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An Overview of Renewable Energy Sources and Their Energy Potential for Sustainable Development in Myanmar

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ABSTRACT

Myanmar has an abundance of renewable energy resources. It has around 50% of forest cover and the gifted geographic locations with four main large rivers flowing across the country. Besides, its economy is mainly based on agriculture. Among the major renewable energy sources in Myanmar, hydropower plays a key role in electrification of Myanmar while biomass provides the major energy supply for cooking and heating in rural areas. Besides, in the years to come, the utilization of solar energy and wind energy will also be emerging to fulfill the additional energy requirements of the country. Therefore, this study highlighted the renewable energy sources and their future energy potential for increasing the energy self-sufficiency in Myanmar. It was observed that Myanmar had the total installed capacity of approximately 3300 Megawatts from the renewable energy sources in 2016, remaining a large amount of future installed capacity potential. If the sustainability and constraints about renewable energy sources would be managed efficiently, Myanmar could meet the future energy requirements for sustainable development of the country.

Keywords: renewable energy sources, energy utilization, renewable energy potential, energy self-sufficiency, sustainable development

INTRODUCTION

Myanmar is one of the developing country in South East Asia and it is composed of 7 states and 7 divisions (Mann and Myint, 2017). The total land area is approximately 677,000 square kilometer, with 2832 kilometer coastal strip facing the Bay of Bengal and Andaman Sea (Khaing, 2012). Myanmar has a total of 51,486,253 populations as per 2014 Census (DPMIP, 2015). The annual population growth rate is approximately1.62 percent and about 30 percent of the total population resides in urban area (Mann and Myint, 2017). The capital city is Naypyidaw and the largest city is Yangon. The gross domestic product (GDP) per capita was about USD 1438.8 in 2017 (Global Finance, 2017). The neighboring countries of Myanmar are China, Thailand, Laos, Bangladesh and India. There are three seasons in Myanmar.

BACKGROUND OF THE STUDY

Biomass is the largest energy source in Myanmar, with over 60% of the total energy sources (**Figure 1**). Crude oil and petroleum product accounts for 13.45%, then, natural gas, 10.67%, hydropower, 9.55% and coal and lignite, 2.48%.

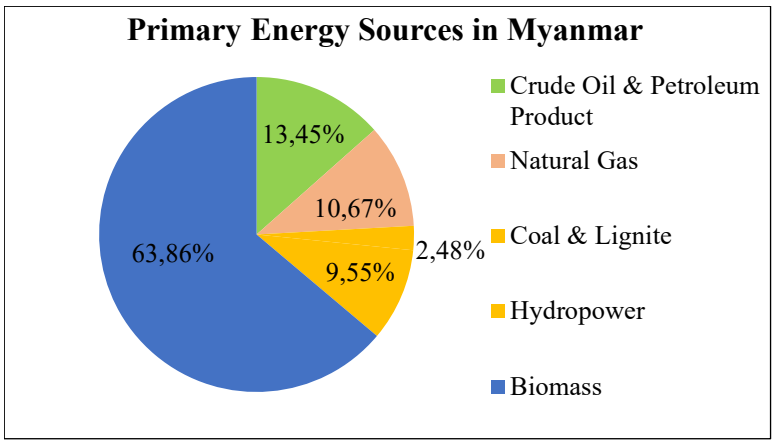

Figure 1. Primary Energy Sources in Myanmar. Source: Ministry of Agriculture and Irrigation, Myanmar

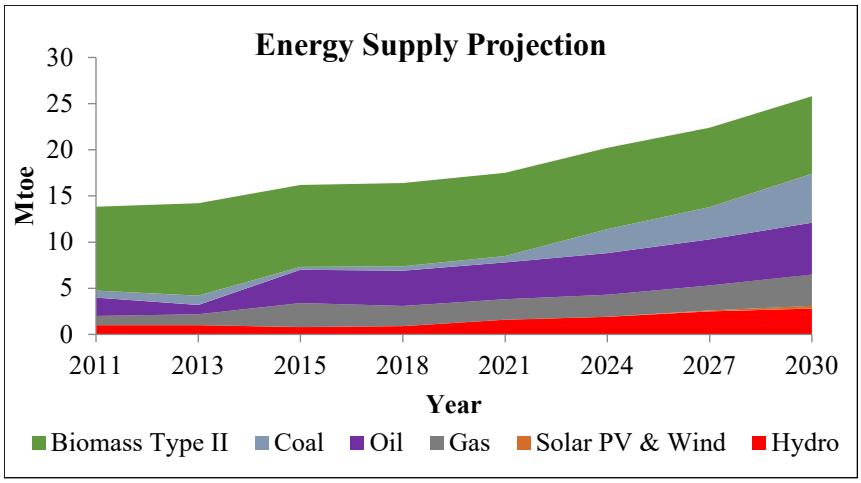

Figure 2. Energy Supply Projections in Myanmar. Source: ADB (2016); Emmerton et al. (2015)

The majority of total energy supply in Myanmar came from biomass, which amounted to around 10 million tons of oil equivalent (Mtoe) in 2012-2013 (Nam et al., 2015). It was over 50% of total energy supply, followed by hydropower (17%), oil (15%), gas (12%) and coal (3%). However, the largest power generation for electricity in Myanmar is gained by hydropower due to the technical and economic feasibility and low risk of power generation in the country. Therefore, the utilization of hydropower had increased significantly during 2000-2013. According to the power generation capacity in Myanmar in 2015 (Pode et al., 2016), hydropower was the most important component for energy security; with approximately 3011 MW of the grid connected capacity and 33 MW of isolated grid capacity. It was over 65% of the total power generation capacity in Myanmar. The second most power generation capacity was gas, which accounted for around 30% of the total power generation. It was observed that since traditional biomass consumption was widely practiced by 70% of the total population around the country—especially for cooking and heating in rural areas, the power generation capacity from biomass energy accounted for only 115 MW by 2015 (Pode et al., 2016).

