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Review

Biomass Energy: An Overview of Biomass Sources, Energy Potential, and Management in Southeast Asian Countries

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Abstract: Potential depletion of fossil fuel and climate change have globally accelerated the demand in renewable and alternative energy. Most of the Southeast Asian countries have an abundance of biomass sources for the energy sector due to their agriculture-based economy and enormous forest resources. Therefore, the study aimed at highlighting an overview of biomass energy in the Southeast Asia countries to convey the environmental and economic benefits from the available biomass sources in the region. In order to achieve the aim, the study synthesized and evaluated the biomass sources, energy potential, utilization, and management in the region, based on the published research papers, review papers, and country reports. It was found that the major biomass sources in this region were fuelwood, wood residues, rice husk, rice straw, sugarcane residues, oil palm residues, and coconut residues. The total annual quantity of the biomass potential from agriculture and forest sector in the region was estimated at more than 500 million tons per year and equal to over 8000 million gigajoules of total energy potential. In order to implement the sustainable utilization of biomass sources, the study specified the barriers and challenges of biomass utilization in these countries and proposed a sustainable approach of biomass energy, by comparing the way of traditional biomass utilization.

Keywords: biomass sources; biomass energy; utilization of biomass; renewable energy; Southeast Asia

1. Introduction

Booming economies have greatly accelerated energy consumption in the Southeast Asian countries. The energy consumption is projected to grow 2.6 times during 2005–2030 [1] and the energy demand will probably rise by almost two-thirds in 2040, representing one-tenth of the rise in global demand [2]. Meanwhile, the energy-related environmental pollutions caused vastly by greenhouse gas emissions from the energy sector will rise regionally and globally, as well. Due to the impact of climate change, the Southeast Asian countries, especially Indonesia, Philippines, Thailand, and Vietnam, need to begin rapidly investing in renewable forms of electricity supply [3,4].

Biomass energy is by far the largest renewable energy sources, representing 10.4% of the world's total primary energy supply or 77.4% of global renewable energy supply [5]. Asia is a key supplier of biomass feedstock to markets such as Europe or the United States but within the region, new opportunities and investments in biomass are emerging, particularly in Southeast Asia [6]. Southeast Asia, with its abundant bioenergy resources, holds a strategic position in the global biomass energy atlas [7]. It is also a big producer of agricultural and wood products, and according to conservative estimates, the amount of biomass residues generated from sugar, rice, and palm oil mills is more than 200–230 million tons per year, which corresponds to cogeneration potential of 16–19 gigawatts (GW) [7].

Nowadays, Southeast Asia is fast becoming an attractive market for developing biomass as an energy source [6] and biomass energy could provide 26% of total primary energy supply, equal to 87% of the renewable energy supply [5]. Many Southeast Asian countries are among the top producers of agricultural commodities such as rice, sugar, cane, palm oil, coconut, and rubber, and the most promising residues are rice husk, sugarcane bagasse, oil palm residue, and wood residues [5].

The average annual energy consumption in the Southeast Asian countries is estimated at approximately 3.9% and the average carbon emission has been increased by over 5% due to the fast economic growth in the region [8]. Bakhtyar et al. [8] state that increasing purchasing power parity leads to an increase in per capita electricity consumption, hence increasing per capita carbon dioxide (CO_2) emission. Figure 1 shows a relationship between per capita electricity consumption, purchasing power parity, and CO_2 emission. Although carbon dioxide is the largest source of global greenhouse gas emissions that come greatly from energy sector, it is not the case for some of the Southeast Asian countries, where forestry and agriculture are the major sources of emissions [9].

Some of the Southeast Asian countries such as Singapore, Brunei Darussalam, Malaysia, and Thailand have already accessed 100% of electricity (Figure 2). Meanwhile, other countries are expected to reach 100% access to electricity by 2030.

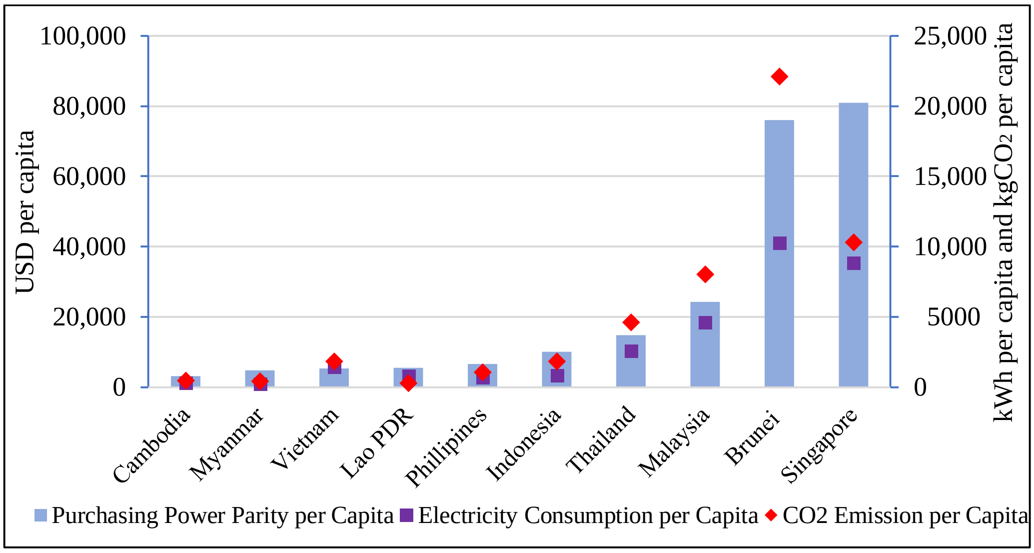

Figure 1. A relationship between per capita electricity consumption, purchasing power parity, and per capita CO_2 emission in Southeast Asia (2014) [10–13].

