Developing Microgrids in the Greater Mekong Subregion (GMS) Countries: Policy Implication and Challenges

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ABSTRACT

A microgrid has its potentials and is expected by several stakeholders to be the best way to supply electricity to rural communities. Based on a localization concept of a single microgrid, local energy production and consumption should be locally optimized. Distributed renewable energy resources can be incorporated into the microgrid. The microgrid is a mechanism to reach a goal of affordable and clean energy, one of the United Nations Sustainable Development Goals. The objective of this research is to investigate the microgrid policies, microgrid constituents, and the implementation of microgrid policies. The research methodology includes primary and secondary data collection from multiple sources by using content analysis, a document study, interview, and microgrid project participation and observation, as well as data analysis and conclusion. A case study is applied as a strategy of the research. The research findings show factors determining microgrid policies and their signs of progress and challenges in the Greater Mekong Subregion (GMS) countries. Besides, the study reveals the emerging additional factors of location, capability, and regulation. These factors are significant for microgrid policy implementation. The status and challenges of the microgrid development in the GMS are the unique contributions of this study.

1. INTRODUCTION

All countries in the Greater Mekong Subregion (GMS) have moved toward sustainable electrification goals which are similar to the United Nations Sustainable Development Goal 7 (SDG7), affordable and clean energy [1]. Cambodia, Lao, and Myanmar, three of the GMS countries with large populations lacking access to electricity, were among the fastest-electrifying countries during 2010-2017, at an annual rate of 8.3, 3.3 and 3.0 percentage respectively [2].

At the global level, the electrification rate moved from 83% in 2010 to 89% in 2017 and the populations without access to electricity dropped from 1.2 billion in 2010 to 840 million in 2017 [2]. Besides, the report showed the unelectrified rural population of 732 million represented 87% of the global access deficit in 2017. It suggested the main focus on rural electrification, supplying electricity to rural communities.

A microgrid has its potentials and is expected by several stakeholders to be the best way to supply electricity to rural communities [3]. The microgrid utilizes a coalescence of renewable energy sources (RESs) (e.g. solar panels, wind turbine) and fossil fuel (e.g. diesel engine generators, and small gas turbines) to provide electricity for remote villages, factories, and among other use cases [4]. Both electricity providers and consumers will benefit from microgrid technology. They are part of the emerging smart grid layouts that seek to enhance cyber security, reduce CO_2 emissions, and reduce utility costs. Meanwhiles, consumers will receive clean and reliable delivery mechanisms, especially in remote areas where electricity is completely or partly unavailable [5].

Clean energy sources in the typical terms of RESs are incorporated into the microgrid. A variety of microgrid constituents and structured energy management are the point of concern from technological and economical perspectives [6]. The locational dependency of RESs, the distributed RESs, suggests the optimization of local electricity generation and consumption. The microgrid policies related to several significant issues including power quality, reliability, efficiency, future trends of microgrid technologies are the main research interests. The challenge of microgrid policies is related to stimulating the implementation of microgrid policies [7].

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The significance of microgrid and its policies as well as microgrid implementation in the present publications lead to the objective of the study. This study aims at investigating (i) the microgrid policies, (ii) microgrid constituents, and (iii) the implementation of microgrid policies.

2. RESEARCH METHODOLOGY

A case study was applied as a strategy of this research because of the investigation of the contemporary microgrid policies and their related issues in their real-life context. The investigator had no control over these objects of investigation. A case of microgrid development in Thailand had been comprehensively investigated. Findings were implied to the microgrid development in other countries in the GMS.

A document study and content analysis were applied to collect the secondary data from reports. Interviewing experts and probe interview techniques were applied to collect first-hand data of the experts' perception. The collected data were analyzed. The results of the analysis were interpreted and reported.

3. RELATED LITERATURE ABOUT MICROGRID POLICIES

A modern concept of the microgrid is an outgrowth of the smart grid concept. Many microgrid studies, technology development, and demonstrations have been taken place in several sites and protocols for a variety of purposes. In Asia, microgrids were not existed to any significant extent in the electricity market [6]. In addition to the microgrid itself, a microgrid policy is a research interest of many researchers [3] - [7].

3.1 Microgrid Constituent

In modern microgrid, digital technologies gradually play significant roles. All modern microgrid constituents are digitalized by degrees. In addition to digitalization, the microgrid constituents are somewhat improved, for example, by using advanced materials and techniques. From an information communication technology (ICT) perspective, the microgrid consists of an information system and a communication system. The ICT system has significant roles in the control and protection unit, one of five main microgrid constituents.

