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A review on energy scenario and sustainable energy in Indonesia

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ABSTRACT

The global energy consumption is likely to grow faster than the population growth. The fuel consumption was growing from 6630 million tons of oil equivalents (Mtoe) in 1980 to 11,163 Mtoe in 2009. This projected consumption will increase 1.5% per year until 2030 and reach 16,900 Mtoe and the main drivers of this growth are mostly developing countries in Asia. Indonesia is one of the developing countries and energy supply is an important factor for all-around development. The country's energy consumption still depends on non-renewable energy such as crude oil, coal and natural gas as sources of energy. Utilization of fossil fuel continuously contributes to huge amount of greenhouse gases emission that leads to climate change. Facing such an unfavorable situation, the government of Indonesia prioritizes on energy supply securities by diversification of energy resources. The energy mixes in Indonesia based on five main resources; these are crude oil, natural gas, coal, hydropower, and renewable energy. Although the country encourages utilizing renewable energy, the contribution is only around 3%. Considering natural condition and geography, this country is blessed with great potential of renewable energy such as solar energy, wind energy, micro hydro and biomass energy. Noting the potential of renewable and sustainable energy resources in the country, the government must pay more attention on how to utilize it. Many efforts have been done to promote renewable energy such as to create energy policy and regulations, yet it still did not give any satisfactory result. Government, non-government agencies and the public should take a more proactive step to promote and use renewable energy in order to achieve the secure and environmentally sustainable energy resources.

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Table 1
Global primary energy consumption.

Source	1980		2009	
	Mtoe	Share (%)	Mtoe	Share (%)
Petroleum	2979.8	44.9	3882.1	34.37
Coal	1807.9	27.3	3278.3	29.02
Natural gas	1296.8	19.6	2653.1	23.49
Nuclear	161	2.4	610.5	5.4
Hydropower	384.3	5.8	740.3	6.55
Total	6629.80	100	11,294.90	100

1. Introduction

Energy supply in the future is a problem that attracts attention of all nations, because human welfare in modern life is closely related to the amount and quality of energy used. The global energy consumption is likely to grow faster than the population growth. The global energy consumption and emission growth data have been discussed deeply in Refs. [1–13]. The fuel consumption was growing from 6630 million tons of oil equivalents (Mtoe) in 1980 to almost double reaching 11,163 Mtoe in 2009 as shown in Table 1 [14]. This projected consumption will increase 1.5% per year until 2030 and will reach 16,900 Mtoe and the main drivers of this growth are developing countries in Asia [15]. Some of the works related to energy scenario, energy efficiency, renewable energy and sustainable energy in selected Asian countries are given in Refs. [16–40]. For Indonesia, which is one of the developing countries in Asia, energy supply is a very important factor in promoting country development. Along with the increased development especially in the industrial sector, economic growth and population growth, demand for energy continues to rise steadily.

At current production rates, Indonesian proven reserves for crude oil and natural gas are estimated to last for 23 years and 52 years respectively [41]. Due to Indonesia's rapid depletion in oil and natural gas reserves, the country must discover alternative energy source to sustain economic development in the future [42]. Besides that, after economic recession in 1998, Indonesian energy consumption rapidly increased with annual growth rate 7% and not followed by enough energy supply [43]. While the fossil fuel reserves are limited, the dependency is still high. The future will see an increase in energy consumption of the country as economic recovery. The transportation and industrial sectors are expected to become the highest energy consumers followed by household sector [44]. Some of the early works related to energy consumption, energy efficiency, renewable energy and sustainable energy in Indonesia are discussed in Refs. [45–51].

The crucial challenge facing the power sector in Indonesia is the issues of sustainability. The country should be urged and should fully support the utilization of new and renewable energy to improve energy security and create energy autonomy. The country also needs for energy management in both, in the generation sides and in the distribution sides due to high energy demand [52]. This study presents an overview of the energy reserves, supply, and demand and on current energy scenario in Indonesia. Also, the situation of the country in using renewable energies such as wind, solar, biomass and geothermal as a new source of energy has been reviewed and the potential of utilizing this renewable energy for the future in Indonesia has been discussed.

2. Indonesia energy scenario

Indonesia is the fourth most populous nation with 230 million people and ranks 13th in the primary energy use which is about 893 Mboe. The country is an archipelago nation consisting of more than 17,000 islands covered area about 9,822,570 km^2. The GDP grew at an average economic rate of 6.1% per year from 1971 to 2008 with GDP per capita about of US$ 2850 in 2010 [41,52]. Like many developing countries, development and economic growth continue to affect the growing of energy consumption demand. Total primary energy supply had increased steadily over the past 19 years. It is estimated to reach about 1270.9 Mboe in 2009 which is more than 200% increase from 1990 as shown in Fig. 1 and it is considered high among developing countries [41]. Some of the early works related to Indonesia energy scenario are discussed by Refs. [53–58].

Even though the world's energy consumption is quite high i.e. 1.7 TOE per capita, Indonesia only used 0.65 TOE per capita with an average growth of primary energy about 7.7% in the past 19 years [52]. However, it is expected to continue to increase in the future. Apart from that, the final energy consumption increased drastically due to rapid urbanization and industrialization. Fig. 2 shows the final energy consumption by sector in Indonesia from 1990 to 2009 [41]. Industrial sectors dominate energy consumption in Indonesia with its consumption is about 296 Mboe (41%) from total consumption of national energy in 2009 and followed closely by transportation sector which consume 226.6 Mboe (37%). Residential and commercial sectors also increased steadily. As shown in Table 2 that most of the energy resources are located out of Java, but the demand of energy is concentrated in Java that can be seen from Fig. 3 [52]. The energy consumption of transportation sector in the future will be an important factor for the future of energy demand supply projection and has potential to become the highest sector of energy consumption.

Currently the final energy supply is dominated by non-renewable energy resources such as oil, gas and coal which contributed for 75% of the final energy consumption. This situation makes the government and the energy society worry as the fossil energy resources and supply will be diminished in the near future. On the other hand, the utilization of new and renewable energy resources has not been optimized due to its high production cost and worsen by the subsidy policy on fossil energy where LPG is used for cooking and as a fuel oil in the transportation sector [52]. The contribution of crude oil in energy supply in Indonesia has decreased from 45% in 1990 to 39% in 2009. On the other hand, the contribution of coal in energy supply has accelerating from 4% in 1990 to 18% in 2009 which is mainly used in power generation and the cement industry. The primary energy supply share in Indonesia is presented in Table 3 [41]. With increasing environmental issues, the use of natural gas also is expected to grow at a steadily increasing pace. The contribution of the other energy resources such as hydropower, geothermal, wind, and solar is only 3% in 2009, which is very low in comparison to other countries.

