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A REVIEW OF RENEWABLE ENERGIES IN TAIWAN

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ABSTRACT

With limited indigenous conventional energy resources, Taiwan imports over 97% of its energy supply from foreign countries, mostly from the Middle East. Developing independent renewables is thus of priority concern for the Taiwanese government. A medium subtropical island surrounded by the Pacific Ocean, Taiwan has enormous potential to develop various renewables, such as solar energy, biomass energy, wind power, geothermal energy, hydropower, etc. According to the estimation, the total renewable energy reserve is about 194 GW, which equals to 4 times of national installed power capacity in 2015, e.g., 48.7 GW, so Taiwan has abundant renewable energy resources indeed. However, owing to the importance of conventional fossil energy in generating exceptionally cheap electricity, renewable energy has not yet fully developed in Taiwan, resulting from a lack of market's competition. In 2016, after the new government came to power, the Bureau of Energy (BOE) Ministry of Economic Affairs (MOEA) set up an active promotion goal for the renewable energies (RE) in Taiwan: the total RE power capacity will be 20% share of the national power installation capacity by 2025. In the meantime, the four inherent shortcomings—low energy density, high cost of power generation, instability of power supply, and current cost of renewable energy being still higher than that of fossil energy—have to be overcome first, before renewable energy is actually formed as a main component in national energy mix. The development of renewable energy not only contributes to the independence of energy supply, but also achieves the benefits of economic development and environmental protection. This study reviews the current status, achievements, polices and future plans in these areas for Taiwan.

KEYWORDS: Renewable energies; Promotion strategies; Reserves; Taiwan.

INTRODUCTION

After the industrial revolution, traditional fossil energy had been explored and adopted in great amount (Table 1), so it is gradually depleting right now, as Table 2 shows the global reserves and remaining available years of major energies. In the meantime, since of the impacts on environment caused by the application of traditional energies, such as: green-house effect and environmental pollution, *etc.*, so how to reduce the dependence on traditional energy and the damage on our environment but, in the meanwhile, sufficient energy being able to supply to fulfill the needs of both economics and livelihood, have become the biggest issue for human being. Renewable energies are sustainable and clean energies, which may overcome the gradual depletion of traditional fossil energies that have impacts on environment, and which may also solve the issues of energy sustainability, economical development, and environmental protection, so the development and application of renewable energies had been accelerated in last decade. Refer Table 3 and Table 4 for related analyses. Basically, low-carbon energyies, like RE and nuclear energy, play an important role in reducing the greenhouse gas emissions in a country's energy mix, while fossil energies, for example, coal, oil, and natural gas, are on the contrary.

***Table 1.* Energy source consumptions in major countries in 2015 (parenthesis means 2014) Unit: MTOE**

	Primary energy	Coal	Oil	Natural gas	Fossil energy ratio (%)	RE ratio (%)	Nuclear ratio (%)
US	2,280.6	396.3	851.6	713.6	86.0 (86.3)	5.7 (5.4)	8.3 (8.2)
Germany	320.6	78.3	110.2	67.2	79.8 (82.2)	13.8 (11.7)	6.4 (7.0)
UK	191.2	23.4	71.6	61.4	81.8 (84.5)	9.8 (7.7)	8.3 (7.6)
China	3,014.0	1,920.4	559.7	177.6	88.2 (89.1)	10.5 (9.9)	1.3 (1.0)
Japan	448.5	119.4	189.6	102.1	91.7 (93.1)	8.1 (6.9)	0.2 (0)
Korea	276.9	84.5	113.7	39.2	85.7 (86.3)	0.8 (0.7)	13.5 (13.0)
Taiwan	110.7	37.8	46.0	16.5	90.6 (89.6)	1.8 (2.0)	7.5 (8.6)
Total World	**1,3147.3**	**3,839.9**	**4,331.3**	**3,135.2**	**86.0 (86.4)**	**9.6 (9.2)**	**4.4 (4.4)**

Data sources: bp-statistical-review-of-world-energy-2016-full-report

***Table 2.* Global reserves and availability of primary energy resources (2015)**

Category Item	Oil (billion barrels)	Natural Gas (trillion cubic meters)	Coal (billion tons)	Renewables (MTOE)	Nuclear (MTOE)
Total Reserves	1,697.6	186.9	891.5	213,337*	47,600**
Yield	33.4	3.54	7.8	1,258 (1,341)*	583.1
Available Years	51	53	114	169 (159)*	82