An electricity microgrid consists of five main functional constituents, as shown in Fig.1, i.e., generation unit, energy storage unit, control and protection unit, distribution system, and consumption unit.

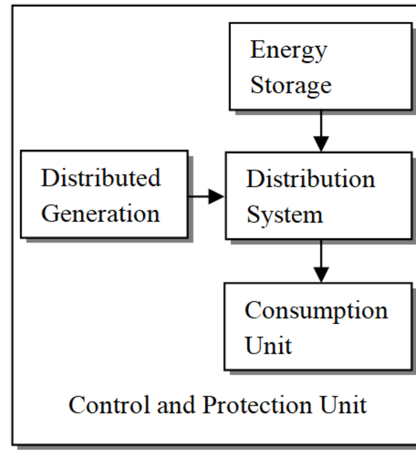

Fig. 1: **Simplified Microgrid Concept.**

RESs have been promoted as the electricity generation unit of microgrid because of their spatial origin and being environmentally friendly [8]. Popular forms of RES are solar PV, wind, biomass, biogas, and hydro. In the case of microgrid, the conceptualized electricity generation unit is based on its spatial potential and maybe sited in various potential locations. The incorporation of RES into microgrid partially contributes to the achievement of SDG7. In addition to clean RES, fossil fuel-based electricity generation unit is one of electricity generation choices.

The energy storage unit in a microgrid is recently a battery pack. It is a complementary combination of the intermittent renewable distributed generation. With the energy storage, the microgrid can prolong electricity supply to customers and improve power quality, reliability, and efficiency.

The control unit, a microgrid controller, has its main functions of controlling, monitoring, and operating in order to make a balance between the generation unit and the consumption unit. The protection unit provides the safety of microgrid equipment and operators. This unit facilitates a demand response feature that allows a controllable load to interact with a state of electricity supply.

The distribution system often refers to a medium voltage and low voltage electrical power system. The long-distance high voltage transmission of electricity is not considered as a microgrid concept. Most microgrid distribution systems are currently the alternative current systems, whereas the direct current systems are for a typical purpose.

The consumption unit, an electrical load, consists of various electrical devices and appliances, e.g., lighting bulbs, mobile phones, radio and television sets, and cooking appliances. Because of the small capacity of electricity generation units, the load is small at a scale of a building, a critical asset, and a campus [9].

Being a microgrid, the electricity generation unit and the microgrid controller are both necessary and sufficient in a modern sense of controllable entity. The generation unit can be both renewable and non-renewable energy sources. The microgrid controller is digital. The isolated or off-grid microgrid in rural areas mainly focuses on access to electricity whereas the on-grid microgrid in urban areas generally emphasizes power quality, reliability, and efficiency of electricity.

3.2 Microgrid policies

Policy refers to not only the announcements of principles, wishes, requirements, ideas, actions, interventions, and plans, but also putting such announced statements into action [10]. Policies were significant in developing microgrids [11] however its definition was not well defined [6]. The common policies of most microgrids were related to, for example, penetration of RES, cost reduction of transmission and distribution systems, greenhouse gas emission reduction, smart measurement/operation/control/communication, and improvement of energy security. Other policies related to interconnection, power quality and reliability, economics, participation in energy market, and low carbon policy were expressed.

There is a variety of studies on microgrid policies. The evaluation of policymaking for microgrids suggested that a variety of engineering-economic analysis and societal impact analysis from both customer and utility perspectives were required [12]. Three policy alternatives, i.e., (i) no additional policy, (ii) market-based policies, and (iii) command and control policies or non-market-based policies were investigated [11]. The market-based policies included the policies of carbon taxation, economic incentive, and time of use pricing. A typical study of electricity and heat microgrid business models identified that four strategic variables of microgrid implementation were natural gas price, electric tariff charges, carbon cost, and electric storage cost [9].

In conclusion, the literature reviews show that the microgrid policies are related to (a) energy security, power quality, and reliability of small power systems of electricity generation, distribution, and consumption, (b) spatial renewable distributed energy resource promotion, (c) regulations of interconnection, market participation, and tariff, (d) technology development such as information technology (IT) system, communication system, controller, and energy storage, and (e) access to affordable and clean electricity.