Due to environmental consequences of burning fossil fuels like greenhouse gas emission [59] and the fact that fossil fuel like greenhouse gas emission will be depleted one day, the dependency of Indonesian energy scenario to fossil fuels will have an adverse effect on the economy in Indonesia. Therefore, action toward using renewable energy source should be put as priority by the government. Some of successful implementation of renewable energy programs from developed and developing countries that can be adopted by Indonesian government and that can be found in Refs. [60–69].

3. Energy mix in Indonesia

Dynamic changes were seen in the energy sector in Indonesia after the 1998 economic crisis. There were a large growth in the demand for energy, changes in legislations and regulation amidst rising oil prices. Indonesia is preparing for a turning point in the future when it will become energy importer rather than energy exporter [70]. Facing such an unfavorable situation, the

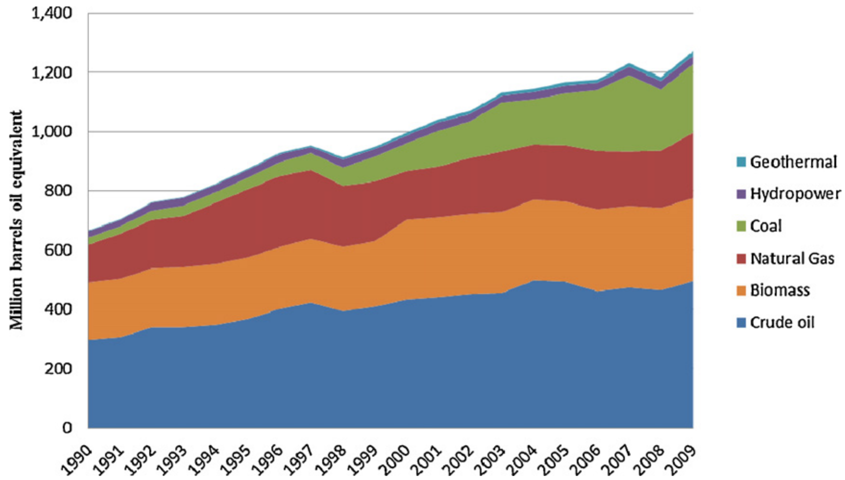

Fig. 1. Primary energy supply by fuel type in Indonesia.

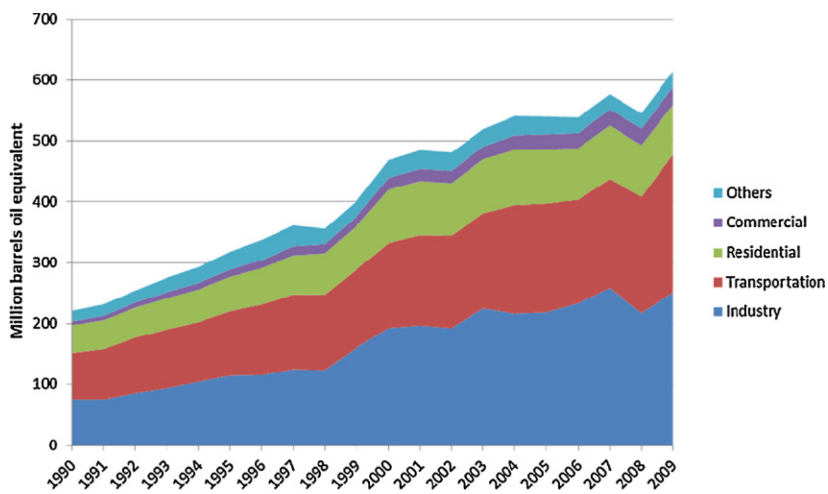

Fig. 2. Final energy consumption by sector in Indonesia.

Table 2
Primary energy supply share in Indonesia.

Regional	Oil (%)	Natural gas (%)	Coal (%)	Hydropower (%)	Geothermal (%)
Java	19	6	0	6	34
Sumatra	69	55	50	21	47
Kalimantan	9	14	50	29	0
Sulawesi	1	2	0	14	8
Others	2	24	0	31	10

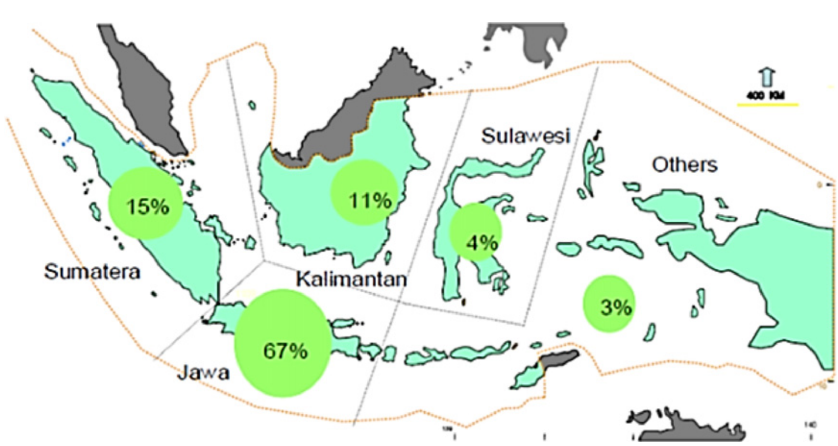

Fig. 3. Distribution share of final energy consumption by region in Indonesia.

Table 3
Primary energy supply share in Indonesia.

Primary energy supply	Amount (kboe)		Share (%)	
	1990	2009	1990	2009
Crude oil	297,435	495,710	45	39
Biomass	193,191	279,251	29	22
Natural gas	127,604	220,930	29	18
Coal	24,390	231,351	4	18
Hydropower	21,678	28,688	3	2
Geothermal	2185	14,973	0	1

government of Indonesia prioritizes on energy supply securities by diversification of energy resources. Nowadays, energy mix in Indonesia includes five main resources which are crude oil, natural gas, coal, hydropower, and renewable energies.