The residential sector was the major energy consumer, with 80.8 % of the total energy consumption in 2012, followed by commercial sector (13%) and transport sector (11%) (Emmerton et al., 2015). Industrial sector had increased the energy consumption by over 2% from 2000-2001 to 2012-2013. It was found that although the economy of Myanmar was mainly based on agriculture, energy consumption by this sector was only a few percentages of the total energy consumption.

According to the Energy Master Plan of Myanmar (Emmerton et al., 2015), the energy supply from coal would grow dramatically up since 2021 for the purpose of additional reliable power supply to the economic development of the country (**Figure 2**). But the energy supply from other fossil fuel like gas and oil would slightly increase during the year 2015-2030. Nowadays, Myanmar's forest policy is designed to promote conservation and efficient use of management of forestry resources regarding the National Forestry Master Plan (ADB, 2012). The total predicted supply of fuelwood from plantations, non-forest land, community forests and natural forests might range from 31.55 million cubic meters in 2000 to 29.37 million cubic meters in 2030, reflecting a slight fall of biomass sources in total energy supply projection. Hydropower utilization could significantly increase from 2018 to 2030 to promote the renewable energy utilization of the country. The contribution of solar energy and wind energy to

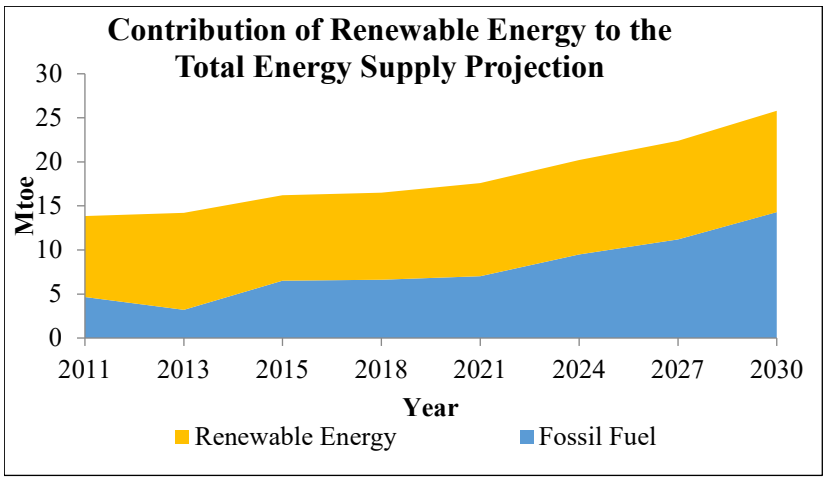

Figure 3. Contribution of Renewable Energy to Total Energy Supply Projection in Myanmar. *Source: ADB (2016); Emmerton et al. (2015)*

the total energy supply might account for approximately 0.1Mtoe in 2027 and 0.3Mtoe in 2030. According to Ministry of Electrical Power (MOEP) (Khaing, 2013), geothermal energy is aimed at contributing the installed capacity of 200 MW to the total energy supply of the country in 2021. But this amount has not been taken into account in the total energy supply projections of the country.

Regarding the research studies (ADB, 2016; Emmerton et al., 2015), the contribution of renewable energy to the total energy supply projection of Myanmar is presented in **Figure 3**. The energy supply from fossil fuel might significantly increase from a total of 6.5 Mtoe in 2015 to 14.3Mtoe in 2030. Meanwhile, the total energy supply from the renewable energy sector would grow gradually up, accounting for approximately 9.7 Mtoe in 2015 and 11.5Mtoe in 2030. Therefore, it was observed that the contribution of renewable energy might have an annual increase of approximately 10% during the year 2015-2030. As per Energy Master Plan (Emmerton et al., 2015), the share of renewable energy to the overall energy supply is targeted at over 45% in 2030.

Renewable energy utilization in Association of Southeast Asian Nations (ASEAN) member countries including Myanmar has been implementing to reduce dependency on fossil fuel, build the green economy, minimize the greenhouse gas emissions from the energy sector and conserve the environment so that the member countries can lead clean and green countries. Yosiyana (2015) stated that most of ASEAN member countries had planned that the renewable energy share of their countries in power generation/installed capacity was targeted at above 20% during the projected years. Renewable energy share in the total installed capacity of Myanmar is targeted at 15-20% by 2030, excluding the power generation from hydro power. According to ASEAN Plan of Actions for Energy Cooperation (APAEC) 2016-2025 (Yosiyana, 2015), the share of renewable energy in the ASEAN energy mix is aimed at 23% by the year 2025.

Four main goals form the basis of Myanmar's energy policy framework include: (i) maintain energy independence; (ii) promoting the wider use of new and renewable sources of energy; (iii) promoting energy efficiency and conservation; and (iv) promoting household use of alternative fuels (ADB, 2012). The concerned ministries and private sector for renewable energy in Myanmar included Ministry of Science and Technology, Ministry of Industry, Ministry of Agriculture, Ministry of Environment, Conservation and Forestry-Fuel wood and Biomass, Ministry of Livestock, Fisheries and Rural Development, Myanmar Engineering Society, Renewable Energy Association Myanmar and Myanmar Geo Science Society (Soe, 2015).