3.3 The implementation of microgrid policies

Putting the microgrid policies into action makes the microgrid exists in a real-life context. Factors determining the success of microgrid policy implementation reflect the determinants of microgrid policy. The policies towards the implementation of a microgrid are required [6]. The sustainable development of microgrid depends on the spatial geographical location, cost of electricity generation, distribution, and consumption, technological viability, standard, and government policy [6]. This is, more or less, in line with five groups of factors determining microgrid policy: society, politics, economy, technology, and environment [13].

Learned from the abovementioned literature and a microgrid demonstration project, the implementation of microgrid policy deals with several factors in a real-life context [14]. Such factors can be classified as (a) stakeholders, (b) technologies, (c) investment, operation and maintenance costs as well as return benefits, (d) management, and (e) policy. At a national or international level, these factor classifications can be broadly viewed from four perspectives of society, politics, economy, and environment. These perspectives are, however, out of the scope of this study.

Stakeholders refer to ones or entities that are, for example, policymakers, regulators, utilities, owners, investors, system operators, market operators, engineering-procurement-construction and operation and maintenance service providers, project planners, project managers, financial supporters, financial institutions, and technology manufacturers and suppliers.

Technologies are products, solutions, and systems both hardware and software of all microgrid constituents. The appropriate technologies are the available choices of selection in designing microgrids. In addition to the characteristics and performance of technologies themselves, their costs and related topics, e.g., collection, delivery, installation, operation, maintenance, and disposal should be taken into account in order to select technologies.

Costs and benefits of the microgrid in both financial and economic valuation reflect the value of microgrid. Financial supporters, investors, and owners take the figures of these costs and benefits into consideration. They spend the money on their beneficial purposes. Sustainability of microgrid needs more economic benefits and less economic costs during a given span of time. Economic costs and benefits reflect not only monetary but also societal and environmental values. From a practical perspective, sustainability will have its roots when significant stakeholders continuously spend their money, time, efforts, and other valuable resources.

Management refers to staffing, organizing, sourcing, prioritizing, and financing a microgrid project. Management makes progress of both planned and newly emerging tasks of microgrid development. A manager, who has a management role, is responsible for resource allocation, human collaboration, and other directing and supporting arrangements. Management requires the skills of the manager and managerial tools in order to perform planning, communicating, and other managerial tasks.

Policies for microgrid implementation are typically related to statements about directions, financial and resource supports, and expected outcomes of microgrid development. They are a commitment statement with the allocated budget. Policymakers may or may not be the same ones who are policy implementers. Microgrid policies deliver the purpose of microgrid development along a microgrid development journey.

4. DATA OF MICROGRIDS IN THE GMS

Sharing the Mekong River, six countries of enhanced subregional economic cooperation in the GMS consist of Cambodia, People's Republic of China (Yunnan Province and Guangxi Zhuang Autonomous Region) or China, Lao People's Democratic Republic or Lao, Myanmar, Thailand, and Vietnam. In 2017, the total population in the GMS was 345 million [15]. One of the cooperation among these six countries was the implementation of high priority subregional projects in energy. The investigation of microgrid progress status and challenges was expected to provide useful insights for developing both the microgrids themselves and microgrid policies.

4.1 Status and progress of microgrid in the GMS

In the GMS, Cambodia, Lao, Myanmar, and Vietnam were lower-middle-income countries whereas China and Thailand were upper-middle-income countries. All countries had on their way to achieving the goal of access to affordable and clean electricity. The records in the 2017 World Bank Group database showed that the percentage of people with access to electricity in the GMS ranged from 69.8% to 100%, as shown in Table 1 [16].

Table 1: **People with access to electricity in the GMS**

Item	Country	Access to electricity (% of population)
1	Cambodia	89.1
2	China	100.0
3	Lao	93.6
4	Myanmar	69.8
5	Thailand	100.0
6	Vietnam	100.0

It could be implied from data in Table 1 that the electricity development in the GMS, in China, Thailand, and Vietnam in particular, should move to the power quality, reliability, efficiency, and sustainability of electricity supply. Microgrids were proposed to sustain the electricity supply. The development of electricity generation units, a constituent of the microgrid, in the GMS reflected having access to electricity.

A smart grid and its emerging microgrid somehow had taken place in the GMS. In the GSM, RESs of the electricity generation unit, one of the microgrid constituents, was described [17], [18].