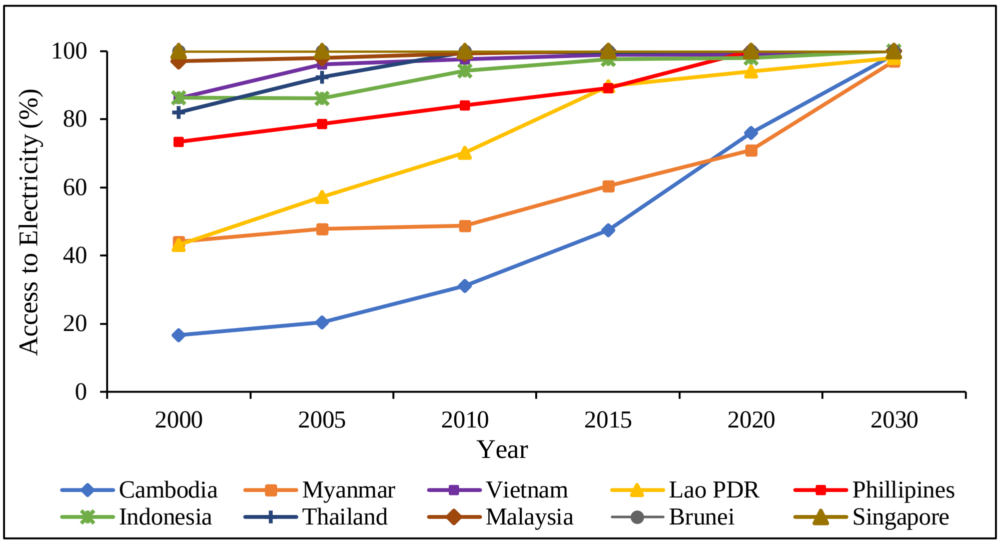

Figure 2. Access to electricity in the Southeast Asian countries [2,14].

Figure 3 shows the share of renewable energy to the total electricity generation. The total electricity generation from the renewable and non-renewable generation amounted to approximately 856 Terawatt-hours (TWh). Out of this, 20% came from renewable energy, accounting approximately for hydropower (74.1%), biofuels (12.6%), geothermal (11.5%), solar phtovoltaic (PV) (1.2%), and wind (0.6%).

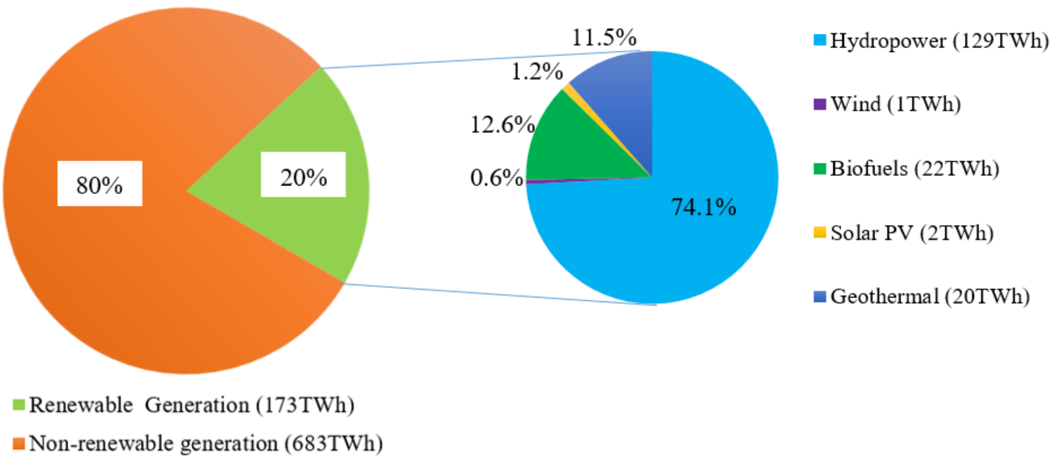

Figure 3. Share of renewable energy to total electricity generation in Southeast Asian countries (2014) [9].

The potential share of renewable energy in total primary energy supply in the Southeast Asian countries is presented in Figure 4. On a country level, the renewable energy share in total primary energy supply seems to increase significantly, especially in the countries that completely phase out traditional uses of bioenergy, such as Cambodia, Lao PDR, Indonesia, and Myanmar [9]. In Lao PDR, the potential share of biomass energy in total primary energy supply is likely to reach over 50% of the total primary energy supply by 2025.

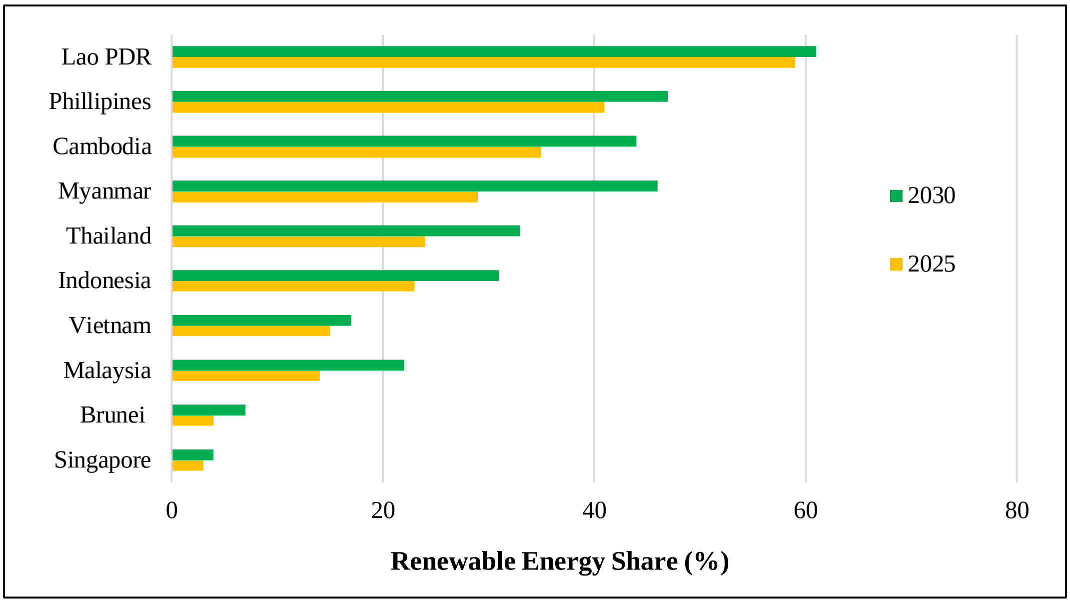

Figure 4. Potential share of renewable energy in total primary energy supply in the Southeast Asian countries. Source: [9]; https://www.irena.org/publications/2017/Mar/Renewable-Energy-Prospects-Indonesia.

Several studies have focused on the renewable energy, biomass energy, renewable energy sources, energy utilization, policy, and emission factors in Asia [2,8,9,15–19] but mostly in specific countries such as Indonesia, Malaysia, Cambodia, Lao PDR, Brunei Darussalam, Philippines, etc. [20–24]. Therefore, the study highlighted the biomass sources, energy potential, and management in Southeast Asian countries to ensure the biomass sources and their energy utilization be applicable to the policy makers, researchers, and non-government organizations for outlooking biomass energy as an important portion of the future renewable energy sector in the region.