To increase the energy self-sufficiency of the country, Myanmar is implementing the energy strategy (Hlaing, 2011), regarding the energy sources within the environmental constraints. To prevent deforestation and environmental conservation, the use of fuel-wood and charcoal is planning to be reduced by substituting biomass energy as alternative fuels in the households and by using other renewable energies such as mini-hydropower, solar energy and wind energy. As a core energy source with currently installed capacity of over 3 GW (Pode et al., 2016) and a resource potential of over 100 GW (MOE, 2011), hydropower could be widely exploited around the country.

Nowadays, Myanmar is one of the Asian developing countries, which has an abundance of natural resources including both renewable and non-renewable energy sources. Since it has around 50% of forest cover and agriculture-based economy, biomass is a major renewable source in the country. In addition, due to the gifted geographic locations with four main large rivers flowing across the country (Ayeyarwady, Thanlwin, Chindwin, and Sittaung), large-scale hydropower has been commercially utilized since the previous several decades. Likewise, the energy utilization from other renewable sources such as solar energy, wind energy, geothermal energy and tidal energy, etc. has a high potential to meet the additional future energy need of the country. Therefore, the objective

Table 1. Hydropower Potential and its Power Generation in Myanmar

Types of Hydropower	Installed Capacity Potential	Identified Installed Capacity Potential	Currently Installed Capacity	Projects	Sources
Large hydropower	108,000MW	46,330MW	3,033MW	92 projects	ADB (2016); MOE (2011); Myanmar Representative (2012); Soe (2015)
Micro-hydro	230MW (210 sites)	-	30MW	26 projects	(ADB, 2016)
Mini-hydro energy				9 projects	(ADB, 2016)

of the study was to highlight the renewable energy sources and their future energy potential for increasing the energy self-sufficiency in Myanmar.

METHODOLOGY

The data about the renewable sources and renewable energy utilization in this study were collated from the previous published research papers, articles, government reports and reports conducted by nongovernmental organizations. Since Myanmar is a developing country in Asia, the available data about the majority of renewable energy sources except hydropower sources were able to be collected mostly during the year 2008-2016. Then, the study summarized the renewable energy sources and their energy utilization around Myanmar. Based on the data availability of the renewable energy sources and the status of renewable energy utilization during the year 2008-2016, the study evaluated the future renewable energy potential of Myanmar.

RENEWABLE ENERGY SOURCES IN MYANMAR

Regarding the geographic location, land resources, main economy of the country and forest coverage around the country, the available major renewable energy sources in Myanmar are described as follows:

(1) Hydropower,
(2) Biomass energy,
(3) Solar energy,
(4) Wind energy
(5) Geothermal energy and
(6) Tidal Power

Hydropower

Myanmar is so rich in natural resources including plenty of rivers and streams for large- and small-scale hydroelectricity generation at reasonable investment costs per unit of generation. With the four main large rivers flowing across the country, namely, Ayeyarwady, Thanlwin, Chindwin, and Sittaung, there are around 200 large dams for hydroelectric power in the country, with a capacity potential of 108,000MW (MOE, 2011). Currently, the total installed capacity amounts to approximately 3,033MW and the identified installed capacity potential amounts to 46,000MW (Myanmar Representative, 2012). There have also been 92 projects implemented for large hydropower plants and the largest hydroelectric power plant in the country is located in Yeywa, with the total installed capacity of 790 MW (ADB, 2016).

Khaing (2013) stated that the Irrigation Department in Myanmar had built about 240 dams for the main purpose of cultivation as well as irrigation for hydropower generation with 3kW to 80 kW of electricity In addition, mini-hydropower plants had produced approximately 872 kW of electricity by irrigation from about 60 dams.

There are a total of 303 hydropower sites in seven states and five divisions around the country (Pode et al., 2016). Their capacity potential accounts for approximately over 46,000 MW. To promote social and economic development of rural areas, Northern part of Kachin state, Eastern part of Shan state and South-eastern part of Kayin state are the most suitable parts of Myanmar to implement small hydropower projects (Pode et al., 2016). According to Asian Development Bank (ADB, 2016), there are almost suitable 60 sites with a total output of 170 MW. About 33 sites have already contributed approximately 35.97 MW of electricity. Besides, small-scale-hydropower plants could be developed for approximately 40 MW by 2030.

As per Ministry of Electrical Power (MOEP) (Soe, 2015), there are currently 750 small-scale hydropower stations in Myanmar. Among them, 35 small-scale hydropower stations are operated by Ministry of Electric Power, 50 stations by Ministry of Agriculture and Irrigation, and 665 stations by private sectors. **Table 1** presents hydropower potential and its power generation around Myanmar. The large-scale hydropower generation could contribute a total capacity potential of approximately 108,000MW but the identified installed capacity potential has only over 46,000MW. Currently, about 3,033 MW of power generation have been exploited from the large