Cambodia's first 10 megawatt (MW) solar power plant was in operation in October 2017. In addition, Cambodia planned to build a 100 MW national solar power park. The development of solar renewable energy as a less expensive electricity supply was based on the very high electricity prices in Cambodia. A pilot wind energy project was located in Sihanoukville. Cambodia needed technical workforces, green energy policies, and source financing in order to scale up renewable energy.

China scales up distributed renewable energy and had the world's largest hydropower, wind, solar PV, and geothermal capacity. Parts of China in the GMS were implied that they were in line with the whole country. China had a plan for increasing renewable energy in total energy consumption to 15% by 2020, 20% by 2030, and more than 50% by 2050.

Lao planned to generate 30% of electricity from renewable energy by 2025. The least-cost planning approach would be applied to make development plans. Apart from energy from solar, wind, biomass, and biogas, most renewable energy resources were from mini-hydropower. About 20,000 small off-grid solar power generation systems, or solar home systems, were installed. The hybrid power generation systems, including solar and mini-hydropower, were the pilot projects in rural areas. Laos was the infancy of development and implementation of microgrid; however, there was the study of the microgrid in Northern Laos as a case study [19]. The configurations consisted of PV panels, a hydroelectric turbine, a backup AC generator, an battery as an electrical energy storage device. This study investigated the suitable simulated software for an average energy demand per household about 75-600 kWh/year [20].

In Myanmar, RESs were mainly based on hydropower. The small-scale solar energy generations, e.g., battery charging stations, solar lighting, solar home systems, and solar mini-grid were common, but not large-scale solar energy sources. The large-scale 1,500 MW solar and 6,500 MW wind energy sources were under development. Myanmar focused on microgrids that would empower cell phone transmitters to expand telephone services in rural areas. One local company had completed 10 telecom microgrid projects from the funding of the World Bank's International Finance Corporation and the governments of Canada and Norway. In addition, the Myanmar state phone utility signed an agreement with Paris-based providers to build 171 telecom towers with solar, battery, and diesel generator microgrid systems [4].

Thailand developed renewable energy partly for the purposeful reduction of imported fossil fuel and greenhouse gas. According to a national power development plan, renewable energy would share 25% of electricity generation by 2021. Solar and wind energy sources had high potential in Thailand. Thailand was at an outstanding stage of renewable energy development among countries in the GMS. The Thailand government cooperated with Japan to build microgrids in Energy Park (Northern Thailand), Rice Manufacturing Plant, and Three National Parks (Phu Kradung, Huay Ka Kang, and Tarutao Island). In addition, Thailand invested their own microgrids in Chanthaburi (Kohjig Project), Chiang Mai (Doi Intanon Royal Project and Wat Chan Royal Project), Sukothai (Kirimas Project), Cha-choeng sau (Tha Takiab Project), Uthai Thani (Huai Kha Khaeng) and Chonburi (Lan Island) [21].

Vietnam planned to develop wind, solar, and biomass power generation. The renewable energy targets were at 6.5% of electricity generation by 2020, 6.9% by 2025, and 10.7% by 2030. Wind energy generation was high potentials along the Vietnam southern coast. In addition, the southern of Vietnam had high potentials in solar energy sources because of the high solar irradiation level in these areas of the country. Microgrids were recently applied with various applications in Vietnam, for instance, city building, small town/village, factory far from the grid, city household, and rural farm [22].

4.2 Factor determining microgrid policies

Based on data from document analysis, interview and group discussion, the factors determining the microgrid development and microgrid policies were shown in Table 2 and described as follows.

The fundamental need for electricity or access to electricity, in line with the affordable and clean energy of the SDG7, was predominant behind the development of microgrids in the GMS. This goal of global sustainable development is prevalent.

Renewable energy resources, e.g., sunlight, wind, water, woods, agricultural residues, and municipal wastes, were a base of electricity generation choice. They were the spatial energy potentials. They provided policymakers the optimal cost and an environmentally friendly option to set microgrid policies.

Locations of a microgrid in the GMS were often in rural areas rather than urban areas. Most microgrids were rural off-grid ones. This spatial factor of rural areas went together with access to electricity being frequently low in rural areas. A majority of needs for the first access to electricity were in the GMS rural areas.

Technologies of a microgrid in several aspects, revealed by the interviewees, were taken into account when the microgrid was proposed as a choice of electricity supply. Some important aspects of the technologies were technical performance, compatibility, cost, and availability. Almost all members of the GMS, excluding China, were a technology buyer rather than a technology producer. Most microgrid technologies would then be imported. An international trade mechanism played its role in a supply chain of the microgrid technology.