3.1. *Crude oil*

Indonesia became a member of Organization of the Petroleum Exporting Countries (OPEC) in 1962, yet the country resigned in 2008 after becoming a net importer of oil in 2004 [71]. Indonesia's petroleum production and consumption are presented in Fig. 4 [41]. In the last decade, oil production of the country decreased steadily caused by disappointing exploration efforts and declining production of oil in the existing oil fields [71]. Almost all Indonesian oil companies reported a drop in oil production as shown in Table 4 [72].

In 2009, Indonesia's oil reserves are estimated at around 8 billion barrels, of which this 4.3 billion are proven reserves that correspond to 0.3% of world proven reserves and 3.7 billion are potential [14,41]. Most of the proven oil reserves are located onshore with the major fields located in Central Sumatra, Northwestern Java, East Kalimantan and Natuna Sea. The largest oil producing province is in Central Sumatra i.e. Minas and Duri oil fields with average production rate 84.000 and 200.000 billion barrel per day, respectively [70,73]. However, the Minas and Duri fields which are operated by Chevron are experiencing a decline in production due to maturation of the fields. Many efforts are underway, but have not brought sufficient results to counterbalance the declining production by older fields [71].

Indonesia produced 347 million barrels of oil including condensate in 2009. This decreased sharply from the year 2000 because of a lack of investment for exploration and development compounded by the ageing oil fields. There are ten active oil refineries in Indonesia with the largest at Cilacap-Central Java of 348 MBSD, in Balikpapan-Kalimantan of 260 MBSD, and Balongan-East Java of 125 MBSD as shown in Table 5 [41,70].

Table 4
Primary energy supply share in Indonesia 2003–2004.

Company	2003	2004	Change (%)
Caltex[a]	506.9	507.0	0.0
Total	81.1	81.8	0.8
CNOOC	94.9	81.5	−14.2
Unocal[a]	53.9	55.7	3.3
Exspan	66.4	54.0	−18.6
Pertamina	43.6	48.4	10.9
Conoco Philips	51.4	44.1	−14.2
Petrochima	40.5	36.6	−9.7
BP	38.8	31.3	−19.4
BumiSiakPusako	32	30.0	−6.2
Vico	32.3	28.8	−10.8
ExxonMobil	25.4	21.2	−16.5
Others	79.6	74.1	−6.9

[a] Changed to Chevron after merger.

Table 5
Refinery capacity in 2009.

Refinery	Refinery capacity (MBSD)
Tri Wahana Universal	6.00
Dumai	127.00
Sungai Pakning	50.00
Musi	127.30
Cilacap	348.00
Balikpapan	260.00
Balongan	125.00
Cepu	3.80
Kasim	10
Tuban (TPPI)	100
Total	1157.10

3.2. *Natural gas*

Natural gas has become an increasingly important resource and as global commodity. Therefore, the demand for natural gas has significantly increased. Indonesia has the largest proven natural gas reserves in the Asia-Pacific region and 11th in the world with 107 trillion cubic feet (Tcf) of proven natural gas reserves that corresponds to almost 1.7% of world proven natural gas reserves as of January 2009 [15]. The natural gas reserves in Indonesia up to end 2009 are presented in Table 6 [14,41].

A large percentage of natural gas reserve (about 70%) are located offshore and can be found in East Kalimantan, South Sumatra, Natuna Island and West Papua [70]. The state oil company Pertamina and six major international companies (Total, ExxonMobil, Vico, ConocoPhillips, BP, and Chevron) dominated more than 90% of the country's natural gas production. The percentage of natural gas production shares is shown in Fig. 5 [71].

In 2009, Indonesia produced 3.06 Tcf of natural gas. The country consumes 1.5 Tcf of natural gas mainly for electricity and industries, while 1.22 Tcf of natural gas production was processed into liquefied natural gas (LNG) to meet the need of the ASEAN market (Japan, South Korea, and Taiwan) and 9.6% of the total natural gas exported to Singapore and Malaysia through pipeline [41,70]. The country's natural gas consumption by sector can be seen in Fig. 6 [41]. An increase in the domestic demand for natural has not seen a parallel development of gas production, infrastructure and pricing policy. These appear to be a restriction of supply of natural gas

Table 6
Natural gas reserves in Indonesia.

Year	Proven (Tcf)	Potential (Tcf)	Total (Tcf)
2000	95	76	170
2001	92	76	168
2002	90	86	177
2003	91	87	178
2004	98	91	188
2005	97	89	186
2006	94	93	187
2007	106	59	165
2008	113	58	170
2009	107	52	160

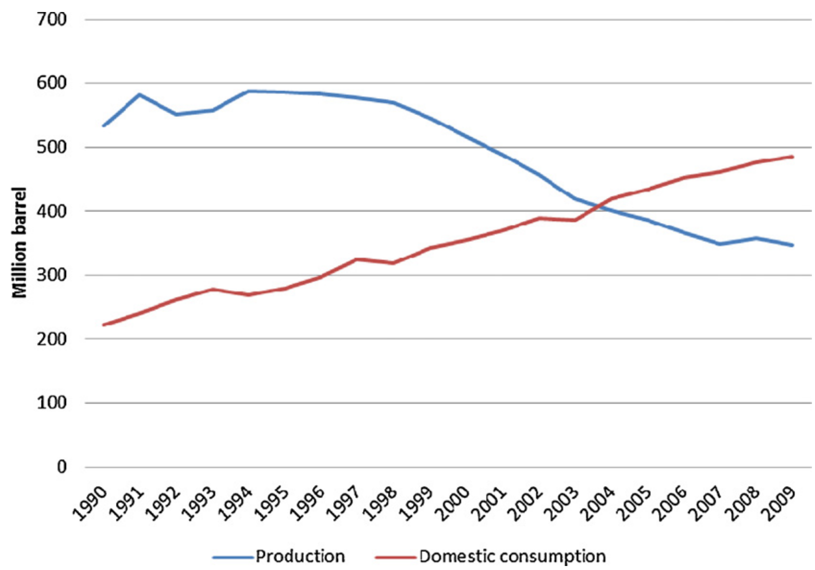

Fig. 4. Indonesia's production and consumption.