2. Methodology

Since most Southeast Asian countries are developing countries, the country-specific data related to biomass sources, energy potential, and utilization in some countries including Myanmar, Cambodia, and Lao PDR have not been sufficiently accessible during recent years. Therefore, the data were collated to a feasible extent from the peer-reviewed research papers, reviewed papers, policy reports by the organizations such as Asian Development Bank, the World Bank, United Nations Food and Agriculture Organization, International Energy Agency, International Renewable Energy Agency, and reports by non-government organizations. Then, the study synthesized and evaluated the biomass sources, energy potential, utilization, and management in the Southeast Asian countries to highlight the potential utilization of the available biomass sources in the region. Additionally, the barriers and challenges of biomass utilization in these countries were also described. Finally, the study proposed a sustainable approach of biomass energy by comparing the way of traditional biomass utilization.

3. Results and Discussion

Biomass Sources and Utilization in the Southeast Asian Countries

The region is situated in a tropical zone and has the capacity to produce the large quantities of biomass all the year round, out of which woody biomass from forests constitutes a particularly valuable source of energy in the form of domestic fuel for local residents [16]. Additionally, the majority of the countries have an abundance of agriculture residues for biomass energy sources, due to their agriculture-based economy. For instance, with 45% of forest cover and agriculture-based economy, Myanmar has gained the biomass resources from the forest sector and agricultural sector. Therefore, the major biomass sources in the country include wood residues, rice husk and rice stalks, sugarcane residues, oil palm residues and other agricultural resides (Figure 5). The forest and agriculture resources for biomass sources in the Southeast Asian countries are presented in Table 1.

Figure 5. Biomass resources in Southeast Asia, based on Myanmar. Photo credit: Aung Myat Thu; Lwan Wai, Myanmar Survey Stars; Myint Naing; Theint Theint Win, Toe Toe.

Table 1. Forest and agriculture resources for biomass sources in the Southeast Asian countries [15,16,20,21,25–27].

Country	Crop/Forest	Growing Land Area (1000 × hectares/year)	Percent of Land Area (%)	Annual Production/ Volume of Stock (million tons/year)	Year	Remarks
Cambodia	Forest	10,094.000	57.000	-	2010	Forest sector could produce 959 Mm^3 of stock per year.
	Old Rubber tress	40,000.000	-	0.250		
	Rice	-	-	10	2017	
	Maize	-	-	0.550	2014	
	Cassava stalk	-	-	2.180		
	Sugarcane	20.000	-	0.140		
	Groundnut	-	-	0.0240		
	Coconut	-	-	0.070		
	Jatropha	1.000	-	-		
	Oil palm	4–10.000	-	-		
Myanmar	Forest	31,773.000	48	-		Forest sector could produce 1430 Mm^3 of stock per year.
	Other wooded land	20,113.000	29.730	-		
	Other	13,869.000	20.500	-		
	Waterbody	1903.000	2.810	-		
	Rice	6872.400	-	19.188 (paddy)	2013	
	Ethanol producible crops	931.000	-	-		Ministry of Agriculture and Irrigation, Myanmar (2008–2009)
	Biodiesel producible crops	6500.000	-	-		

Table 1. *Cont.*

Country	Crop/Forest	Growing Land Area (1000 × hectares/year)	Percent of Land Area (%)	Annual Production/Volume of Stock (million tons/year)	Year	Remarks
Vietnam	Forest	13,797.000	44.000			Forest sector could produce 87 Mm^3 of stock per year.
	Planation	3200.000	-	-		
	Bamboo	1400.000	-			Vietnam produces 10–13 tons of bamboo per ha.
Lao PDR	Forest	15,751.000	68.000			Forest sector could produce 929 Mm^3 of stock per year.
	Rice	-	-	0.218	2017	
	Maize	-	-	1.193	2017	
	Cassava	0.440	-	1.061×10^{-3}	2012	
	Sugarcane	20.490	-	1.056×10^{-3}	2012	
Philippines	Forest	7665.000	26.000			Forest sector could produce 1278 Mm^3 of stock per year.
	Agricultural crops	13,000.000	47.000			Total land area for agriculture crops has 30 million ha.
	Rice	1200.000	-	16.000	2015	
	Sugarcane	380.000	-	-		
	Biomass Residues	-	-	16.000		Biomass residues include the residues from rice, coconut, palm oil, sugar, and wood industries.
Indonesia	Forest	94,432.000	52.000	-		Forest sector could produce 11,343 Mm^3 of stock per year.
	Palm oil	8430.026	-	19.760	2011	
	Coconut	3808.263	-	3.267	2011	
	Sugar	448.745	-	2.694	2011	
	Rubber	3445.121	-	2.592	2011	
	Rice	12,147.637	-	66.412	2011	
	Corn	4131.676	-	18.328	2011	
Thailand	Forest	18,972.000	37.000			Forest sector could produce 783 Mm^3 of stock per year.
	Agriculture	27,072.000	-	-		
	Paddy	11,270.000	-	-		
	Field Crop	5020.000	-	-		Field crops include cassava (1.7 million ha), sugarcane (1.67 million ha), and maize (1.65 million ha).
	Perennial Crop	4420.000	-	-		Perennial crops include Para Rubber (3.31 million ha), Oil Palm (0.6 million ha), and Eucalyptus (0.51 million ha).
	Orchard	1540.000	-	-		Orchard includes mixed fruit (1.16 million ha), coconut (0.19 million ha), and longan (0.19 million ha).
Malaysia	Forest	20,456.000	62.00			Forest sector could produce 4239 Mm^3 of stock per year.
	Agriculture	4890.000	14.900			
	Coconut	-	-	0.459	2009	
	Sugarcane	-	-	0.700	2009	
	Oil Palm	-	-	90.070	2009	
	Rice	-	-	3.5	2017	
	Municipal solid wastes	-	-	7.772	2015	
Brunei Darussalam	Forest	380.000	72.000	-		Forest sector could produce 72 Mm^3 of stock per year.
Singapore	Forest	2.000	3.000	-		-

Table 2 presents biomass sources and their energy potential in the Southeast Asian countries while Table 3 describes the utilization of biomass energy in the region. It is found that the total quantity of the residues from the agriculture and forest sector is estimated at over 500 million tons per year. Additionally, the total biomass energy potential in the countries has over 8000 million gigajoules. Based on Tables 2 and 3, biomass sources and biomass energy utilization in each of the Southeast Asian countries are briefly described as follows:

(a) Cambodia

Cambodia has 10,094,000 hectares of forest area, having 57% of the total area of the country. Therefore, wood and wood charcoal account for approximately 80% of the total energy consumption in Cambodia. Approximately 80% in urban and 94% in rural areas are used for cooking [26]. The other major biomass sources come from agricultural residues including rice husk, rice straw, corn cob, cassava stalk, bagasse, groundnut shell and husk, and coconut shell and front. Currently, the total installed capacity from biomass is about 23 MW. Cambodia is planning to produce 73 MW of installed capacity from biomass by 2030.