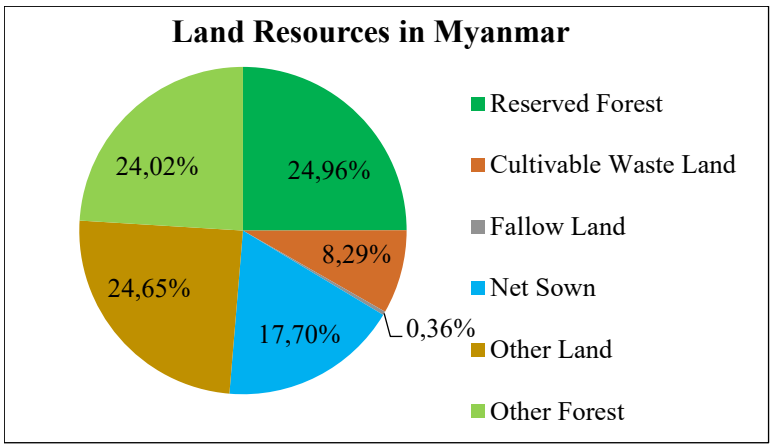

Figure 4. Land Resources in Myanmar (2009-2010). *Source: Ministry of Agriculture and Irrigation, Myanmar*

Table 2. Types and Quantity of Bioenergy Sources in Myanmar

Type of Biomass	**Quantity**	**Remarks**
Biomass	**kilotons per year**	
Rice Husks	4,392	
Lumber Waste	1,500	Hoornweg and Bhada-Tata (2012); Hlaing and Khine, (2014)
Bagasse	2,126	
Molasses	240	
Municipal solid wastes	2,050	
Fuelwood	**Million cubic meters per year**	
Plantations	1.110	ADB (2012)
Non-forest land	7.780	
Community forests	1.905	
Natural forests	20.313	
Ethanol Producible Crops	**Million gallons per year**	
Sugarcane	309	Hlaing (2011)
Cassava	30	
Sorghum	2	
Maize	81	
Potato	NA	
Sweet Potato	NA	
Bio-Diesel Producible Crops	**10^3 x Million tons per year**	
Oil Palm	52	Hlaing (2011)
Niger	30	
Rape Seed	22	
Sunflower	218	
Sesame	334	
Groundnut	358	
Soybean	29	
Coconut	350(copra)	
Jatropha	3	
Livestock and Poultry	**Quantity of Manure** (kg/day)	
Buffalo	24,720,000	Ener and Devel (2015)
Cattle	112,160,000	
Pigs	18,600,000	
Chicken	12,256,000	

NA: non-accessible

hydropower plants. The total installed capacity of micro- and mini-hydro power has approximately 30 MW with the potential capacity of 230MW. Thus, the role of hydropower might be crucial in the future, with a plan of increasing from approximately 3000MW in 2014 to 4213 MW in 2021 and 21360 MW in 2031 (ADB, 2016; Khaing, 2013), reflecting a large pillar for the energy supply to the electrification of the country, with around 70% of the total power generation in 2031 as per MOEP 2013 (Khaing, 2013).

Biomass Energy

Around 50% of the total land in Myanmar is still covered by forest. As show in **Figure 4**, reserved forest and cultivable waste land have around 50% of the total land resources in Myanmar while the remainers are the other land resources including fallow land, net sown, other forest and land, etc. The area of the closed forest has over

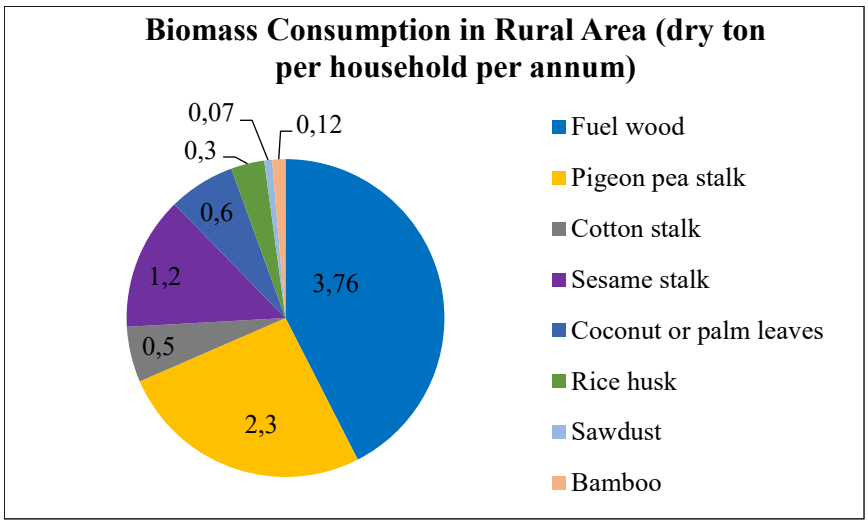

Figure 5. Biomass Consumption in Rural Area (per household per annum). *Source: Ministry of Agriculture and Irrigation, Myanmar*

13 million hectares and that of open forest has over 18 million hectares (Laemsak and Haruthaithanasan, 2017). Almost 6 million hectares (about 8.29%) of the total land area of Myanmar is still available for growing biofuel crops (Tar, 2013).

As Myanmar has an agriculture-based economy and about 48% of forest-cover (32.2 million hectares) (MOE, 2011; Laemsak and Haruthaithanasan, 2017), biomass is a major energy source which can contribute more than 60% of total energy consumption. During 2012-2013 (Nam et al., 2015), the majority of total energy supply came from biomass with more than half of total energy supply (around 10 Mtoe). The sources of biomass in Myanmar are majorly collected from the forest sector, agricultural sector and municipal sector. Therefore, the major biomass sources in Myanmar (Hlaing, 2011) include rice rusk, rice stalk, sugarcane bassage, maize stalks, cassava stalks, oil palm stalks, sawdust, other wastes of forest products, agricultural wastes, urban wastes and livestock wastes.