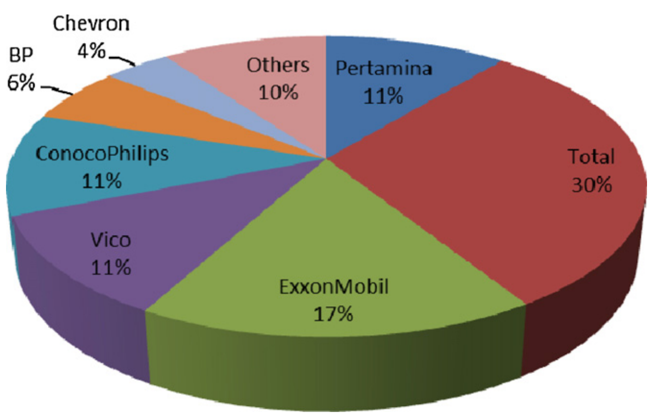

Fig. 5. Natural gas production share.

for domestic utilizations such as fertilizer industry, ceramic industry and electricity as well as the deferment of some LNG cargoes for export [70]. Substitution of oil based energy with natural gas has been considered as the country's declining oil output. Although Indonesia has large reserves of natural gas and most of them are being exported, the efforts of shifting natural gas toward domestic uses are being hindered by poor natural gas transmission and network distribution [71].

Arun and Bontang, which are major LNG production plants, have seen a drop in oil production in recent years. In an effort to make up for this shortfall, there has been an increase in natural gas exploration so that Indonesia is able to satisfy its long-term contract obligation and rise in domestic demand. The several new projects being developed, the Tangguh LNG project in West Papua is a high profile project with total proven reserves of 14.4 Tcf followed by Donggi LNG project in Centre of Sulawesi [71]. The development of BP's Tangguh field in Papua is intended for export markets and has been secured for a long term contract sales that include the Fujian LNG project in China, K-Power in Korea, POSCO in Korea, and Sempra Energy in Mexico [71].

3.3. Coal

Being the cheapest and most abundant available fossil fuel, coal will always have a role in energy mix in Indonesia. The estimated of coal resource in this country is about 21.13 billion short

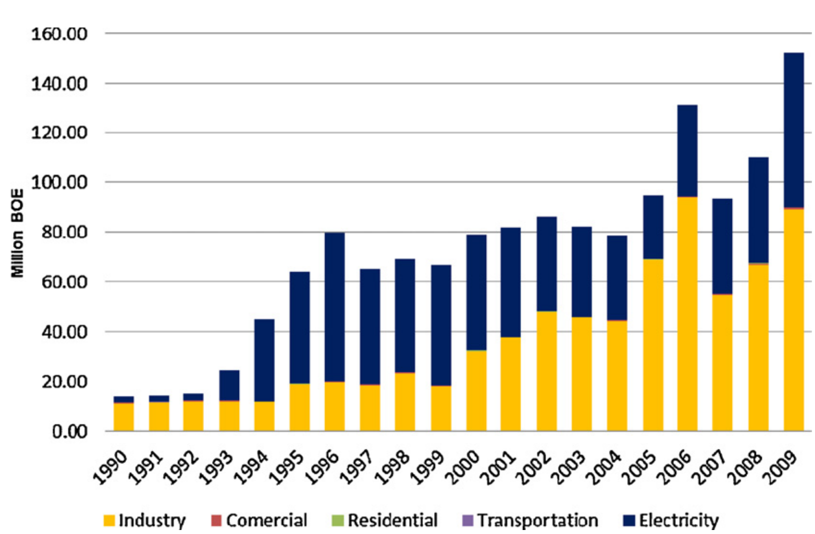

Fig. 6. Natural gas consumption by sector.

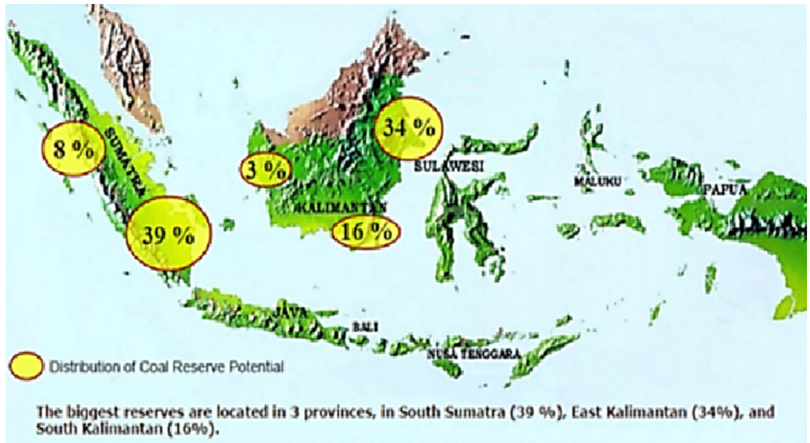

Fig. 7. Indonesia's distribution coal reserve potential.

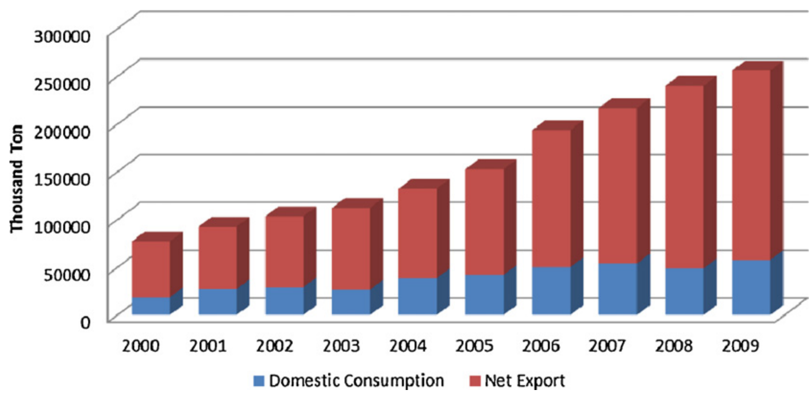

Fig. 8. Indonesia's production, domestic consumption and net exporter.

tons (approximately 85% consist of lignite and sub-bituminous), of which most of the reserves are located in Sumatra and Kalimantan, with the balance in West Java, and Sulawesi as presented in Fig. 7 [41,71,74]. In 2009, Indonesia produced 256 million short tons (MMst) of coal, up about 232% more than in 2000 and 95% of the coal produced from surface mining operation. This is because of large amount of Indonesian coal are available close to surface [70]. The country exports 198 million tons which represented 77% of total coal production to Japan, Taiwan, China, India, South Korea, Hong Kong, Malaysia, Thailand, and Filipina. The remaining 58 MMst of coal which is relatively small compared to its production, mainly used for power generation and industrial sectors such as cement production, iron and steel plants as presented in Fig. 8 [41]. The share of coal in Indonesia's primary energy supply has been on rise, from 4% in 1990 to 18% in 2009, primarily due to the rapidly expanding use of coal for power generation [41]. Indonesia plans