(b) Myanmar

Myanmar is an agriculture country, covering 45% of the area with forest. Myanmar produces over 20 million tons of paddy annually. Therefore, the major biomass sources of the country are obtained largely from the forest and agriculture sector. Since 70% of the population resides in rural areas, they are mostly dependant on solid biomass fuels. Approximately 65% of the total energy consumption of the country comes from biomass sources [28]. The total capacity potential from biomass and biogas is estimated at 6899 MW and 4741 MW, respectively [29]. Out of this, the total installed capacity has reached 115 MW.

(c) Lao PDR

With 68% of the forest cover, Lao PDR has an abundance of biomass resources from the forest sector. Since the majority of the population live in the rural areas, 80% of the households rely on fire wood and charcoal, having 68% of its primary energy supplies [26,30]. In addition to the forest sector, the agriculture could provide a wealth of biomass resources due to its agriculture economy. The installed capacity of biomass energy is about 40 MW and is being planned to achieve 58 MW by 2025.

(d) Vietnam

Being an agricultural country, Vietnam has an abundance of biomass energy sources, with over 300 GW of theoretical capacity potential [31]. Biomass is mainly used in households (76%), and the rest (24%) is used in small industrial boilers and combined heat and power (CHP) plants in sugar mills [32]. The major biomass sources include forest residues, rice husk, rice straw, bagasse, cane trash, maize trash, cassava stem, peanut shell, coffee husk, and coconut shell. The main energy consumption potential in Vietnam is aimed at municipal and industrial co-generation power plants [32]. Vietnam has set a target of having a combined capacity of 500 MW of biomass power by 2020, which is raised to 2000 MW in 2030 [33].

(e) Philippines

As the energy needs of the Philippines rely predominantly on the imports of fossil fuels, the government have looked at renewable energy for possible alternatives [34]. Among the alternatives, biomass energy is crucial to the country and nearly 30% of the energy for the 100 million people living in the Philippines come from biomass and are mainly used for household cooking by the rural population [27,35]. Additionally, biomass industry is rapidly advancing, with 276.7 MW of a total installed capacity around the country [36]. Biomass energy application accounts for around 15% of the primary energy use in the Philippines [35].

(f) Indonesia

Among the Southeast Asian countries, Indonesia has an abundant growing stock in forests due to its most extensive forest area, having 94,432,000 hectares [16]. Besides, in Indonesia economies, important biomass fuels are derived from agriculture residues and used in both traditional and modern applications [21]. The major agriculture biomass sources are oil palm residues, sugarcane residues, rice husk and rice straw, and corn cob. It is estimated that Indonesia produces 146.7 million tons of biomass per year, equivalent to about 470 million gigajoules (GJ) per year [37]. The total estimated capacity potential from biomass accounts for approximately 50,000 MW, with 312 MW of installed capacity.

(g) Thailand

Thailand is an agricultural country, with a huge biomass energy potential for fulfilling additional energy requirements of the country. Biomass sources could cover up to 15% of the energy demand of the country [38]. The capacity potential from utilization of biomass and biogas is estimated at 7000 MW and 190 MW, respectively [8,39]. Most of the biomass-fired industrial facilities are large-scale, centralized plants operating at economies of scale [40]. The installed capacity from biomass and biogas accounts for 1610 MW and 46 MW, respectively, with 3.630 GW of installed capacity for a project target by 2021 [8,39]. Thailand's board of investment (BOI) promotes the production of electricity or steam from renewable energy, such as biomass by an eight-year tax holiday, exemption of import duty on machinery, raw, or essential materials used in manufacturing export products [40].

(h) Malaysia

Malaysia has a huge forest area, with around 62% of the total land area. Agriculture also covers approximately 4,890,000 hectares of the whole country. Therefore, Malaysia has the numerous biomass resources such as oil palm residues, sugarcane residues, and coconut resides. The palm oil industry alone contributes to about 8% or over RM 80 billion to the country's gross national income (GNI), making it by far the largest contributor within the agricultural sector, naturally generating the largest amount of biomass [6]. Industry figures put this amount at 83 million dry tons in 2012 and this is likely to increase to 100 million dry tons by 2020 [6]. The total installed capacity potential from biomass is estimated at 29,000 MW, with 211 MW of the installed capacity [8].

(i) Brunei Darussalam

With plentiful oil and gas resources, Brunei Darussalam relies majorly on fossil fuel not only for its national energy security and booming economy [23,41]. For this reason, it had minimal interest in the use of renewable energies, but due to mounting worldwide interest in this and in order to diversify its energy sources and bolster its energy security, it set out a goal of adopting 10% electricity from renewable energies in 2035 [41]. Biomass sources in the country account for coconut shell, coconut fiber, corn fiber, rice husk, and saw dust, with approximately 8.773 kilo GJ of the annual biomass energy potential.

(j) Singapore

Being composed of 63 islands, Singapore has a total area of 722.5 square kilometers and approximately two hectares of forest area. In 2007, Singapore identified clean technology as a key driver of economic growth, allocating S$700 million to fund research and development (R&D), innovation, and manpower development in the sector [6]. Singapore has gained a reputation as a clean, green "garden city" [42]. Utilization of horticultural and wood wastes processed by ecoWise could produce approximately 0.9 MW of electricity and 5.4 MW of heat for co-generation plant [6]. The total biomass energy potential from biomass accounts for approximately 2.901 million GJ [43] and the installed capacity from biomass sources accounts for 220 MW [8].

Table 2. Biomass sources and their energy potential [15,20–23,26,27,32,33,43–45].