Since agriculture is the main industry of Myanmar, rice becomes the most crucial agricultural commodity of the country (Encyclopedia of the Nations, 2017; Nagothu, 2014). Annual paddy production in Myanmar was approximately 32.68 million tons in 2009. The quantity of rice husks, lumber waste, bagasse, molasses and municipal solid wastes amounted to 4,392 kilotons per year, 1,500 kilotons per year, 2,126 kilotons per year, 240 kilotons per year and 2,050 kilotons per year respectively (**Table 2**). Since 2008-2009, bioethanol production had contributed over 400 million gallons per year while biodiesel production accounted for 1,400, 000 million tons per year. The 99% of ethanol plants are operated by Myanmar governments (Khaing, 2012). Moreover, with an agriculture-based economy, it has so many livestock and poultry in central Myanmar regions (Myanmar Representative, 2012). Myanmar could theoretically produce approximately 167,736,000 kg of total manure per day from livestock and poultry in 2011-2012 (**Table 2**). Myanmar is also planning to start the implementation of waste-to-energy power plants in the major cities of the country. The total quantity of annual waste generation accounted for 5616 kilotons per day in 2012, trending around 21012 kilotons per day in 2025 (Hoornweg and Bhada-Tata, 2012). Out of this, the quantity of annual waste generation in Yangon, the major city of Myanmar, represented over 30% of the total generation of the country in 2012 and would contribute over 20 % of the total in 2025 (Hoornweg and Bhada-Tata, 2012; Tun and Dagmar Juchelková, 2018).

Since 70% of the total populations live in rural areas, they are more dependent on traditional biofuels such as fuelwood, pigeon pea stalk, etc., for cooking and heating. As shown in **Figure 5**, it is observed that annual fuelwood consumption accounts for 3.76 tons per household per annum. Then, it is followed by pigeon pea stalk consumption, with 2.3 tons per household per annum, and sesame stalk consumption, with 1.2 tons per household per annum. The total annual biomass consumption is estimated at about 8.85 tons per household per annum. Biomass consumption in rural has been observed to be much larger than urban area where has regular access to electricity from the national power grids.

Figure 6 describes the major biomasss energy from four main sectors—agricultural sector, forest sector, municipal sector and livestock and poultry sector. The total estimated biomass energy potential accounted for approximately 20 Mtoe in 2016. Nowadays, the government of Myanmar have invested efforts on research and development of rice husk gasification and biogas technologies. There have been over 1000 biomass gasification plants built in all states and regions of the country (ADB, 2012; Khaing, 2012; Khaing, 2013; GEGG, 2017). Besides, there have been over 867 floating type biogas plants with family size digesters and 174 fixed-dome type biogas plants around Myanmar (ADB, 2012; Khaing, 2012; Khaing, 2013; GEGG, 2017). The utilization of biomass energy in Myanmar accounted for 115MW in 2013 (Pode et al., 2016) and the overall bio-energy capacity

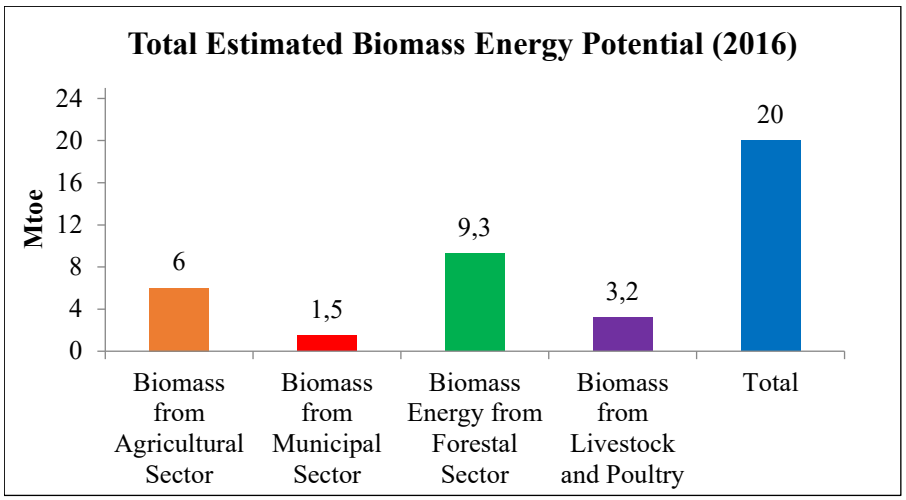

Figure 6. Total Estimated Biomass Energy Potential (2016). *Source: ADB (2012); Ener and Devel (2015); Hlaing (2011); Hoornweg and Bhada-Tata (2012); Ricepedia, (2018)*

Figure 7. Yearly Average of Daily Solar Radiation in Myanmar. *Source: Assessment of Solar Energy Potentials for the Union of Myanmar, September 2009*

potential around the country is estimated at approximately 11,640 MW (MONREC, 2018). Out of this total, about 4,741 MW might come from biomass and the rest, from biogas. Therefore, as Myanmar is highly rich in biomass resources, the sustainable energy from biomass utilization could provide the high potential to ensure a significant portion of energy security and to increase the higher living standards of the nations around the country in the years to come.