Data sources: BP, *REN21, **IPCC

***Table 3*. Global power generation structure**

Electricity generation by energy resources	Installed capacity (2015)	Electricy generation (2014)	Electriciy emission coefficient (2014, IPCC)	Carbon dioxide emission
	GW	TWh	g-CO_2/kWh	Mt
Coal	1,939 (2016, July)	8,726	820	7,155
Natural gas	1,311 (2010)	4,933	490	2,417
Oil	~ 509	1,068	778	831
Hydraupower	1,064	3,769	24	90
Wind power	433	700	11	8
Geotherml	13.2	207	38	8
Solar PV	227	167	48	8
Biomass	106	429	18	8
Nuclear	390	2,417	12	29
Summary	**5,992**	**22,416**	**471**	**10,554**

Data sources: REN 21, tsp-data-portal.org, WNA, Global Coal Plant Tracker, Power Magazine

Table 4. Electricity emission coefficients in major countries (2014)

Country	Fossil fuel electricity ratio (%)	RE electricity ratio** (%)	Nuclear power ratio (%)	Average electricity emission coefficient*** (g-CO_2 / kWh)
India	80	16	3	638
China	73	24	3	602
Saudi Arabia	100	0	0	600
Japan	86	14	0	557
Taiwan	79	4	16	521
Korea	69	2	29	496
US	72	8	20	494
Germany	57	27	16	442
United Kindom	63	18	19	424

Russia	65	17	17	381
France	6	17	76	57
Global	**66**	**24**	**11**	**471**

Notes:
*Components that make up fossil fuel electricity include: coal, natural gas, and oil.
**Components that make up RE electricity include: hydraupower, wind power, geothermal, solar PV, and biomass, etc.
***The electricity emission coefficient (g-CO_2/kWh) represents the amount of CO_2 emitted per kilowatt hour (kWh) of power generated by the country's power plants.
Data sources: http://www.tsp-data-portal.org/Breakdown-of-Electricity-Generation-by-Energy-Source#tspQvChart, IPCC

More than 97 percent of Taiwan's energy demand imports from abroad, and most from the Middle East that is political instable, which is indeed the biggest worry of energy independence policy. For example, in 2015, Taiwan imported 141.9 million kiloliters of oil equivalent (MKOE) energy under the expense of US$36.7 billion, accounting for 7 percent of gross domestic product (GDP) US$523.6 billion. These high prices of energies have enormous impact on Taiwan's economy, so the development of renewable energy becomes an only survival way for Taiwan.

The so-called renewable energies include solar energy (further including solar photovoltaics and solar thermal energy), wind energy, hydropower, geothermal energy, ocean energies (such as: ocean thermal energy conversion, tidal power, and wave energy, etc.), which are all natural energy resources coming from the sun or possessed by earth, other renewable energies also including biomass energies, such as: waste energy, biogas electrification, and biofuel, *etc.*

Although renewable energies are essentially exploited from nature, indigenous, and clean, and they are theoretically inexhaustible and sustainable, in the applying characteristics of renewable energies, several drawbacks do exist, such as: low energy density (in photovoltaic system, 9-10 m^2 of installing area is needed for each kilowatt of power), unstable supply (for example, clear day is the condition for solar electrification; for wind electrification, sufficient wind resource must be existed, and wind turbine can only be started at a specific range of wind speed, while blades must be stopped rotating when wind is too strong), and higher cost (for example, the installing expense for each kilowatt of PV is 300 thousands NTD, and its electrification cost is about 15-24 NTD for each kilowatt-hour, and the costs of other ways of RE electrification are also much higher than those of traditional ways of electrification). So, when applying renewable energies, local conditions must be cooperated, such as: solar radiation, wind power potential, available land area and suitable sites, *etc*., which must be assessed before installing any kind of renewable energy system. Therefore, under these conditions of insufficiently economic impetus at present stage, the development and promotion of each category of renewable energies must depend upon each individual incentive or subsidizing scheme, by which a government may promote her corresponding RE policy in a much easier and effective way.