Country.	Biomass	Annual Production (million tons/year)	Energy Content (MJ/kg)	Energy Potential (million GJ/year)	Year	Remarks
Cambodia	Rice husk	1.690	12.850	21.730	2011	
	Rice straw	2.070	14.000	28.920	2011	
	Corn cob	0.090	16.630	1.570	2011	
	Logging residues	-	7.400	0.577	2011	Logging residues has approximately 75 km^3 per year.
	Saw wood	-	-	0.024	2011	Saw wood has approximately 2.9 km^3 per year with 8.4 GJ of energy per m^3.
	Plywood	-	-	0.043	2011	Plywood has approximately 0.51 km^3 per year with 8.4 GJ of energy per m^3.
	Cassava stalk	0.192	16.990	3.260	2011	
	Bagasse	0.035	6.430	0.228	2011	
	Groundnut shell	0.008	11.230	0.086	2011	
	Groundnut husk	0.025	14.710	0.373	2011	
	Coconut shell	0.011	16.430	0.184	2011	
	Coconut front	0.016	14.550	0.229	2011	
Myanmar	Rice husk	4.392	12.850	56.437	2012	
	Lumber waste	1.500	-	-	2012	
	Bagasse	2.126	6.430	13.670	2012	
	Molasses	0.240	-	-	2012	
	Municipal solid waste	2.050	-	-	2012	
Vietnam	Forest Residues	11.000	-	-		Forest residues include logging (40%) and sawmilling (38% solid + 12% Sawdust)
	Rice husk	7.520	11.900	89.300	2010	
	Rice straw	37.570	11.500	432.800	2010	
	Bagasse	7.200	6.500	54.400	2010	
	Cane trash	2.400	15.100	37.200	2010	
	Maize trash	15.000	16.600	248.400	2010	
	Cassava stem	2.280	15.100	34.500	2010	
	Peanut shell	0.180	18.400	3.000	2010	
	Coffee husk	0.400	15.500	6.200	2010	
	Coconut shell	0.140	15.800	2.200	2010	
	Firewood	27.600	14.800	407.400	2010	
	Wood residues from sawmills	4.080	7.600	30.800	2010	
	Municipal solid waste	44.000	-	-	2015	
Lao PDR	Rice husk	0.670	12.850	8.560	2011	
	Rice straw	0.880	14.000	12.310	2011	
	Corn cob	0.110	16.630	1.870	2011	
	Logging residues	-	7.400	0.955	2011	Logging residues has approximately 129 km^3 per year.
	Saw wood	-	-	0.728	2011	Saw wood has approximately 87 km^3 per year with 8.4 GJ of energy per m^3.
	Plywood	-	-	0.256	2011	Plywood has approximately 31 km^3 per year with 8.4 GJ of energy per m^3.
	Cassava stalk	0.015	16.990	0.260	2011	
	Bagasse	0.054	6.430	0.349	2011	

Table 2. *Cont.*

Country.	Biomass	Annual Production (million tons/year)	Energy Content (MJ/kg)	Energy Potential (million GJ/year)	Year	Remarks
Philippines	Rice husk	2.000	-	-	2017	
	Rice straw	5.000	-	-	2017	
	Sugarcane waste	2.520	-	-	2017	Residues from 29 operating sugar mills has 6900 tons per day.
	Bagasse	6.400	-	-	2017	
	Coconut husk	6.000	-	-	2017	Coconut husks are obtained from 500 million coconut trees.
	Maize cobs	1.000	-	-	2017	Grain maize amounts to 4 Mtons.
Indonesia	Log cutting residues	3.705	-	15.643	2012	
	Saw timber	4.200	-	42.000	2012	
	Wood industry	7.860	-	83.840	2012	
	Palm oil fruit empty bunches	-	-	138.300	2012	
	Palm shell	-	-	54.800	2012	
	Coconut shell and fibre	-	-	40.700	2012	
	Rubber small log	-	-	36.300	2012	
	Bagasse	-	-	129.800	2012	
	Rice husk	-	-	143.300	2012	
	Corn cob	-	-	71.500	2012	
Thailand	Rice straw	10.728	12.330	132.300		Rice straws could produce 786.19 MW of capacity potential.
	Rice husk	4.598	13.520	62.200		Rice husk could produce 81.99 MW of capacity potential.
	Sugarcane leaves and tops	7.811	15.480	120.900		Sugarcane leaves and tops could produce 716.15 MW of capacity potential
	Bagasse	7.645	7.370	56.300		Bagasse could produce 0.38 MW of capacity potential.
	Corn leaves and stems	3.269	9.830	32.100		Corn leaves and stems could produce 201.92 MW of capacity potential.
	Corn cobs	0.957	9.620	9.200		Corn cobs could produce 10.69 MW of capacity potential.
	Cassava roots	4.172	5.490	22.900		Cassava roots could produce 151.47 MW of capacity potential.
	Palm trunk	1.442	7.540	10.900		Palm trunk could produce 71.25 MW of capacity potential.
	Palm leaves and branches	10.529	1.760	18.500		Palm leaves and branches could produce 117.69 MW of capacity potential.
	Palm empty fruit bunch	2.370	7.240	17.200		Palm empty fruit bunch could produce 45.70 MW of capacity potential.
	Root, stump and rubber tree branches	0.808	6.570	5.300		Root, stump, and rubber tree branches could produce 32.05 MW of capacity potential.
	Rubber wood ship and sawdust	0.485	6.570	3.200		

Table 2. *Cont.*

Country.	Biomass	Annual Production (million tons/year)	Energy Content (MJ/kg)	Energy Potential (million GJ/year)	Year	Remarks
Malaysia	Bagasse	0.204	18.110	1.467	2009	
	Sugarcane top and trashier	0.211	17.450	1.103	2009	
	Oil palm empty fruit bunch	38.550	21.520	239.170	2009	
	Oil palm fiber	1.320	22.070	97.420	2009	
	Oil palm shell	4.410	23.510	69.590	2009	
	Coconut husk	0.166	19.600	2.701	2009	
	Coconut shell	0.735	20.150	1.319	2009	
	Coconut empty bunches	0.022	19.600	0.347	2009	
	Coconut Frond	0.103	19.600	1.655	2009	
Brunei Darussalam	Coconut shell	11.812×10^{-6}	19.400	0.229×10^{-3}	2012	
	Coconut fiber	25.101×10^{-6}	19.850	0.498×10^{-3}	2012	
	Corn fiber	128.280×10^{-6}	17.250	2.213×10^{-3}	2012	
	Rice husk	351.204×10^{-6}	16.370	5.749×10^{-3}	2012	
	Sawdust	-	21.500	-	2012	65.241 cubic metre per year
Singapore	Municipal solid wastes	2.630	-	-	2012	
	Biomass	-	-	2.901	2016	Biomass amounts to approximately 69.3 ktoe of energy.