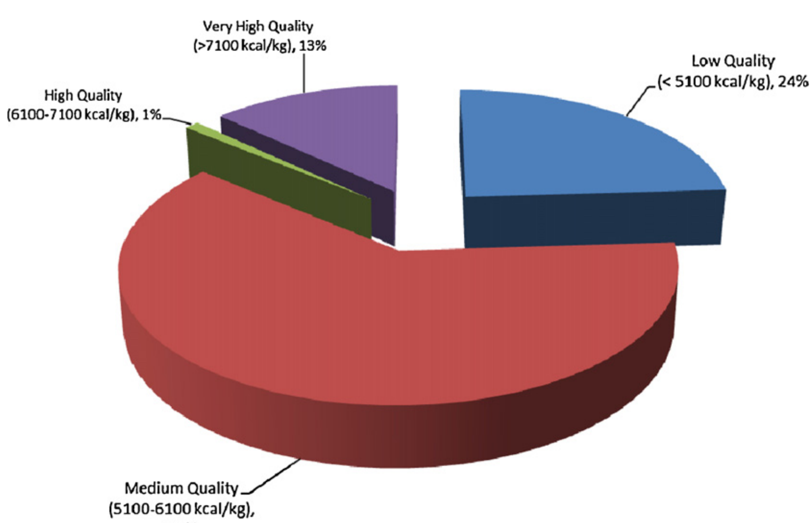

Fig. 9. Indonesia's distribution coal reserve potential.

Table 7
Typical quality specification for Indonesian export coal.

Quality parameter	Bituminous coals	Sub-bituminous coals
Total moisture (wt%)	10–12	24–38
Ash content (wt%)	2–12	1.5–7.5
Volatile matter (wt%)	31–42	28–37
Sulfur content (wt%)	0.10–0.95	0.07–0.90
Heat content (kcal/kg)	5300–6700	4100–5200

to develop coal fired power plants with capacity 10,000 MW by 2010 [75]. Compared to oil and natural gas, coal is preferable as energy resource in Indonesia due to its relatively low price and huge amount of reserves. Indonesia's distribution coal reserve potential is presented in Fig. 9 [74].

The country has played an important role as the worldwide coal supplier. The country has become the second largest coal exporter and the largest thermal coal exporter in 2009 [76,77]. Coal production in Indonesia was contributed by 251 companies, while 85% of total coal production was dominated by nine large companies [78].

The coals for export purpose generally come from bituminous to sub-bituminous coals with widely varying sulfur, moisture, ash, and volatile matter characteristics. The coals with a heat values ranging from 4100 to 5300 kcal/kg are classified as sub-bituminous coals while heat contents excess of 5300 kcal/kg are regarded as bituminous coals. Indonesian coals characteristic for export purpose are summarized in Table 7 [79].

The bituminous and sub-bituminous with higher heat content sub-bituminous are characteristically supplied for export purpose. The sub-bituminous coals with lower heat content are supplied both for export and domestics markets in a certain proportions. However, due to their ultra-low sulfur contents (less than 0.2%), most of the sub-bituminous coals with lower heat content have gained acceptance in export markets [79].

3.4. Hydropower

Hydropower is one of renewable energy technology that is commercially viable on large scale in Indonesia. Moreover, hydropower dams have made important and significant contributions to human development. Firstly, it is a renewable energy source and produces negligible amounts of greenhouse gases. In the long term, it produces large amounts of electricity at low cost and it can be adjusted to meet consumer demand. Furthermore, hydro dams are multipurpose and are built primarily for socio-economic developments such as irrigation, water supply, flood control, electric power and improvement of navigation. The country has a huge amount of hydropower resources. The potential of hydropower is estimated about 75,000 MW which makes Indonesia ranking fourth in Asia after China, the former Russian Federation and India. However, only 34,000 MW of 75,000 MW is exploitable [70,80]. This is basically due to the high capital investment required to develop the hydropower and often involves socio-economic issues. The development of a hydropower dam is overwhelmingly complex because the issues are not confined to the design, construction and operation of dams themselves but embraces the issues of social, environmental and political issues. Successful implementation of hydropower plant in selected countries was discussed deeply by Refs. [81–87]. Table 8 shows the installed capacity of hydropower stations in Indonesia [88].

Besides that, the country also has potential for small hydro power which is spread out across the country. The potential of micro hydro is estimated about 459.91 MW and 20.85 MW or 4.54% of the potential has been developed by PLN for power generation in rural areas [70]. The potentials are located in West Kalimantan,

Table 8
Installed capacity of hydropower station in Indonesia.