THE ENERGY SUPPLY AND DEMAND SITUATION IN TAIWAN

The total energy consumption in Taiwan, R.O.C. has grown greatly over the past two decades, going from 66.11 million kiloliters of oil equivalent in 1995 to 115.03 million kiloliters in 2015, which is an average annual growth of 2.81%. Of that in 2015, 78.21% was for energy use, and non-energy uses consumed 21.79%. When classified by consumer, the consumption of energy for each sector in 2015 was as follows: energy and industrial sectors consumed 43.67%; transportation sector, 11.90%; agriculture, forestry and fishery sectors, 0.91%; services sector, 11.03%; residential sector, 10.69%. Classified by form of energy, coal and coal products contributed 8.43% of consumption in 2015; petroleum products provided 38.84%; natural gas shared 3.36%; biomass and waste accounted for 0.18%; electricity constituted 48.89%; solar thermal 0.10% and heat 0.21%.

Electricity production grew from 133.1 TWh in 1995 to 258.0 TWh in 2015, an average annual increase of 3.36%. Of the total electricity production in 2015, the hydro power of Taiwan Power Company comprised 2.87%, thermal power 50.74% (coal shared 22.98%, oil 4.47%, LNG 23.29%), nuclear power 14.13%, wind power and solar photovoltaic 0.29%, cogeneration 15.24%, and IPP 16.72%. Also, the peak load in 2015 reached a record 35,248 MW.

In 2015, the dependence on imported energy in Taiwan, R.O.C. was 97.53%; the value of energy imports was US$36.7 billion, which was 42.87% less than the previous year; the per capita energy imports cost burden in 2015 was NT$50,542, which was a decrease of 40.19% compared with NT$84,508 in 2014.

According to the aforementioned statistics, Taiwan's current energy structure is facing following three crises:

(1) Completely dependent energy supply - Taiwan imported more than 97 percent of energy demand from foreign countries, and mostly from politically unstable Middle East, this is indeed a biggest worry in the policy of energy independence.

(2) Serious greenhouse gas emissions – the greenhouse gas emissions per capita in 2013 Taiwan was 10.62 tonnes carbon dioxide equivalent/person-year, 2.35 times the global per capita greenhouse gas emissions, namely, 4.52 tonnes carbon dioxide equivalent/person-year, ranking the world's top 20. The main cause is the excessive use of fossil fuels, while fossil fuel combustion with carbon dioxide emissions is recognized as the main cause of the greenhouse effect in the atmosphere, which in turn is the main cause of global climate change.

(3) Energy efficiency is too low - energy intensity was 0.13 thousand US dollars per tonne of oil equivalent in 2012 Taiwan, although lower than 0.22, 0.19, 0.15 of China, South Korea and the United States respectively, but still higher than 0.11, 0.11, 0.09 of neighboring Japan, and the United Kingdom, Germany in Europe, and the more important is that Taiwan's energy intensity is still far higher than 0.10 of the global average. This shows the structural mode of Taiwan's energy supply and demand needs to be changed, at the same time, which directly confirms the importance of energy conservation and energy efficiency to enhance the country's economic competitiveness.

To solve the above-mentioned three major crises in Taiwan's energy mix. We recommend specific practices that should have no more than the following 5 items, as depicted in Fig. 1, in which the responsive means for energy saving and carbon reduction strategies are listed.