Nowadays, there already exists several applicable technologies for biomass energy utilization in the Southeast Asian region. These technologies include direct combustion and cofiring of biomass products for heat and electricity, anaerobic digestion of animal wastes for methane-rich gas, pyrolysis of biomass products for bio-char, gas, and oil, gasification of agricultural waste such as rice husk and others, wood chips, sawdust, forest residues, product waste, etc. In Thailand, the combustion of agriculture residues for power generation can be widely seen around the country. Meanwhile, in Myanmar, power generation from biomass gasification has been conducted by the government institutions and private sectors. Upon the different fuel alternatives and local supply demand, various ranges of generating capacities for the gasification plant can be found; especially rice husk biomass gasification shares the most due to that the staple food is rice in Myanmar agricultural system. Additionally, small villages within 100–200 households could be provided electricity for lighting with 10 kW power generation capacity via 25 hp gas engine, which was operated by biogas produced from 50 m^3 fixed-dome type biogas plant using the cow dung waste from the household. A comparison between theoretical biomass energy potential and installed capacity with project targets in the Southeast Asian countries is presented in Table 3. By far, the total installed capacity in the Southeast Asian countries accounts for approximately 3 GW from biomass and around 330 megawatts (MW) from biogas. It was observed that the applied technologies for the installed capacity of biomass energy included gasification, co-firing, and direction combustion while the installed capacity of biogas power plants was majorly gained from anaerobic digestion.

Table 3. A comparison between theoretical biomass energy potential and installed capacity with project targets [6,8,24,27,29,31,33,36,39,46–49].

	Biomass			Biogas			Remarks
	Potential (MW)	Installed Capacity (MW)	Project Target	Potential (MW)	Installed Capacity (MW)	Project Target	
Cambodia	18.852 GWh/year	23	73 MW by 2030	na	na	-	In 2015
Myanmar	6899	na	-	4741	na	-	115 MW of a total installed capacity from biomass and biogas in 2013
Vietnam	318,630	270	500 MW by 2020 2000 MW by 2030	na	na	-	(a) 318,630 MW of biomass capacity (theoretical) as per Vietnam Renewable Energy Report 2018 (b) 25,000 household biogas digesters (1–50 m^3)
Lao PDR	>200	39.740	58 MW by 2025	na	0.290	51 MW by 2025	Ministry of Energy and Mines 2013–2015 data
Philippines	na	276.7	-	na	na	-	
Indonesia	50,000	312	-	na	278		
Thailand	7000	1610	3.630 GW by 2021	na	46	600 MW by 2021	
Malaysia	29,000	211	-	na	na	-	400 MW of municipal solid waste potential
Brunei	na	-	-	na	na		
Singapore	na	220	-	na	na	-	(a) Potentially 0.9 MW of electricity and 5.4 MW of heat from biomass co-generation plant (b) 9.9 MW of electricity from mix of waste biomass and solar power (2013)

na = not-accessible.

As a major source of biomass fuels, fuelwood plays a key role for cooking and heating in the rural areas of most Southeast Asian countries. However, due to deforestation and logging (including illegal logging), the projected annual woody biomass production in natural forests declined from 815.9 million tons (16.3 EJ) in 1990 to 359.3 million tons (7.2 EJ) in 2020 [50]. Hence, average annual woody biomass production in all forests in Southeast Asia between 1990 and 2020 was estimated at 563.4 million tons (11.3 EJ) per year declining about 1.5% per year [50]. In addition to deforestation, the development of renewable energy sector has largely affected the fuelwood consumption in the Southeast Asian region. Therefore, it could be seen that there is a decline in the projected annual consumption of fuelwood in Southeast Asia after 1990, trending from 222 million cubic meters in 1990 to 122 million cubic meters in 2020 (Figure 6a). Additionally, beyond 2020, it might potentially be seen that there could also be a substantial decline in annual fuelwood consumption in the Southeast Asian countries due to not only deforestation and logging [50] but also the strategic plans and implementations of the ASEAN (Association of Southeast Asian Nations) community related to the promotion of the renewable energy sector development (majorly in hydropower, biomass energy, geothermal energy, solar, and wind energy). In the ASEAN community, it is found that the share of the renewable energy has been set a target from 15% for the total ASEAN installed power capacity by 2015 to 23% for the total ASEAN energy mix by 2023 [18].

However, the annual charcoal consumption in the Southeast Asian region seems to remain nearly stable from 2005 (Figure 6b). This situation could probably highlight that since some of the Southeast Asian countries, especially Myanmar, Lao PDR, and Cambodia, are trying to provide 100% access to the electricity nationwide by 2030 [2,14], the people in rural and urban areas are still relying on charcoal consumption for cooking and heating in case of the electrical power outage and electricity shortage, despite the reduction in avoidance of direct consumption of fuelwood.

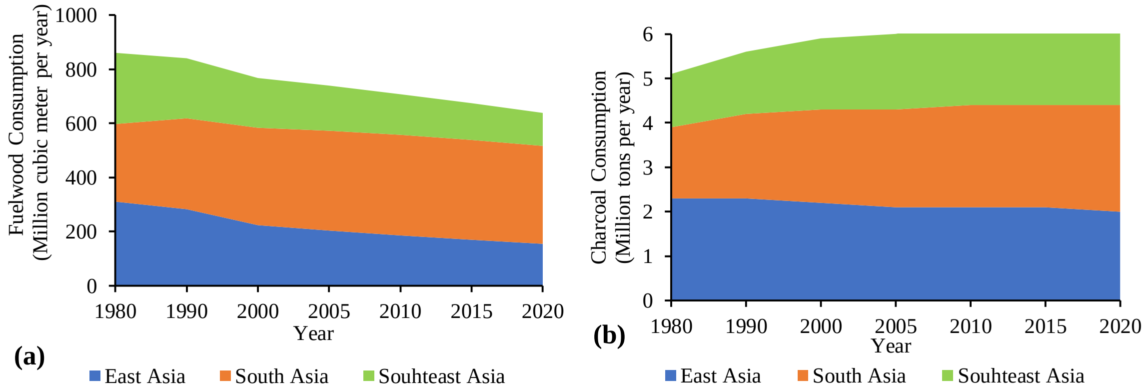

Figure 6. Trends of (**a**) fuelwood consumption and (**b**) charcoal consumption in Asia Region [51].