Station	Installed capacity (MW)	Total
1. Aceh		
PLTA Angkup	–	–
PLTA Peusangan	2 × 22.1 MW; 2 × 21.2 MW	86.6 MW
2. North Sumatra		
PLTA Sigura-gura	4 × 71.50 MW	286 MW
PLTA Tangga	4 × 79.25 MW	317 MW
PLTA Lau Renun	2 × 41 MW	82 MW
PLTA Sipan Sihaporas	2 × 25 MW	50 MW
PLTA Asahan I	2 × 90 MW	180 MW
3. West Sumatra		
PLTA Agam	3 × 3.5 MW	110.5 MW
PLTA Maninjau	4 × 17 MW	68 MW
PLTA Singkarak	4 × 43.75 MW	175 MW
4. Bengkulu		
PLTA Tes	4 × 4 MW	16 MW
PLTA Musi	3 × 70 MW	210 MW
5. Riau		
PLTA Koto Panjang	3 × 38 MW	114 MW
6. Lampung		
PLTA Besai	2 × 46.4 MW	90 MW
PLTA Batu Tegi	2 × 14 MW	28 MW
7. West Java		
PLTA Ubrug	2 × 10.80 MW; 1 × 6.30 MW	17.1 MW
PLTA Bengkok	3 × 3.15 MW; 1 × 0.70 MW	3.85 MW
PLTA Cibadak	–	–
PLTA Cikalong	3 × 6.40 MW	19.2 MW
PLTA Saguling	4 × 175 MW	700 MW
PLTA Cirata	8 × 126 MW	1.008 MW
PLTA Jatiluhur	7 × 25 MW	175 MW
PLTA Lamajan	3 × 6.40 MW	19.2 MW
PLTA Parakan kondang	4 × 2.48 MW	9.92 MW
8. Center Java		
PLTA Jelok	4 × 5.12 MW	20.48 MW
PLTA Timo	4 × 3 MW	12 MW
PLTA Ketenger	2 × 3.52 MW	7 MW
PLTA Gajah Mungkur	1 × 12.4 MW	12.4 MW
PLTA Garung	2 × 13.2 MW	26.4 MW
PLTA Wadas Lintang	2 × 8.2 MW	16.4 MW
PLTA Mrica	3 × 61.5 MW	184.5 MW
PLTA Kedung Ombo	1 × 23 MW	23 MW
PLTA Sidorejo	1 × 1.4 MW	14 MW
PLTA Klambu	1 × 1.1 MW	1.1 MW
9. East Jawa		
PLTA Mendalan	3 × 5.8 MW	23 MW
PLTA Siman	3 × 3.6 MW	10.8 MW
PLTA Giringan	2 × 1.35 MW; 1 × 0.5 MW	3 MW
PLTA Selorejo	1 × 4.48 MW	4.48 MW
PLTA Karangkates	3 × 35 MW	105 MW
PLTA Wlingi	2 × 27 MW	54 MW
PLTA Lodoyo	1 × 4.5 MW	4.5 MW
PLTA Sengguruh	2 × 14.5 MW	29 MW
PLTA Tulung Agung	2 × 23 MW	46 MW
PLTA Tulis	2 × 7 MW	14 MW
10. South Kalimantan		
PLTA Riam kanan	3 × 10 MW	30 MW
11. North Sulawesi		
PLTA Tonsea Lama	1 × 4.44 MW; 1 × 4.5 MW; 1 × 5.44 MW	14.38 MW
PLTA Tanggari I	1 × 17.2 MW	17.20 MW
PLTA Tanggari II	1 × 19 MW	19 MW
12. South Sulawesi		
PLTA Larona	3 × 55 MW	165 MW
PLTA Balambano	2 × 65 MW	130 MW
PLTA Karrebe	2 × 70 MW	140 MW
PLTA Bakaru	2 × 63 MW	126 MW
13. Center Sulawesi		
PLTA Sulewana Poso I	4 × 40 MW	160 MW
PLTA Sulewana Poso II	3 × 60 MW	180 MW
PLTA sulewana Poso III	5 × 80 MW	400 MW

Table 9
Geothermal distribution potencies by region.

Area	Resource (MW)		Reserve (MW)		
	Speculative	Hypothetic	Probable	Possible	Proven
Sumatra	4975	2121	5845	15	380
Java	1960	1771	3265	885	1815
Bali-Nusa Tenggara	410	359	973	–	15
Sulawesi	1000	92	982	150	78
Maluku	595	37	327	–	–
Kalimantan	45	–	–	–	–
Papua	75	–	–	–	–
Total	9060	4380	11392	1050	2288

West Sumatra and Central Sulawesi, while the largest installed capacity of micro hydro can be found in North Sumatra, Central Java, West Java and Bengkulu [89]. For Indonesia as an archipelago agree with a few large rivers, development of micro and mini hydropower plants will play a prominent role in energy mix of the country. About 6000 plants of the mini hydropower range (300 kW–5 MW) which contributing at least 7500 MW are economically feasible these days [80]. Considering the small scale of hydro potentials that are distributed evenly around the islands, small hydro power plants are seen as one option that may be used as local energy resource especially in remote areas for rural independent power generation [89]. By exploring this potential intensively with involvement of private sector, it gives an excellent opportunity to develop energy sector as well as the policy [80].

4. Renewable energy

Renewable energy is the energy derived from natural processes that do not involve the consumption of exhaustible resources such as fossil fuels and uranium. Apart from the main sources of energy such as natural gas, oil, coal, and hydropower, Indonesia has great potential renewable energy resources such as geothermal, wind energy, and biomass. Despite high growth rates, renewable energy still represents only a small part of today's global energy picture. Therefore, this study will look into the aspect of renewable energies such as geothermal, biomass, solar, and wind in this country. The hydropower will not be discussed here because it has been used widely and is discussed deeply in the previous section.

4.1. Geothermal

Many countries use geothermal successfully as power generation. Some works that deal with geothermal power generation are given in Refs. [90–96]. In Indonesia, geothermal power is an increasingly significant source of renewable energy as deeply discussed by Refs. [97–106]. As a consequence of Indonesia's location in The Ring of Fire and its volcanic geology, the country is blessed with untapped potential of geothermal energy. It is estimated, the country has 28,000 MW of geothermal potential, corresponds to 40% of world's potential geothermal resource. The country construct about 1200 MW of power plant from seven geothermal areas in North Sulawesi, North Sumatra, and Java [41,70]. In 2009, geothermal energy represented 1.22% of the country's total energy supply and 3.6% of its electric power [41]. The country also plans to develop nine Geothermal Working Areas such as GWA Seuwalah Agam (Aceh), GWA Soboi (Aceh), GWA Jailolo (North Maluku), GWA Telaga Ngebel (East Java), GWA Ungaran (Central Java), GWA Gunung Tampomas (West Java), GWA Cisolok-Cisukarame (West Java), GWA Tangkuban Perahu (West Java), and GWA Sokoria [107,108]. Geothermal distribution potential in Indonesia by region is given in Table 9 and geothermal power plant capacity is presented in Table 10 [41].

4.2. Biomass

Biomass is natural energy source, mostly coming from agriculture crops and residues, forest waste, commodities of plantation, and animal waste. Biomass is the only one of the renewable energy, which can be used to produce three kinds of fuel, liquid, solid and gas fuels [70]. Some of early works on biomass energy conversion in Indonesia are discussed by Refs. [109–113]. The country's total biomass production was around 146.7 million tons per year, equivalent to 470 GJ/y and mostly used by rural areas and small industries to provide energy for cooking, heat and electricity. Biomass energy source in the country can be obtained from palm oil residues, rice residues, rubber wood, palm oil residues, sugar residues, etc. as presented in Table 11. Rice residues have the biggest energy potential about 150 GJ/year, followed by rubber wood, sugar residues, and palm oil residues with energy potential 120 GJ/year, 78 GJ/year, and 67 GJ/year, respectively. The rest are from agricultural wastes and residues from any other agriculture activities such as logging residues, coconut residues, sawn timber residues and plywood and veneer residues with potential energy smaller than 20 GJ/year [114].