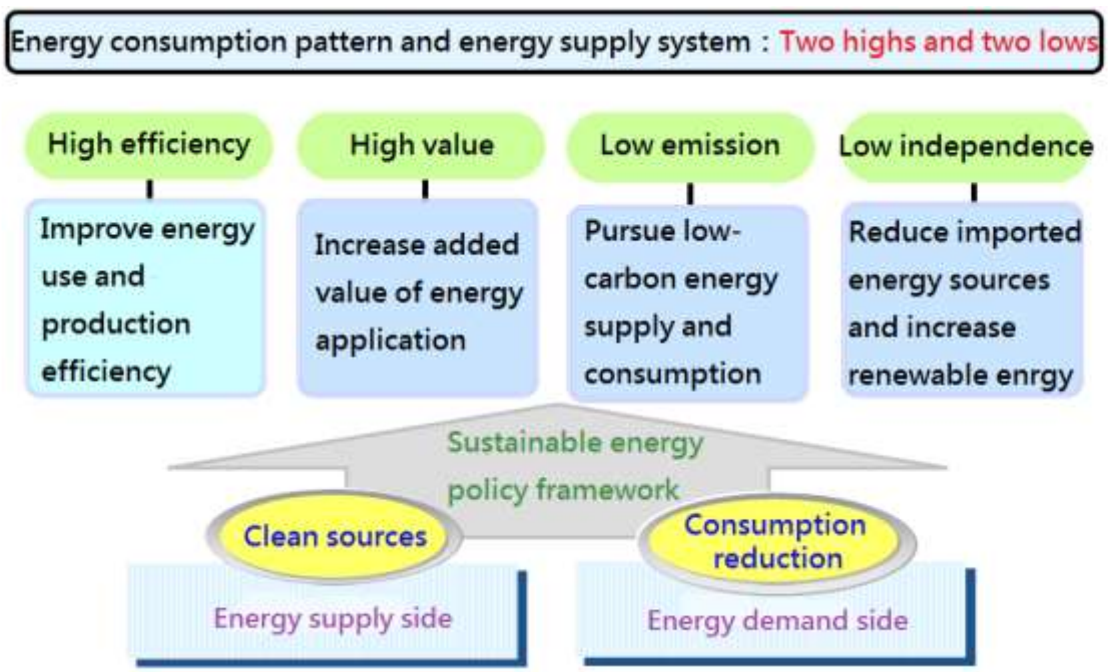

Fig. 1. Sustainable energy policy framework for Taiwan

- Clean sources: For the electricity sector on the supply side, low-carbon powers, such as renewable power, gas-fired power, high-efficiency coal-fired power, and nuclear power, are used to achieve low carbon emissions. Thereinafter, the proposed practices focus on the emerging power generation technologies.
- Consumption reduction: For major energy consumers, such as the industrial, transportation, residential and commercial sectors, energy-saving technologies can achieve reductions in carbon emissions.
- The industrial sector: This sector is comprised of six energy-intensive industries: petrochemicals; semi-conductors; iron and steel; cement; paper and pulp; and textiles. The deployment of the Best Available Techniques (BAT) in these industries is a focus.

- The transportation sector: The focus in this sector is on electrical vehicles, rail transport, high-efficiency vehicles, and bio-fuels.
- The residential and commercial sector: The focus is on high-efficiency appliance, such as Light-Emitting Diode (LED) and inverter Air Conditioning (AC).

ASSESSMENT OF RENEWABLE ENERGY RESERVES IN TAIWAN

In fact, reserves of renewable energies in Taiwan should be quite rich, because there are plenty of remarkable conditions as follows. First of all, Taiwan is located in subtropical area, in which the Tropic of Cancer passes through central Taiwan, so the insolation time is long and the angle of daylight deflection is small, very suitable for the development of solar energy. In addition, there are summer and winter monsoons along the western ring of Pacific Ocean, making Taiwan Strait like a fast wind tunnel. Meanwhile, with the west coast stretching a large bank, Taiwan has a great potential for offshore wind power generation. Particularly, with wind speed up to 7m/s and above all year round, the area of Penghu is a wind field of high-quality. Potential of biomass energy can't be underestimated either. Apart from wastes generated from livelihood of people, industry and agriculture, plenty of energy crops can be used for producing biofuels. Particularly, the second generation of biomass crops, such as oil algae and cellulose, won't lead to the food crisis. Because thousands of kilometers of coastal waters and the vast majority of forest land can be used to farm or cultivate these energy crops, there are considerable potential with respect to biomass energy in Taiwan. In the meantime, Taiwan located at the juncture of Eurasian Plate and Philippine Sea Plate is also a part of the Ring of Fire series including the Philippines, Japan, Indonesia and other countries, where geothermal energy has developed in grand occasion, so we can see that the development potential of geothermal energy here in Taiwan should not be taken lightly. High mountain terrain and abundant rainfall (annual average of about 90 billion tons) also provide considerable hydroelectric potential. At last, Taiwan is surrounded by the ocean and is suitable for the development of marine energy. Not far from the east coast, the sea water on the ocean surface is warn, but is ice-cold at the depth of thousands of meters, providing an excellent location for ocean thermal energy conversion. With flow rate of 1 m/s and average width of 100 km, Kuroshio, part of North Pacific circulation, turning north through the Philippines, passing by the eastern coast of Taiwan, finally flowing north steadily throughout the year to Japan, is a huge momentum for Taiwan's ocean energy to develop electricity generation with infinite potential.