Table 2: **Key Factors determining microgrid policies in GMS**

Factors	Determinants
Electricity needs	• Affordable and clean electricity
Renewable energy sources	• The optimal cost and environmentally friendly choice to produce microgrid policies
Locations	• Microgrid for the GMS is attractive in rural areas rather than urban areas • The spatial factor of rural areas went together with access to electricity being frequently low in rural areas
Technologies	• Technical, performance, compatibility, cost, and availability are important aspects of concern • Most GMS countries are a technology buyer rather than a technology producer
Capabilities	• The factors of design, procure, install, operate, and maintain of a microgrid are the major concerns • Qualified persons, e.g., engineers and technician, are reflected by interviewees
Costs and benefits	• Renewable energy sources had their potentials of operating cost reduction and positive environmental benefits • Project funding and project financing, the significant factor to build the microgrid project happen
Regulations	• It is the unique factors in each country of GMS for developing microgrid policies • Commitment is strong drivers to push microgrid into action

Capabilities to design, procure, install, operate, and maintain a microgrid and its constituents were a factor, raised by a majority of interviewees, determining a practical success of microgrid development. The readiness of these capabilities and the capability building, related to the factor, were also reflected by interviewees. Requirements for qualified persons, e.g., engineers and technicians, are obvious.

Costs and benefits were the undeniable factors taken into consideration when formulating microgrid policies. A least-cost approach was reported that it was applied in a step of microgrid planning in the case of Lao microgrids. Renewable energy resources had their potentials of operating cost reduction and positive environmental benefits. The selection criteria for renewable energy resources are spatial availability and cost. On the cost side, a source of fund and project financing was significant to make the microgrid projects happen.

Regulations and other supports from governments or government agencies were the unique factors of microgrid policies in the GMS. The commitment of each national government was strong drivers to push micrograds into action. In all cases of the GMS microgrids, governments and government agencies were major players in developing microgrids. There was no free electricity supply market in the GMS.

The aforementioned determining factor of access to electricity reflected the desire and determination to supply electricity to target customers. It was the desired impact of proposed microgrid policies. Other factors reflected the significant issues of microgrid development.

In addition to the factors discovered from the GMS microgrid cases, some findings were worth noticed that most microgrids in the GMS are mainly aimed at providing electricity to customers. Some of them were in the research and development, demonstration, and pilot projects.

5. MICROGRID POLICY DISCUSSION AND IMPLICATION

5.1 Rationale

It can be implied, based on data of microgrids in the GMS, that needs for microgrid policies are based on (a) a lack of electricity and (b) the improvement of an existing electric power system in terms of power quality, reliability, and energy efficiency. There is now no evidence indicating that the microgrid development serves other aims. It is likely to be in contrast to the initial observation at the beginning of this study, especially those countriess of 100% electrification. The traditional coverage of 100% electrification areas reported in [16] excludes the sensitive areas, for example, the preservation areas and the restricted access areas.

Most microgrids in the GMS aims at fulfilling the purpose of access to electricity. They are the off-grid microgrid in GMS rural areas, while others are the grid-connected ones. In the remote rural areas, it is much more expensive to construct the electricity lines to supply electricity to such areas.

In addition to the fundamental access to electricity and the improvement of an existing power system, the government's commitment is an obvious determining factor making microgrids initially happen in the GMS. This factor of the government's commitment drawn from the GMS cases is rigorous in a way that microgrids take broadly place in several places in a short period of planned time.

5.2 Challenge of microgrid policies

Although six countries in the GMS share some similar conditions, they are, to some degree, different in some senses, i.e., demands for electricity, geographical constraints, financial constraints, and other constraints, e.g., capabilities and regulations. The rate of access to electricity is also different in these countries.

It is worth noting that microgrid policies are context dependency. Like other policies, microgrid policies in one country are different from those in other countries. It is very difficult to design a microgrid policy that can be applied to every country. The challenge of microgrid policies is identified as shown in Fig.2.