Solar Energy

Myanmar has around 36% of the total area receiving annual solar radiation ranging from 18 to 19 Mega Joules per square meter-day (MJ/m²-day), despite a few percentages of the total area with less than 15MJ/m²-day as shown in **Figure 7** (Khaing, 2012). It is observed that most parts of the country receive enough solar radiation for generating solar power for lighting and cooking. Since solar radiation could vary month to month and season to season, a variation might occur between rainy season and dry season in the country. The Dry Zone such as Magway,

Table 3. Solar Energy Installed Capacity of Myanmar

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016 (target)	Sources
Installed Capacity (MW)	0.33	0.35	0.66	0.70	1.422	2.379	NA	NA	50	Khaing (2012); Soe (2015)
Overall Capacity Potential (MW)					26,962					MONREC (2018)
Remaining Capacity Potential (MW)					26,960					

NA = non-accessible

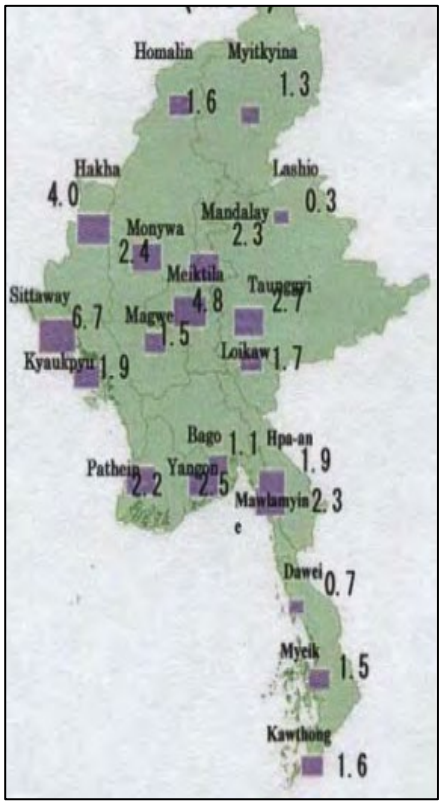

Figure 8. Yearly Average Wind Velocity (meter/sec) in Myanmar. *Source: U Win Khaing, GEGG (2013)*

Mandalay, and Sagaing regions, with an average radiation of over 5 kilo watt-hour (kWh) per square meter per day, is most suitable for developing mini-grids from solar power despite a limited variant radiation during the rainy season (ADB, 2017). However, outside the Dry Zone, solar power generation is less suitable due to a heavy and prolonged rainy season (June to October) and lower solar radiation (over 50% of irradiance lower than the Dry Zone) (ADB, 2017) .

According to the scholars (Khaing, 2012; Soe, 2015), Myanmar started utilization of solar energy for power generation in 2008, with the installed capacity of 0.33 MW (**Table 3**). In 2016, the total targeted installed capacity of solar energy around Myanmar was approximately 50 MW. Myanmar also welcomed the first-ever solar energy project, through the investment of about 480 million US dollar by a US company in the country, expecting the project to account for 10–12% of the country's power generation (2 x 150-megawatt) in 2016 (Myanmar Project Update, 2018). The overall solar energy potential in Myanmar is estimated at about 51973.8 Terawatt-hour per year (TWh per year) (Soe, 2015), with an installed capacity potential of 26,962 MW (MONREC, 2018).

Wind Energy

The overall yearly average wind velocity of Myanmar is in the range of 0.3 – 6.7 meter per second, depending on the locations—coastal regions, hilly regions and central parts (**Figure 8**). Although there is a high capacity potential of wind energy in the country, it is observed that the average wind speed required for wind turbines is not sufficient in most parts of the country. Therefore, the hilly regions of Chin states and the central part of Myanmar with wind speed of around 4 meter per second and the coastal regions in the western part of Myanmar with wind speed of over 6 meter per second are suitable areas to generate electricity from wind energy in Myanmar.

The electricity generation target from wind energy in Myanmar amounted to about 420 MW during 2008-2016 (**Table 4**). The overall wind energy potential in Myanmar is around 365 TWh per year (Soe, 2015), and the installed

Table 4. Wind Energy Installed Capacity of Myanmar

Year	2008	2009	2010	2011	2012	2013	2014	2015	2016 (target)	2021 (target)	Sources
Installed Capacity	1.2 kW	3 kW	5 kW	400 kW	0.5 kW	120 MW	NA	NA	420 MW	1209 MW	(Khaing, 2012; Soe, 2015)
Overall Capacity Potential (MW)	33829 MW										(MONREC, 2018)
Remaining Capacity Potential (MW)	**33709 MW**										

NA = non-accessible

Table 5. Geothermal Resources of Myanmar

State/Region	Number of Hot Springs	Range of Surface Temperature (°C)	Average Surface Temperature (°C)	pH Number	Remarks
Kachin State	2	-	-	-	(Khaing, 2012)
Kayah State	5	-	-	-	
Kayin State	15	37.78-61.67	48.61	-	
Sagaing Region	10	29.44-48.89	32.41	7.8	
Taninthayi Region	19	37.78-51.67	51.46	-	
Magway Region	5	32.22-48.49	40.78	7.6	
Mandalay Region	3	30.56-40	36.65	6.5	
Mon State	19	37.78-65.8	51.08	7.7	
Rakhine State	1	-	-	-	
Shan State	17	27.8-61.7	43.5	6.9	
Overall Capacity Potential	**400 MW**				(MONREC, 2018)

capacity potential of wind energy is about 33,829 MW. Currently, the energy generation from wind power in the country has been targeted at approximately 1,209 MW in 2021.

Geothermal Energy

Myanmar is so rich in geothermal resources which could additionally fulfill energy requirements of the country for heat and power generation. There are a total of 93 potential locations in Myanmar which are commercially suited for generating geothermal energy (ADB, 2016). Widespread occurrences of hot springs had been known to exist not only in the younger volcanic regions but also in non-volcanic and metamorphosed areas where ground water heated at depths have ascended through faults, fractures and fissures (Aung, 1988). Hot springs in the various locations of Myanmar are shown in **Table 5**. The average surface temperature of hot springs might range approximately from 32 to 51 °C and the highest surface temperature could reach at over 65 °C in Mon States.