Figure 7 shows the ratio of bioenergy demand and supply in selected Southeast Asian countries in 2025. Among the selected countries, the ratio of bioenergy demand and supply in Myanmar is likely to be the lowest, with 20% in low estimate and over 30% in high estimate, due to its major focus on hydropower and solar power utilization. On the other hand, Thailand seems to have the highest ratios in both low and high estimate in 2025, along with the quality improvement of biomass fuels, technology advancements, and market opportunities. Table 4 show the methods of biomass energy utilization in the Southeast Asian countries. Since most of the countries have a higher rural population, the traditional ways of biomass energy utilization such as traditional consumptions for cooking and heating, animal feeds, dumping, and open burning are significantly practiced. Due to the high capital cost of technologies, lack of skilled personnel, and uncertainty of economic benefits, most developing countries could not afford to apply the technologies related to refuse-derived fuel (RDF), pyrolysis, and liquefaction. For instance, the actual status for RDF application in Myanmar could be hardly seen. However, some demonstrated facilities for biomass briquettes, especially for rice husk, donated from the foreign countries could be seen in the country. Therefore, the technologies related to biomass energy have been well applied only by a few countries such as Singapore, Thailand, and Malaysia in the region.

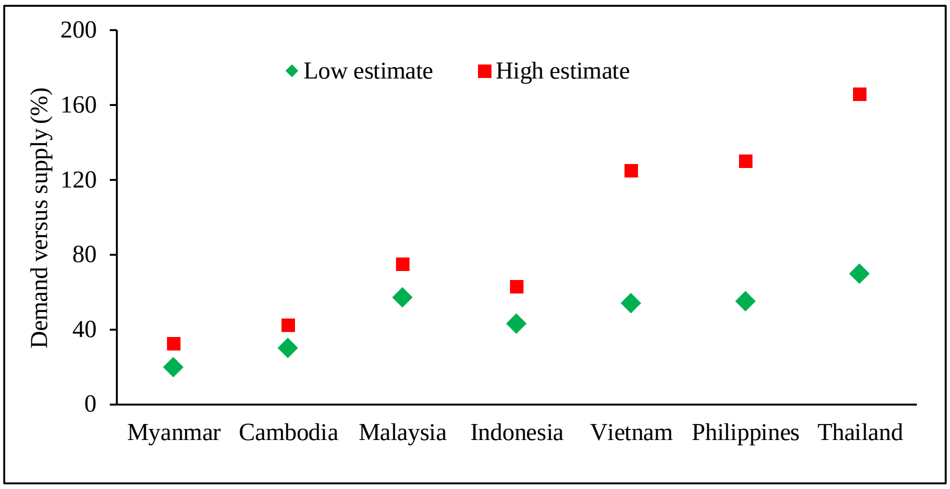

Figure 7. Ratio of bioenergy demand and supply in Southeast Asia countries in 2025 [9].

Table 4. Methods of biomass utilization in Southeast Asian countries [6,8,9,15,18,27,29,31,33,36,46,48,52].

Country/Methods	Animal Feed	Traditional Consumption for Cooking and Heating	Dumping and Open Burning	Traditional Agriculture Nutriments	Composting	Direct Combustion	Gasification	Pyrolysis	Liquefaction	RDF	Anaerobic Digestion	Hybrid System
Cambodia	**0**	θ	θ	θ	++	++	++	-	-	-	++	++
Myanmar	**0**	θ	θ	θ	++	++	++	-	-	-	++	++
Vietnam	**0**	θ	θ	θ	++	++	++	-	-	-	++	++
Lao PDR	**0**	θ	θ	θ	++	++	++	-	-	-	++	++
Philippines	**0**	θ	θ	θ	++	++	++	-	-	-	++	++
Indonesia	**0**	θ	θ	θ	++	++	++	-	-	-	++	++
Thailand	**0**	θ	θ	θ	++	++	++	+	+	+	++	++
Malaysia	**0**	**0**	**0**	**0**	++	++	++	+	+	+	++	++
Brunei	-	-	-	-	-	-	-	-	-	-	-	-
Singapore	-	-	-	-	-	-	++	-	-	-	++	++

Note: **-** = not applied/practiced; **+ =** in a development stage; **++** = applied technically and commercially; **0** = practiced in a traditional way; θ = much-practiced in a traditional way.

4. Barriers and Challenges for Utilization of Biomass

Scaling up sustainable, modern forms of bioenergy will be crucial both to address the energy access challenge, and to increase renewable energy use in both industry and transport [9]. Table 5 presents the barriers and challenges for utilization of biomass. Policy and institutional aspects are crucial to development of biomass energy sector. However, specific goals and targets on the biomass energy development could not clearly seen in most of the countries yet. Meanwhile, as driven by the low economy growth of the countries, lack of sufficient funding for research and development and purchase of technologies is one of the biggest challenges in the development of biomass energy sector in most of the Southeast Asian countries such as Myanmar, Lao PDR, and Cambodia. Likewise, public and private sector involvement is still uncertain owing to the uncertain profits and risks of utilization of biomass energy, since utilization of biomass sources concerns with low energy contents, bulky volume of biomass sources, need for large storage systems and high transportation costs, data reliability issues, underdeveloped biomass industries, and lack of local skilled personnel. Additionally, some of the useful and important information about biomass sources are not widespread among the local people thorough education and training programs. Consequently, the cooperation of the local people in the development of the bioenergy sector remains weak. As one of the most crucial things, market development still seems slow because of lack of sufficient funding, research and development, and weakness of all stakeholder involvement.

Table 5. Barriers and challenges for utilization of biomass [6,9,15,18,19,29,30,53–56].

Country/ Description	Policy and Institutions	Market Development	Collaboration among Users/Producers and (Local) Government	Cooperation of Private Sectors	Involvement of Stakeholders	Knowledge Level	Skilled Personnel and Training Facilities	Data Reliability	Technology	Research and Development
Cambodia	x	x	x	x	x	x	x	x	x	x
Myanmar	x	x	x	x	x	x	x	x	x	x
Vietnam	x	x	x	x	x	x	x	x	x	x
Lao PDR	x	x	x	x	x	x	x	x	x	x
Philippines	x	x	x	x	x	x	x	x	x	x
Indonesia	x	x	x	x	x	x	x	x	x	x
Thailand	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Malaysia	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx
Brunei	na	na	na	na	na	na	na	na	na	x
Singapore	na	na	xx	xx	xx	xx	xx	xx	xx	xx

Note: na: not accessible; x: lower; xx: higher.

5. Traditional Approach and Sustainable Approach to Biomass Energy

Nowadays, due to the climate change, fast growing populations, and economic growth in the region, the Southeast Asian countries have outlooked the renewable and alternative energies to reduce the greenhouse gas emissions and other environmental impacts from the energy sectors. Out of them, utilization of biomass energy derived from the enormous biomass sources from agriculture and forest residues has become a crucial factor of meeting the future energy needs. In addition to environmental and energy benefits, the economic benefits from utilization of biomass energy could also be gained largely from the production of value-added biomass fuel and agriculture nutrients, fewer imports of fossil fuels and agricultural nutrients from other foreign countries, reduced cost of waste disposal, and local job opportunities that could increase the household incomes of local people.