Solar energy

Taiwan, a medium island in subtropical area, geographically located between east longitude 120 °-121 ° and north latitude 22 °-25 °, is very in favor of the development of solar energy, due to the benefits of long duration of insolation and small angle of daylight deflection. Solar energy not only can improve security of energy supply, but also can immediately relieve the peak load of electricity. In Taiwan, during daytime of summer, the air conditioning consumes a large amount of electricity, which can be supplied by PV facility powered by intensive solar radiation in time. While natural conditions are good, land conditions are very inadequate for the installation of solar equipment in Taiwan. Based on statistical data of Ministry of the Interior, the total population in Taiwan is about 23 million, while the land area is approximately 36,000 km^2, resulting in that the land area per capita is 1,560 m^2/p. Second only to Bangladesh, the population density of Taiwan is second highest in the world. Worse still, 2/3 of the island land is mountain area, only 1/3 of land suitable for housing, which is concentrated in the south-west coast, making Taiwan have great limitation in the area of land to install solar power facilities.

Regarding the mean estimates of the amount of insolation in Taiwan, first of all, under the provisions of land areas of cities and counties by the Ministry of the Interior and the regional annual average amount of insolation by the Central Weather Bureau , this paper adds the regional product of both the area and the amount of insolation for hundreds of national land areas. Then, the sum is divided by the total country area; as a result, the average amount of insolation per unit area per year in Taiwan is 1,130 kWh/m^2-y = 129 W/m^2 (the British average solar intensity referred by MacKay [1] was 100 W/m^2).

If large solar photovoltaic systems would be built in Taiwan, not only their equipment costs are still much higher than the fossil energy equipment's, but also a major obstacle is incurred from the costs of a large area of land required for the installation of PV farms (or large stand-alone systems). Therefore, in order to obtain operating profits and value, the development of PV farm must be under the premise of no land cost.

By the overall integration of the above types of data, the total reserve of solar energy (including solar thermal energy 2.28 GW and solar PV energy 74.2 GW) of rooftop-type in Taiwan is about 76.48 GW [2], so it can be said that the solar energy in Taiwan is quite abundant.

Wind power

According to the investigation of NASA [3], the average density of wind power exceeds 750 W/m^2 in the coastal areas of Taiwan, so the conditions of the developments of wind power in Taiwan are fairly favorable. Although wind power has the problem of poor stability, with the progress of storage technologies, the related issues are expected to be addressed one by one.

With fewer and fewer areas available in land, the development of offshore wind farm on the sea is inevitable. Setting up offshore wind farm on the sea can keep the people from the affects of noise or visual impact and avoid the high land cost. At the same time, due to fewer obstructions, the wind on the sea surface has higher speed than the inland area's, in addition to smooth airflow and stability, so the overall availability of offshore wind farm is higher than that of terrestrial wind farm. But, since involving marine works, the erection cost of the former is higher than that of the latter. The cost of constructing offshore wind turbine is proportional with the sea depth. In waters less than 30 m depth, pile- or gravity-typed base can be used as a wind turbine platform to reduce costs; in 30-60 m deep waters, the three-legged truss is generally used as the pile or foundation of the wind turbine; while in the water depth of 60 m and above, a floating platform should be used as the wind turbine base. Although the United States has developed a technology of deep-sea floating platforms for offshore wind turbine, making wind turbine able to be installed in water area with depths of more than 200 m, there is still no actual measurement data seen in the open literatures yet.

To sum up, the potential installation capacity of wind power in both areas of land and sea in Taiwan is 4 GW and 73.5 GW respectively. The electricity generation per year is about 251.01TWh/year, which is not far off 258.02 TWh [4], the total electricity generated in 2015 Taiwan. Although wind still can not provide stable power under current technology, with the advances of nano-materials technology to develop energy storage device in small volume and with high energy density, the stability of wind power can be improved significantly in the future.

Biomass energy

In addition to wastes of industry, agriculture, forestry, urban and others, there is a wide range of biomass, and so are the biomass crops of first generation, such as the sugar cane for ethanol and the rapeseed for biodiesel. The population of Taiwan is so dense that the development potential of biomass can't be put on par with those of large countries, such as Brazil, China and the United States. However, in addition to the global turmoil of energy saving and carbon reduction at present, under the predicament of a large number of abandoned farmland in Taiwan, the development of biomass not only can significantly enhance the security of energy supply and revitalize the agricultural economy, but also can boost the technology of energy industry. The benefits are so rich that it is worthy of careful assessment and planning.