Biodiesel is an alternative fuel mainly derived from renewable raw materials such as vegetable oils or fatty acid through esterification process to serve as addition to diesel fuel. Vegetable oil as the main source of biodiesel can be produced from plant oils such as kapok seed oil, palm oil, jatropha oil, coconut oil, and other 30 kinds of Indonesian plants [115–123].

There are some advantages of biodiesel over ordinary diesel fuel. Biodiesel can be mixed with any composition of diesel oil and can be applied directly to the diesel engines without any modification because biodiesel has similar physical properties compared to ordinary diesel fuel. It also has higher cetane number than regular diesel fuel, does not produce black exhaust gas, contains no toxic and sulfur, and is biodegradable and environmental friendly [115].

Indonesia was known as the largest palm oil producer in the world after overtaking Malaysia in 2006. The country produce 21.6 million tons of palm oil, rise 3.8% from 2009. One of the factors leading to higher production is the expansion of palm oil plantation area by 6.7% to 5.73 million hectare in 2010 [124]. However, most of the CPO (around 60%) that exports to other countries still in raw form which is considered as low value-added industries [125]. Due to the abundance of raw materials in the country, Indonesia should explore the potential of biodiesel as an alternative fuel [126].

The potential of biogas energy for applications in small rural areas is somewhat encouraging. Biogas from buffaloes, pigs and cows droppings can be found in all provinces in Indonesia, though the quantities are in different amount. Table 12 shows the summary of biogas energy potential by provinces in Indonesia [70].

Table 10
Geothermal power plant capacity.

Working Area	Location	Turbine capacity	Operator	Total capacity
PLTP Kamojang	West Java	1 × 30 MWe 2 × 55 MWe 1 × 60 MWe	PLN	200 MW
PLTP Lahendong (Pertamina)	North Sulawesi	2 × 20 MWe 1 × 20 MWe	PLN	60 MW
PLTP Sibayak (Pertamina)	North Sumatra	1 × 12 MWe	Pertamina	12 MW
PLTP Salak (Chevron GS)	West Java	3 × 60 MWe 3 × 65 MWe	PLN CGS	375 MW
PLTP Darajat (Chevron GI)	West Java	1 × 55 MWe 1 × 90 MWe 1 × 110 MWe	PLN CGI CGI	255 MW
PLTP Wayang Windu	West Java	1 × 110MWe 1 × 117 MWe	SE	227 MW
PLTP Dieng (Geo Dipa Energi)	Central Java	1 × 60 MWe	GDE	60 MW
			Total	1189 MW

Table 11
Major biomass energy potential as energy resources.

Biomass	Main region	Production (million/year)	Technical energy potential (GJ/year)	Remarks
Rubber wood	Sumatra, Kalimantan, Java	41 (replanting)	120	Small log < 10 cm medium and big logs are used as fire wood in brick and roof tile industry
Logging residues	Sumatra, Kalimantan	4.5	19	
Sawn timber residues	Sumatra, Kalimantan	1.3	13	Residues of the factory often used as fire wood by local communities, residue available for free
Plywood and veneer production residues	Kalimantan, Sumatra, Java, Irian Jaya, Maluku	1.5	16	Residues are generally used yet
Sugar residues	Java, Sumatra, Sulawesi, Kalimantan, Bali/Nusa Tenggara	Bagasse: 10 Cane tops: 4 Cane leaf: 9.6	78	Bagasse is generally used in sugar factories (90%), The use of cane leaf and tops need to be investigated
Rice residues	Java, Sumatra, Sulawesi, Kalimantan, Bali/Nusa, Tenggara	Husk: 12 Bran: 2.5 Stalk: 2 Straw: 49	150	Stalk and straw are generated at the field and generally burnt, in some areas used for feeding or raw material for paper industry Husks often burnt uncontrolled
Coconut residues	Sumatra, Java, Sulawesi	Husk: 12 Bran: 2.5 Stalk: 2 Straw: 49	7	Residues are used generated decentralized and usually left on the plantation field. Largely used as Firewood and for production charcoal
Palm oil residues	Sumatra, new areas: Kalimantan, Sulawesi, Maluku, Nusa Tenggara, Irian Jaya	Empty fruit Bunches: 3.4 Fibers: 3.6 Palm shells: 1.2	67	Palm cells and fiber are common fuel source, EFB are generally incinerated

4.3. Wind

Wind energy is considered as one of green power technologies since it produces no air pollutants or greenhouse gas and contributes minor impacts toward the environment [127]. Wind energy is the conversion of wind speed into a useful form of energy such as generating electricity, wind mills for mechanical power, wind pump for pumping water or sails to propel ships [128]. At the end of 2009, worldwide wind powered generators capacity was 159.2 GW [129]. All wind turbines installed worldwide are generating 340 TWh per annum, which is about 2% of worldwide electricity usage. Wind power is growing rapidly and having doubled in the past three years [130].

Table 12
Biogas energy potential in each province.

Province	Biogas potential (MW)
East Java	125.9
Central Java	63
NTT	56.7
North Sumatra	46.8
Aceh	42.7
South Sulawesi	28.8
West Java	40.1
Bali	32
NTB	28.2
South Sumatra	26.8
West Sumatra. Province of Central Sulawesi, West Kalimantan, North Sulawesi, Lampung, and Southeast Sulawesi	10–19
Other provinces	<10

Utilization of wind power as an energy source in the country has great potential for further development, especially in coastal areas where wind is abundant. With the wind speeds between 2 and 6 m/s, the suitable wind power generators to develop in Indonesia are small (10 kW) and medium scale power generations (10–100 kW) [70]. Some works on wind energy in Indonesia can be found in Refs. [131–137].Indonesia has constructed 5 units of windmills generators across the country each with a capacity of 80 kW and 7 other units with the same capacity have been developed in four locations, North Sulawesi, the Pacific Islands, Selayar Island and Nusa Penida, Bali. However, until now Indonesia has not had a comprehensive map of potential wind due to the mapping of wind energy potential estimated would cost billions of dollar. Based on data collected by the Institute of Aeronautics and Space Agency (Lapan) in 120 locations, areas that have wind speeds above 5 m/s are West Nusa Tenggara, East Nusa Tenggara, South Coast of Java and South Sulawesi [138]. The Sumba's and West Timor's wind energy mapping is given in Figs. 10 and 11 [139].