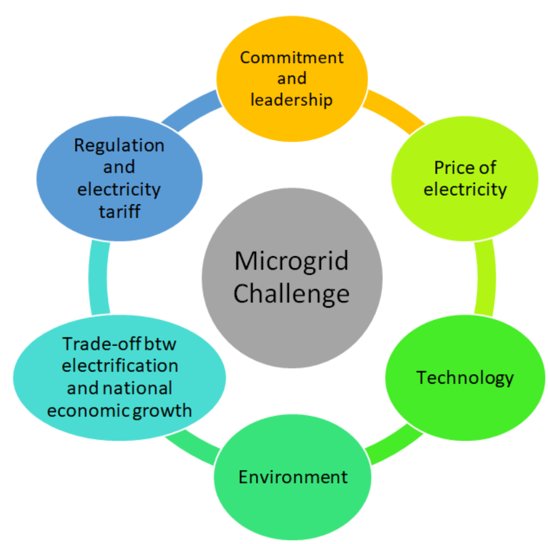

Fig. 2: **Microgrid challenge for GMS countrie**s.

It is likely to gain a commitment from politicians and leaders because of the innate microgrid values of clean energy sources, renewable energy in particular. Having electricity prices that are not too high allows people to connect and take benefits from electricity. Access to affordable electricity is always a sustainability challenge in the sense of everlasting existence and environmental contribution. Whenever customers pay for electricity bills, microgrid investors have revenues. Whenever investors gain more revenues than the total costs, they are likely to sustain their investment. In the sense of environment, the more RES in a microgrid, the more benefits to the sustainable environment. Under the acceptable cost constraints, finding the maximum environmental and financial benefits is one of the great challenges faced by researchers in a field of microgrid policy.

Technologies of microgrid constituents are different in several aspects, e.g., quality, efficiency, compatibility, user-friendly, origin, and cost. All given aspects of the technologies are significant for making microgrids happen. The technologies applied to develop microgrids in each country in the GMS are, to some extent, different from others in some aspects. From an aspect of technology, China microgrids in the GMS seems to have more advantage than others. A suitable interaction between a microgrid technology supply side and a demand side, running a microgrid technology market, sustain the existence of microgrids.

The challenges of the microgrid policymakers are the aligning electrification, together with appropriate technologies, with the optimal national economic growth. A trade-off between electrification and national economic growth is a decision-making topic of microgrid policymakers. If a microgrid is a mechanism of wealth creator and distributor, it will be considered a sustainable policy. However, if it is a burden of the national economy, it is likely to be not a time of coming into appearance.

RESs in a microgrid have their contributions to sustain the environment. A microgrid market that generates and distributes benefits to all stakeholders plays a significant role in the sustainability of electricity supply. At an early stage of the GMS microgrid development, it can notice the RES roles, but it is still questionable about the sustainability of the microgrid electricity supply.

There are few data about special regulations and electricity tariffs of microgrids in the GMS. For this reason, it is questionable whether or not the regulations and electricity tariffs can make microgrids, especially those isolated rural microgrids, happen in the long term.

6. RECOMMENDATION

Results from discussion and implication provide scholars and practitioners, the policymakers in particular, the following recommendations.

Most prior studies on microgrids mainly focus on technological development from engineering points of view. These engineering-based studies lead to technological advancement and cost reduction of products, solutions, and services. These topics are not a case in this study of the GMS microgrids. Results show that, from a policymaker perspective, simplified workable solutions of a microgrid are required. The application of microgrid technologies in rural areas is a desired area of research. Sustainability of microgrid existence in the long term, reflecting the sustainable environment, is a challenging topic of field research.

In addition to engineering knowledge, policymakers also need another knowledge. The essence of microgrid comes from outstanding values of electricity supply and local renewable energy integration. Under some circumstances, the microgrid is the only choice of an electricity supply system. When a microgrid policy is aimed at supplying electricity to unelectrified areas, choices of the policy components are (i) type, size, scope, and price of microgrid constituent technologies, (ii) local renewable energy sources, (iii) regulations and pricing, and (iv) capabilities to implement a microgrid. When policymakers take these determining factors into account in an optimal way, the acceptable scope and cost of microgrid policies are expected.

7. CONCLUSION

This study had dealt with microgrids in the GMS. A case study methodology was applied to this study. Firsthand data from interviews and discussion processes, as well as, secondhand data from academic and non-academic literature, had been collected, analyzed, and reported.

The research findings show: (i) factors determining microgrid policies, i.e., electricity needs, renewable energy resources, locations of a microgrid, technologies of a microgrid, capabilities to implement a microgrid, cost and benefit feasibility, regulations, and other supports from the government; (ii) the signs of progress and challenges of microgrids in the GMS countries. Academic and practical recommendations are given to scholars and policymakers, respectively.

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