita/2023-indonesia-timur-jadi-target-kejar-rasio-elektrifikasi#:~:text=Hal%20ini%20terlihat%20dari%20Pencapaian,capaian%20rasio%20elektrifikasi%20di%20Indonesia

The Open Group. (n.d.-a). *About Us. The Open Group: Leading the development of open, vendor-neutral technology standards and certifications*.

The Open Group. (n.d.-b). *ArchiMate® 3.2 Specification: Stakeholders, Architecture Views, and Viewpoints*. Retrieved December 4, 2023, from https://pubs.opengroup.org/architecture/archimate3-doc/ch-Stakeholders-Architecture-Views-and-Viewpoints.html#sec-Defining-and-Classifying-Viewpoints

The Open Group. (n.d.-c). *Definitions*. Retrieved January 18, 2024, from https://pubs.opengroup.org/architecture/togaf91-doc/arch/chap03.html

The Open Group. (2001). *TOGAF in the Enterprise*. http://www.opengroup.org/public/arch/p1/enterprise.htm

The Open Group. (2009). *What is Architecture in the Context of TOGAF?* https://pubs.opengroup.org/architecture/togaf90-doc/arch/chap02.html

The Open Group. (2019). *Relationship to Other Standards, Specifications, and Guidance Documents*. https://pubs.opengroup.org/architecture/archimate31-doc/apdxd.html

Ubilla, K., Jiménez-Estévez, G. A., Hernádez, R., Reyes-Chamorro, L., Irigoyen, C. H., Severino, B., & Palma-Behnke, R. (2014). Smart microgrids as a solution for rural electrification: Ensuring long-term sustainability through cadastre and business models. *IEEE Transactions on Sustainable Energy*, *5*(4), 1310–1318. https://doi.org/10.1109/TSTE.2014.2315651

Valja, M., Honeth, N., Buschle, M., Lagerstrom, R., Sasi, K. K., & Nithin, S. (2014). An archimate based analysis of microgrid control system architectures. *2014 International Conference on Embedded Systems (ICES)*, 297–301. https://doi.org/10.1109/EmbeddedSys.2014.6953179

Wieringa, R. J. (2014). *Design Science Methodology for Information Systems and Software Engineering*. Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-43839-8

Wijeratne, W. M. P. U., Yang, R. J., Too, E., & Wakefield, R. (2019). Design and development of distributed solar PV systems: Do the current tools work? *Sustainable Cities and Society*, *45*, 553–578. https://doi.org/10.1016/j.scs.2018.11.035

World Bank and the World Health Organization. (2021). *Measuring Energy Access: A guide to collecting data using 'the core questions on household energy use'*. https://www.worldbank.org/en/programs/lsms/publication/MeasuringEnergyAccess

Xu, Z., Nthontho, M., & Chowdhury, S. (2016). Rural electrification implementation strategies through microgrid approach in South African context. *International Journal of Electrical Power & Energy Systems*, *82*, 452–465. https://doi.org/10.1016/j.ijepes.2016.03.037

APPENDIX

Appendix A: Household's Interview Sheet

Household Interview

Name:
Age:
Contact Number:

Site Name:
Date:
Surveyor:

Category	Code	MTF	Indicator / statement	Response / comment	
General	GE1		How many individuals reside in the household?		
	GE2		What is your profession?	Main livelihood	
	GE3		What is the yearly/monthly income of the family?	IDR	
	GE4		What is the yearly/monthly expenditure of the family?	IDR	
	GE5	HE1	Do you have electricity in your household?	Yes/No	
	GE6	HE2	What source of electricity is used in this household? (circle all that apply)	PLN	1
				Solar microgrid	2
				Solar home system	3
				Solar lantern (LTSHE)	4
				Diesel genset	5
				Rechargeable battery (Talis)	6
				Other (specify)	0
	GE7		Since when do you use the service?		
Capacity	CA1	HE3	What source of electricity is used **most** of the time in this household? [main electricity system]	PLN	1
				Solar microgrid	2
				Solar home system	3
				Solar lantern (LTSHE)	4
				Diesel genset	5
				Rechargeable battery (Talis)	6
				Other (specify)	0
	CA2	HE4	What appliances are powered using this household's [electricity system from HE3]?	Lamp	1
				Mobile phone charger	2
				Radio	3
				Television	4
				Fan	5
				Refrigerator	6
				Rice cooker	7
				Pump	8
				Other (specify)	0
	CA3	HE5	How many lightbulbs can be powered using [electricity system from HE3]?	Number of lightbulbs and if possible the type (CFL, LED,	
	CA4		How much energy quota do you have per day?	Wh/day	
Availability	AV1	HE7	In the last 7 days, how many hours of electricity were available each day on average from [electricity system from HE3]? (Maximum 24 hours)	Number of hours or minutes or don't know	
	AV2	HE8	In the last 7 days, how many hours of electricity were available each evening on average, from 6:00 pm to 10:00 pm from [electricity system from HE3]? (Maximum 4 hours)	Number of hours or minutes or don't know	
Reliability	RE1	HE9	In the last 7 days, how many times were there unscheduled outages or blackouts from the [electricity system from HE3]?	Number of outages or don't know	
	RE2	HE10	In the last 7 days, what is the total duration of all the unscheduled outages or blackouts?	Number of hours or minutes or don't know	
	RE3		In the last 7 days, do you experience light flickering at home?	1 (always) to 10 (never)	
	RE4		Electricity helps me do activities at home better	1 (strongly disagree) to 10 (strongly agree)	
	RE5		Electricity helps me get entertainment at home	1 (strongly disagree) to 10 (strongly agree)	
	RE6		I know who to contact if I experience electricity problems at home	Who or don't know	
	RE7		I know where to buy replacements for broken home appliances	Who or don't know	
Quality	QU1	HE12	In the last 12 months, did any of this household's appliances get damaged because the voltage was going up and down in the [electricity system from HE3]?	Yes/No	
Affordability	AF1		How much do you pay for the first connection?	IDR	
	AF2		How much do you pay for the electricity monthly tariff?	IDR	
	AF3		Are you satisfied with the connection fee?	1 (very not satisfied) to 10 (very satisfied)	
	AF4		Are you satisfied with the monthly electricity fee?	1 (very not satisfied) to 10 (very satisfied)	
Formality	FO1	HE6	To whom does this household currently pay for [electricity system from HE3]?	PLN	1
				Pre-paid meter	2
				Community/village	3
				Cooperative/BUMD	4
				No one	5
				Other (specify)	0
	FO2		Are you satisfied with the payment method?	1 (very not satisfied) to 10 (very satisfied)	
Health and Safety	HS1		I think the electricity connection to [electricity system from HE3] is safe	1 (strongly disagree) to 10 (strongly agree)	
	HS2		In the last 12 months, did anyone using electricty from [electricity system from HE3] injured?	Yes/No	
	HS3	H13	In the last 12 months, did anyone using electricty from [electricity system from HE3] die or have permanent limb (bodily injury) damage?	Yes/No	