Dubyne and Koh (2015) pointed out that hot spring system with surface temperatures near or greater than 50°C would have potential for Binary Cycle Power Plant Generation, with an estimated break even power cost of 5.3-8.6 US cents per kWh or in Myanmar Kyat 53-86 K per kWh. Myanmar is also planning to generate 200 MW of electricity from geothermal energy in the eastern part of the country (Richter, 2016).

Tidal Energy

Myanmar has a coastline of 2832 kilometre and twice a day experience of a powerful water current due to rising and falling of the tide (Khaing, 2012). Many coastal villages along the coastline can harness this nature's gift to generate clean electrical energy (GEGG, 2017). The overall tidal energy potential in Myanmar is estimated at approximately 1150 MW (MONREC, 2018). However, currently, electricity generation from tidal energy is at a research and development state.

Renewable Energy Potential in Myanmar

Being rich in renewable energy sources, the total renewable energy installed capacity potential could account for over 120,000MW, out of which hydropower might be the largest energy source, with a capacity potential of 46,330MW, followed by wind energy (33,829MW), solar energy (26,962MW) and bio-energy (11,640MW) (**Figure 9**). Although bio-energy is more than half of the total energy supplier, Myanmar just consumes the major portion of bio-energy (8.9Mtoe) traditionally. Therefore, while an installed capacity potential of the country would be taken into account, the capacity potential of bio-energy could be much lower than that of wind and solar energy due to several requirements including policy and regulations, suitable technologies, quality of biomass, reliable supply of biomass and market support. Currently, the total installed capacity of approximately 3300 MW has been exploited from the renewable energy sources, but there is also still a large capacity potential left, with the estimated capacity of over 117,011 MW (**Figure 9**). **Table 6** shows the renewable energy sector development, restrictions and requirements in Myanmar.

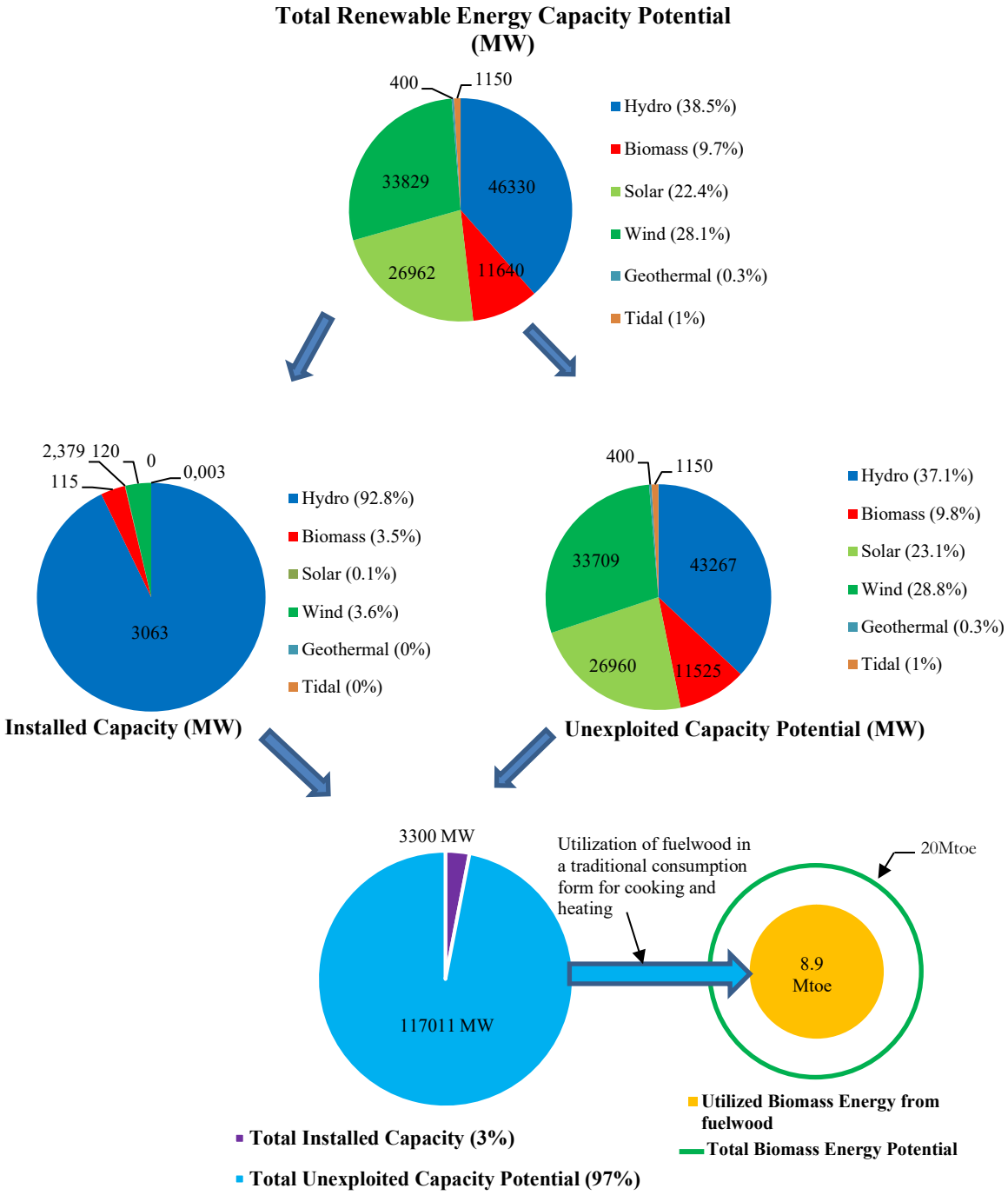

Figure 9. Comparison between Utilization of Renewable Energy and Renewable Energy Potential (Theoretically) in Myanmar. Note: The renewable energy utilization and potential were evaluated based on the data during the year 2008-2016, not considering the target capacity.