As shown in Table 5, the total reserves of biomass energy can be obtained by orderly aggregating the energies from the three categories: first generation of biomass crops, urban waste, and wastes of agriculture and forestry. The reserves of biomass in Taiwan can provide Taiwanese with energy of 38,197.25 GWh/year, equivalent to the electric power of 15,278.90 GWh/year. Among these three kinds of biomass, the wastes of agriculture and forestry possess the highest amount of thermal energy, but also have relatively low cost, unlike biomass crops needing a huge cultivation land. However, in order to be benefitted from economic effectiveness, the most important prerequisite is that the power plant of high performance should be located in the vicinity of waste collection field, where the wastes come from industry, agriculture, forestry or urban.

Table 5. Assessment of the total reserves of biomass energy in Taiwan

	Reserves (GW)	**Equivalent Power (GWh/year)**
Biomass Crops	0.86	3,022.2
Urban waste	1.07	1,208.88
Wastes of Agriculture and Forestry	3.15	1,1047.82
Total Potential	**5.08**	**15,278.90**

Source: [2]

Ocean energy

Taiwan is surrounded by sea and has coastline of 1,500km or more. Therefore, lots of wave energy or tidal energy may be reserved. This section assesses the reserves of these two kinds of energies.

Wave energy

To be converted into electricity, the wave energy requires appropriate machinery. If Pelamis is considered as the machinery to convert wave energy into electricity, in accordance with its operating curve, it is known that for waves with period less than 5, the wave height of start must be greater than 1 m, and for waves with period between 5 and 13, the wave height of start must be greater than 0.5 m. Similarly to the distribution of the above calculation, if a Weibull Distribution is adopted, then the total available power is 8,200 MW. If the generation efficiency of Pelamis is supposed 50% [1], then the maximal electricity generated in one day is 100 GWh.

Tidal energy

The coasts in main island of Taiwan are mostly flat and sandy (e.g., the western coast) or rocky and straight (e.g., the eastern coast). In lack of the bay like Severn Estuary in the UK, it is not easy to build tidal pools in Taiwan. In the meantime, the areas of abandoned or less-used harbors are too small to reserve large potential of tidal energy. Although the tide in Penghu is not much (its average tide is 1.96 m), if Harbor Magong, a bay of rocky coast, is built dam at the exit to intercept tide, then the reserve of tidal energy might have sufficient potential to explore, due to economic benefit.

The detailed assessment is as follows.

The calculation of tidal energy is available in equation (1).

$$P_t = (\frac{1}{2}\rho g H_t{}^2 A_t)/t \qquad (1)$$

where H_t is the tidal difference, A_t is the area of tide accommodated by reservoir, and t is the upping (or lowing) time of tide (about 6 hours or 21,600 seconds in Penghu).

According to the calculation of equation (1), the tidal power provided by Harbor Magong during a high tide or low tide is about 9 MW, where H_t is 1.958 m and A_t is 10 km^2, and then the total energy reserved in one day is about 0.22 GWh. If the conversion efficiency of tidal generator is 0.9 (which is the highest efficiency only owned by hydro-turbine of dam type) [1], then the available electricity generated in one day is 0.20 GWh.

If the tidal reservoir area further includes the periphery of Penghu Bay (i.e., Penghu Bay, Harbor Magong and Inner Harbor Magong), the total area is expanded to about 70 km2. The generated power can be increased to 62 MW during a high tide or low tide, and the produced energy in one day is up to 1.49 GWh. If the mechanical power conversion efficiency is assumed 0.9, then the electricity generated in one day is 1.34 GWh.

In addition to Penghu, Kinmen and Matsu also have potential to develop tidal energy. According to the analysis of literature [5], the tides of Kinmen and Matsu are about 3.8 m and 4.3 m respectively. If tidal dams are built at southern outside of Liaoluo Bay of Kinmen and Beigan of Matsu, the areas of tide accommodated in the reservoirs are approximately 40 km2 and 10 km^2 respectively. And then from equation (1), the tidal power reserved in Kinmen and Matsu are approximately 131 MW and 43 MW, and the energies produced in one day are about 3.14 GWh and 1.03 GWh. If the mechanical power conversion efficiency is supposed 0.9, then the electricity generated in one day are 2.83 GWh and 0.93 GWh respectively.