Appendix B: Expert Opinion

Table 18 Validation Interview Transcript

Theme	Questions	Participant A	Participant B	Participant C	Participant D	Participant E
Capability to Model O&M Processes & O&M Components	How well does the reference model support the modelling of diverse O&M activities and O&M components within the system?	That's enough, because it covers technical, economic and environmental sustainability aspects too. The maintenance strategy studied also includes preventive, corrective and predictive.	(It is) necessary to add warranty management.	Very good. It is true that the problem we encountered was the competence of the operators, most of them do not understand the components in PV microgrids.	It is quite comprehensive. The process, hardware components, software are very clear and representative of what is needed. Additionally, apart from local operator training, there needs to be empowerment of local service providers. As one of the sustainability factors is access to long-term local providers. This can be achieved by identifying local enterprises and involving them in O&M training. In the future, they can become the potential local service provider.	Yes, it can describe the processes and components in O&M
Integration of Stakeholders and Roles	How well does the reference model enable the modelling of various stakeholders involved in O&M, defining their roles, responsibilities, and interactions?	This is quite clear.	Be careful with the assumptions made, you must understand the authority of each stakeholder based on the law	Very good	In my opinion, for modelling it is possible to describe, but in reality, the implementation at the stakeholder level will be limited and less impact because the organisational culture and rigid procedural tasks. O&M is also influenced by the planning stage.	Yes, they can be described clearly in this reference model
Flexibility and Adaptability	To what extent does the model support the adaptability and flexibility?	The opportunity for implementing this model is very applicable, but it must be considered again regarding the condition of budget funds at the relevant BUMDes. Because the thing that often hampers work processes in the field is lack of funds and before implementing this, we must ensure that the quality of human resources at the location is sufficient to carry out a series of O&M processes from management to technical. Maybe if there is further study related to this, it will further enrich the model offered.	(It) depends on the local context	It would be very good if it could be applied in our area (Maluku) because there is a structure (in the reference model), such as challenges weaknesses, which can be described in real terms according to situations in the field.	Social culture is also very influential, because it is diverse, and difficult to predict. maybe for villages with similar characteristics, the model can be implemented, but overall, this reference model does not cover a great variety of social aspects.	It is flexible and adaptative enough to be applied
Visualisation & Usability	To what extent do the visualisation tools aid in comprehending the O&M strategies within the reference model?	For me, the visualisation depicted is quite easy to understand because it displays a diagram with a clear flow, not only in descriptive form.	It's easy to understand, but it must be determined who the overall safeguard is for.	With visualisation it can be easily understood	Very good, especially using colours and it is easy to understand. This model will be very useful if it can be conveyed well to operators, because they have the potential to be empowered, but mostly limited access, resources and information are the	The model can be used

Theme	Questions	Participant A	Participant B	Participant C	Participant D	Participant E
					obstacles. Hopefully this reference model can help operators	
High-level goal achievability	To what extent does this reference model support the sustainability (technical, economic, and environmental sustainability) of community-based PV microgrids?	If this model can be implemented in the future, it will greatly influence the sustainability of PV systems in remote areas. Especially if the three maintenance strategies can be carried out directly by the committee.	If good O&M is not supported by financial capacity, it will not be sustainable. For PV microgrids in the community, we cannot implement tariffs like national tariffs, but only contribution payments. Therefore, incentives from the Indonesian government are still needed for supporting O&M of the government-initiated PV microgrids.	Very supportive	Yes, this reference model can support sustainability if the model can be translated and conveyed well by stakeholders, especially operators in the community. At a higher level, especially for the Indonesian MEMR, the reference model can be a turning key point and reflection, especially in planning and budgeting, for better projects in the future.	The reference model is needed to support sustainability. So far, Off-grid PV microgrid has been hampered by its sustainability on the O&M side because it is constrained by post-operation aspects such as technical, economic and environmental management aspects.
Adoption of Reference Model	If these strategies will be adopted, what aspects that hinders this adoption?	Budget constraint, local operator competency, political will	(local) energy management	Competency of local operators	The barrier to adoption is that the reference model does not adequately cover social differences.	The adoption of this reference model, if implemented nationally, could be hampered due to technical aspects, network limitations, and inadequate skills in each remote area.