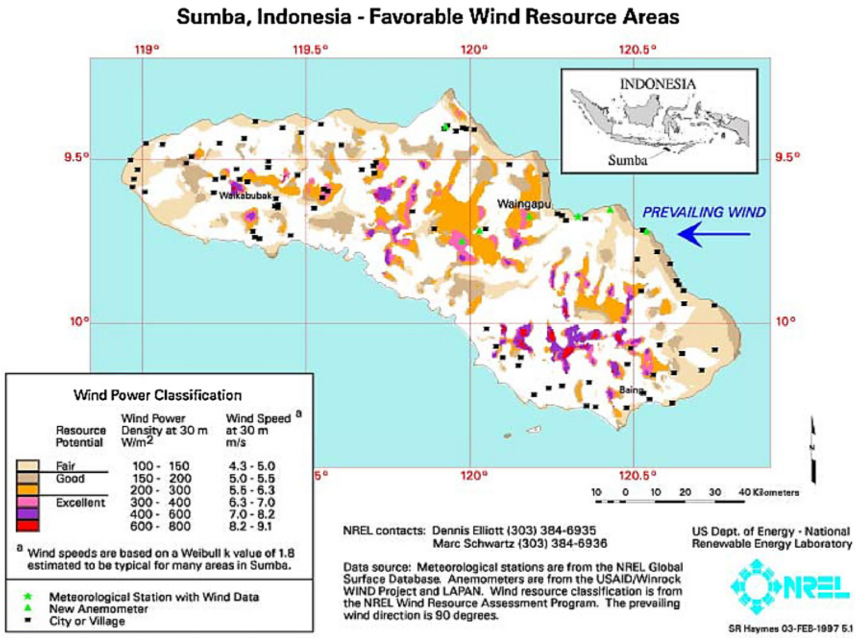

Fig. 10. Sumba's wind energy mapping.

4.4. Solar

Solar energy is one of the most promising source of clean, renewable energy and it has the greatest potential than any other power resource to solve the world's energy problems [140]. Nowadays, solar energy has become more popular as an energy supply in the world [10,141]. Many countries have been utilizing solar energy.

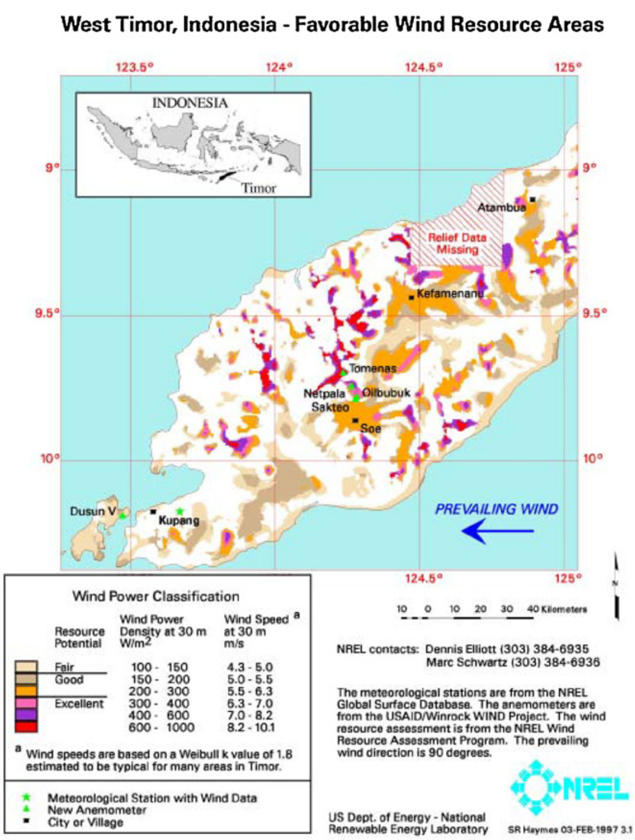

Fig. 11. West Timor's wind energy mapping.

Successful implementations of solar power plant in selected countries are discussed by Refs. [142–155].

Since Indonesia is a tropical country and located in the equator line, the country has an abundant potential of solar energy. Most of Indonesian areas get a quite intense of solar radiation with the average daily radiation approximately around 4 kWh/m^2 [70]. Based on the data collected from 18 locations in the country, the solar radiation distribution can be divided into Western and Eastern regions. It is estimated that the distribution of solar radiation is about 4.5 kWh/m^2/day with monthly variation around 10% for Western Region and 5.1 kWh/m^2/day with variation around 9% for Eastern Region [156]. For Indonesia which has so many small and isolated islands where electricity demand is quite low, photovoltaic solar energy system may be used to fulfill power demand in rural areas including lighting for public service area and places of worship. Successful implementation of photovoltaic solar energy system in rural areas can be found in Refs. [157–168]. In order to develop a photovoltaic solar energy system, the government tries to design a variety of strategies including the integration of photovoltaic solar energy system for consumptive and productive purposes. However, many challenges must be sorted to develop this system such as expensive prices of solar module which is the main component of the system. This condition not only affects the financial bodies to provide a funding to develop this system, but also reduces the interest of local communities to use this system due to its exorbitant cost. Due to these problems, development of this system is highly dependent on funding from the government [169].

5. Conclusion

Indonesia energy consumption still depends on non-renewable energy such as crude oil, coal and natural gas as a source of energy. Even though Indonesia has huge amount of energy source which most of it coming from oil, coal and natural gas, cannot be helped it will be run out someday. In addition, utilization of fossil fuel continuously contributes huge amount of greenhouse gases emission and can lead to climate change. Considering the depletion of fossil fuel reserves and adverse of greenhouse gas emission, using sustainable and renewable energy is unavoidable. Although the country has applied and extends utilization of renewable energy, the contribution of renewable energy in power generation is only around 3%. Considering Indonesia's natural condition and geography, it is blessed with great potential of renewable energy such as solar energy, wind energy, micro hydro and biomass energies. Noting the potential of this country in using renewable and sustainable energy resources, the government must pay more attention to the renewable energy utilization. Many efforts have been done to promote renewable energy such as by developing energy policy and regulations, yet it still did not give any result. Government, non-government agencies and the public should take more proactive steps to promote and use renewable energy in order to achieve sustainable energy.

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