To sum up the foregoing analyses, the total power reserved in above-mentioned three tidal waters in outer islands of Taiwan is approximately 240 MW. The totally largest energy generated in one day is approximately 5.76 GWh. If the mechanical power conversion efficiency is supposed 0.9, then the greatest sum of electricity produced in one day is 5.10 GWh.

Geothermal energy

In the geological point of view, Taiwan is located on orogenic collision belt between Philippine Sea Plate and Eurasian Plate, so the geology is easy to squeeze and collide, making the occurrence of earthquake be particularly frequent. Meanwhile, the formation is also prone to faults and folds, so that rock layers are constantly uplifted and broken. Furthermore, since rock is a material of low thermal conductivity, heat dissipation is not easy. With the constant uplift of formation and geothermal accumulation in the long term, there is high geothermal gradient resulted in the area of Central Mountain Range. Additionally, in northern Taiwan and eastern islands, large-scale volcanic activity had been occurred; at present, although the volcanic activity is suspended, the hot magma is still reserved under volcano.

In the view point of climate, since Taiwan is located at the edge of West Pacific Ocean, with the influences of northeast monsoon in winter and the southwest monsoon and typhoons in summer, the average rainfall in one year is 2,500 mm and above. After rain falls down to ground, water flows along fissures or broken rock into ground and is heated by geothermal gradient or hot magma, resulting in rich geothermal resources, so hot spring is an important feature of a geothermal system. From the present geothermal development of grand occasion in other neighboring countries with the same geological and climatic conditions, such as the Philippines, Japan and Indonesia, we can see that the development potential of geothermal in Taiwan should not be underestimated.

Based on the long-term survey data [6] of Industrial Technology Research Institute (ITRI), we organize the energy reserves of the above six shallow geothermal areas, as listed in Table 6. Since the detailed data required in the analysis of geothermal reserves are unavailable (e.g., temperature gradient of formation, distribution of rock geology and groundwater hydrology changing with the seasons), this article directly uses the data [7] for the assessment. Overall, the installation capacity of the possible development in these six main geothermal sites in Taiwan is 714MW. We adopt 90% as the utilization of geothermal power plants, then the annual geothermal power generation potential in Taiwan is 714 MW × 8,760 h/y × 90% = 5.63 TWh/year.

Table 6. ***List of installation potential of geothermal power in six main sites of Taiwan.***

Geothermal Sites	Temperature Range (℃)	Installation Potential (MWe)	Power Potential (GWh/year)
Chinsuei, Ilan	180-220	61	503.7
Tuchang, Ilan	160-180	25	167.9
Lushan, Nantou	150-210	41	335.8
Chihpen, Taitung	140-200	25	167.9
Kinglun, Taitung	140-180	48	419.8
Mt. Tatun, Taipei	200-290	514	4,029.6
Total Potential		**714**	**5,624.65**

Source: [7]

Hydro power

The average annual rainfall of Taiwan is about 800 million tons (or 2,500 mm) with hydro-power potential of about 22,725 MW [8]. Compared to the existing total installed capacity of 2,081.4 MW, the development proportion of hydro power in Taiwan is very low. Most people believe that the development of reservoirs in Taiwan has reached saturation, and it is unlikely that there will be any new reservoirs going to be developed. But in fact the development of water resources should not be limited to the traditional large-scale reservoirs and should be extended to various types of rivers capable of being set up small and medium sized turbines. This article will follow the analytical methods of MacKay [1] in the hydro aspects of Taiwan. By combining the drainage area and rainfall data [9] of 76 major rivers with terrain data of Taiwan [10], the information on the intersection of these two areas is obtained. By cutting the entire Taiwan into dozens of regions, and under a grid computing precision of 800 m × 800 m, the averages of topography height and annual rainfall in each region are calculated. Finally, the products of each two averages are summed up to get the estimated potential of hydro power.