For the efficient utilization of biomass sources, the countries will need to develop the way forward from traditional management to sustainable one, as described in Figure 8. As the traditional management of biomass sources in most of the Southeast Asian countries, it is observed that firstly, the management process generally seems to go through harvesting and storage, then traditional consumption patterns follow—animal feed, traditional consumption for cooking and heating, open burning and dumping, and traditional agriculture nutrients. However, if a sustainable approach is considered, the aspects about policy and institutions, targets and goals, funding, public–private partnership, stakeholder involvements, research and development, and public awareness and educational trainings will become crucial. Based on policy and goals, research and development would need to be promoted from the growing stages of biomass resources to market development.

To ensure the higher quality of the biomass fuels for energy utilization, Koppejan and van Loo [57] suggest that the quality of the raw biomass could be improved by two stages—growing stage, and harvest and storage stage. During the growing stages, based on soil type, the chemical characteristics of biofuels and the desired yield such as type of species, agricultural and silvicultural practice, fertilization, and harvesting date should be influenced. Likewise, in the harvest and storage stage, the physical characteristics of biomass fuels can be improved by harvesting methods, transshipment, drying, sanitation, upgrading, and storage. Biomass fuel quality and utilization can be finally upgraded by fuel processing such as the improvement of calorific value, and technological conversions such as pyrolysis, combustion, gasification, fermentation, and anaerobic digestion. In addition, co-firing of biomass with coal and hybrid system could also be incorporated.

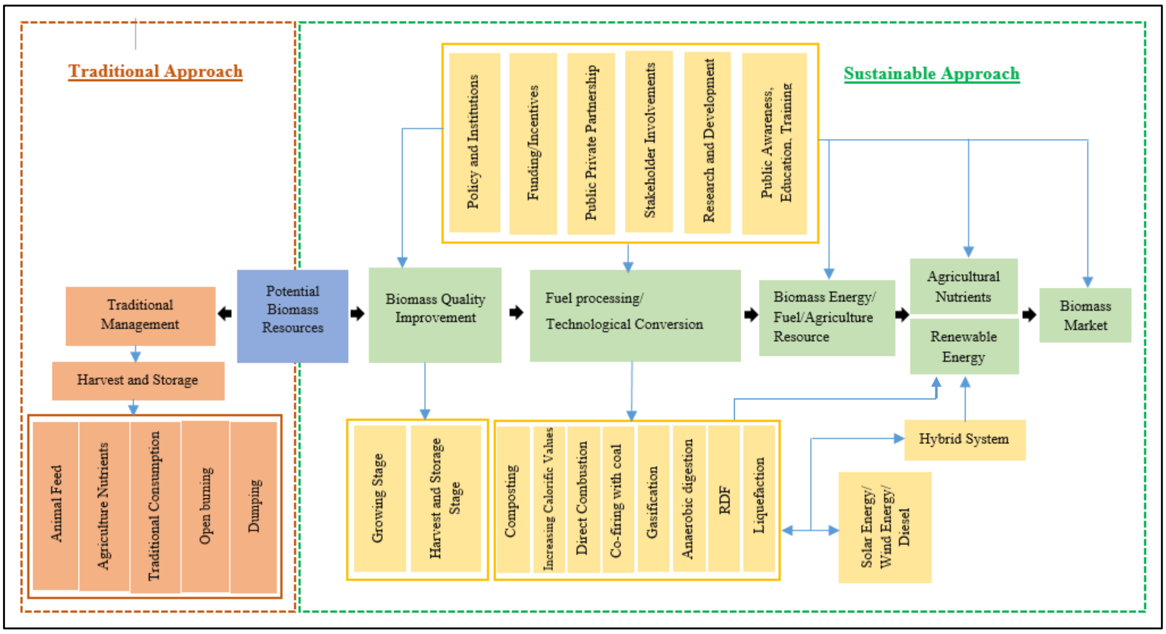

Figure 8. Flow diagram of traditional approach and sustainable approach to biomass utilization.

However, one of the most crucial factors that need to be considered for the estimation of available energy potential from biomass resources is the amount of energy that would be necessarily involved in the plantation of biomass crops and trees, harvesting and transporting of them, and valorization and conversion of the biomass sources into energy or agricultural nutrients. This amount of energy that must be consumed to supply the biomass energy to the society might depend upon several factors such as climate, strategic plans, and applied technologies; hence, it might contribute a substantial decrease in the amount of potential biomass energy from available biomass sources.

To achieve the sustainability and the efficient utilization of biomass as domestic solutions, financing and micro-financing could enable households and communities to purchase energy equipment through loans and other financing packages [53]. Besides, local governments and concerned authorities should implement education and awareness campaigns, public–private partnerships, creation of national technology standards, establishment of maintenance and training centers, international cooperation, technology, and intellectual property transfer [53]. In some Southeast Asia countries, the governments have already provided the project developers with investment incentives, guaranteed minimum prices, power purchase agreements with the utility grid, and exemptions pertaining to the import of equipment and certain tax credits [6]. As a result, the development of biomass energy from the locally accessible biomass sources could be systemically made in a long run. Therefore, looking forward from policy and institutions to all stakeholder involvements, a holistic approach to biomass energy sector will certainly play a key role in efficient utilization of biomass sources as a renewable and sustainable energy in the Southeast Asian countries.

6. Conclusions

Due to potential depletion of fossil fuel and climate change, the Southeast Asian countries have outlooked the renewable and alternative energies to reduce the greenhouse gas emissions and other environmental impacts from the energy sector. As most Southeast Asian countries have an agriculture-based economy and a large area of forest cover, biomass has become one of the most interesting energy sources to fulfill the primary and additional energy needs of the countries. The total annual quantity of the residues from agriculture and forest sector in this region is estimated at more than 500 million tons per year, equal to over 8000 million gigajoules of total biomass energy potential. Additionally, the total installed capacity in the region accounts for approximately 3 GW from biomass and around 330 Megawatts (MW) from biogas. Currently, biomass energy utilization and market development in the region seems progressive. Some of the Southeast Asian countries such as Thailand and Malaysia have effectively developed more innovative solutions to biomass energy utilization despite the barriers and challenges. Therefore, along with the advancements of technologies, research and development, growing energy markets, and knowledge and technology transfer from the other developed countries, biomass energy could be crucial in offering the environmental and economic benefits in the near future of the energy sector in the region.

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