RECOMMENDATIONS

Myanmar is largely abundant in renewable energy sources. Among them, biomass and hydropower are observed to be the major energy sources. However, the investment in renewable energy is larger than that of running renewable energy (Khaing, 2012). Therefore, there are so many considerations to efficiently implement the renewable energy sector of the country. In Myanmar, although hydropower generation is being mature and well-developed in a large scale, the energy production from other renewable sources is at a fast-emerging stage. For example, the major energy consumption in Myanmar is biomass, with 70% of the total energy consumption, but the major consumption is only a traditional biomass consumption type. Technological biomass conversion

Table 6. Renewable Energy Sector Development, Restrictions and Requirements in Myanmar

Renewable Energy Source	Total Capacity Potential	Installed Capacity	Unexploited Installed Capacity Potential	Status	Restrictions	Requirements	Remarks
Hydropower	108,000 MW (overall) 46,330 MW (identified)	3063 MW	43267 MW	Established; Mature	Environmental concerns, Seasonal profile	Policy, Regulations, Standards, inancing, Research and Development	ADB (2016); Khaing (2012); Kyaw, et al. (2009); MOE (2011); MONREC (2018); Soe (2015)
Bio-Energy	11, 640 MW (6899 MW from Biomass + 4741MW from Biogas)	115 MW	11525 MW	Mature; Emerging	Environmental concerns, Seasonal biomass supply	Policy, Regulations, Quality, Market support, Financing, Research and Development	Khaing (2012); Kyaw, et al. (2009); MONREC (2018); Pode et al. (2016); Soe (2015)
Solar Energy	51973.8 TWh per year 26962 MW	2.379 MW	26960 MW	Emerging	Environmental concerns, Day/night, Seasonal profile	Policy, Regulations, Targets, Quality, Standards, Financing, Research and Development	
Wind Energy	365.1 TWh per year 33829 MW	120 MW	33709 MW	Emerging	Environmental concerns, Seasonal profile	Policy, Regulations, Targets, Standards, Financing, Research and Development	
Geothermal Energy	400 MW	0 MW	400 MW	Emerging	Environmental concerns, Restricted resource	Policy, Regulations, Targets, Standards, Financing, Research and Development	Khaing (2012); Kyaw, et al. (2009); MONREC (2018); Scoular (2018); Soe (2015)
Tidal Energy	1150 MW	0.003 MW	1150 MW	Research and Development	Environmental concerns, Seasonal profile	Policy, Regulations, Targets, Standards, Financing, Research and Development	ADB (2016); (Khaing (2012); Kyaw, et al. (2009); MONREC (2018); Soe (2015)
Total	**120311MW**	**3300MW**	**117,011MW**				

processes are being developed so far, expecting to lead the technically and economically large-scale energy generation around the country in the years to come. Despite the high capital cost of renewable energy technologies, renewable energy utilization could reduce dependency on fossil fuels including imported fuels, minimize the global warming and protect the environment against deforestation as well as prevent the public health from air-pollution which comes from traditional biomass consumption. Further, it might boost the employment and income of the local people in rural areas of the country.

Nowadays, renewable energy technologies have been adopted and mature in developed countries. The developing countries could gain the technologies, knowledge and experiences from the developed countries. Besides, the developing countries could create locally available green technologies that are well-suited for their locations and conditions. Research and development from the academic institutions will play an important role in developing such green technologies. Yosiyana (2015) suggested that as decisive factors, the government's long term commitment to renewable energy was totally crucial with reliable and predictable renewable energy policy and regulatory measures and sound economical projects. As domestic solutions, financing and micro-financing National banks could enable households and communities to purchase energy equipment through loans and other financing packages (Sovacool, 2013). Besides, international cooperation with local government, public private partnerships and donor agencies are also a must for reliable financing to the development of renewable energy technologies. Public awareness and participation might also largely affect the development of renewable energy sector. A hybrid power generation system such as solar power and small-scale hydropower, solar power and diesel/gas engine power, wind power and bio-gas combustion, etc. could become a more reasonable approach to a small-scale power supply for the villages in rural areas of the country. Since Myanmar is so blessedly rich in renewable energy resources, renewable energy might play a key role in energy sector for the energy self-sufficiency, economic development and conservation of the environment of the country in the future.

CONCLUSION

Among the renewable energy sources in Myanmar, hydropower plays a key role in electrification of Myanmar while biomass provides the major energy supply for cooking and heating in most rural areas, with 70% of the total population of Myanmar. In the years to come, the solar and wind energy will be utilized to fulfill the additional energy requirements of the country as well as to promote electrification of the remote areas around the country. The other renewables such as geothermal energy and tidal energy are currently of little energy supply to the country, but might be emerging for a large scale energy production in the future. Therefore, cooperation of private sectors, international non-government organization, research institutions, local people and donor agencies with local government will be crucial to lead the sustainable development of renewable energy sector in the future of Myanmar.

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