In the estimation of terrain height, since current terrain map [9] is only divided into three regions, the resolution is somewhat insufficient. In order to reduce the error of the estimation of average height, this paper adopts the data of The Total Hydro-Census Report for Taiwan [8] to estimate the average height of the two regions of "100m~1,000m" and "above 1,000m" to be 454m and 1,838 m, respectively. According to the data of literature [10], the average height of the regions with height "below 100m" is about 25m (the heights of most regions of the western half are between 0-50m). Regarding the estimates of the rainfall in various regions, this paper adopts the mean value of variation amounts (for example, in rainfall range of 1000-2000mm, 1750mm is taken). In the regions with total rainfall of 4,000 mm or more, because the upper limit is unknown and the area is very small, the upper limit of 4,000 mm is chosen.

From the results of calculation, it is known that the reserves energy of hydro power in Taiwan in one year is about 25,700 MW; namely, the energy available in one day is 6.17×10^8 kWh. If the mechanical efficiency of water turbine is supposed 90 % [11], then the maximal electricity available per year is about 202,618.8 GWh. Since the population of Taiwan is mostly concentrated in the region with height between 0-100 m, if this area is deducted from the calculation procedure, then the annual maximum of hydro energy available in Taiwan is 201,396.05 GWh and is then reduced to 140,952.05 GWh, if the evaporation of about 30% [12] is considered.

Summary of Taiwan's RE reserve

According to the results of this assessment (as shown in Table 7), the reserves of renewable energies in Taiwan are 76.48 GW of solar energy, 77.5 GW of wind power, 5.08 GW of biomass, 8.44 GW of ocean energy, 0.7 GW of geothermal and 25.7 GW of hydro power. The total RE reserve is 193.9 GW, which is 4 times of 48.7 GW, the national power capacity in 2015, so we can say that the reserves of renewable energies in Taiwan are quite abundant.

***Table 7.**Statistics of power potential of the (commercial) renewable energies reserved in Taiwan (unit: GW)*

	Solar* (Thermal)	Solar* (PV)	Wind** (land)	Wind (offshore)	Biomass	Marine (Wave + Tide)	Geothermal (shallow)	Hydro	Total
Reserves	2.28	74.2	4	73.5	5.08	8.44	0.7	25.7	193.9
Proportion	39%		40.0%		2.6 %	4.4 %	0.4 %	13.2%	100%

*rooftop-type only.
**open space on land, including rooftop and onshore.

Comparison of renewable energy reserves in all major countries

We search related sites for the relevant information of the reserves of renewable energy around the world and organize them in Table 8, Table 9 and Table 10. The referred countries and regions are Denmark, Britain, Germany, China, India, four states of the United States, and the world. We take kWh/d/p (the energy available per person per day) as a unit of comparison, in order to avoid the loss of reasonability caused by differences of size of land area or national population.

***Table 8**. Global renewables electricity generation status and potential*

Electricity generation by energy resources	Installed capacity (2015)	Electricity generation (2014)	Global reserves	Electric generation potential	Installed capacity potential
	GW	TWh	EJ	TWh	GW
Hydropower	1,064	3,769	50	5,768	1,586
Wind power	433	700	401	24,057	12,716
Geothermal (2013)	12	76	45	9,037	1,427
Solar PV	227	167	1,693	50,652	53,685
Biomass and Waste	106	445	344	48,061	10,908
CSP	5	7	992	49,600	31,456
Total	**1,847**	**5,164**	**3,525**	**187,175**	**111,778**

Data sources: REN 21, tsp-data-portal.org

***Table 9.** List of the reserves of renewable energy of the countries or regions around the world in term of installed capacity of electricity generation.*

Item	Country (or region)	Renewable energy reserves density (W/p)		Description
1	Denmark [13]	3,386.0		Population: 5.4 million
2	The U.K.	A.[14]	1,438.6	Population: 5.4 million East Region, England
		B.[1]	7,318.3	Population: 60.9 million The U.K.
3	Germany [15, 16]	788.1		Population: 82 million Excluding ocean energy
4	China [13]	1,644.2		Population: 1321.29 million
5	India [17]	126.7		Population: 1,200 million Potential of total installation capacity: 152,000 MW
6	California [18]	635.6		Population: 38 million Potential of total installation capacity: 24,153 MW (including 9,153 of pump

			storage)
7	Massachusetts [19]	2,581.2 (theoretical value) 548.8 (technically feasible)	Population: 6.5 million
8	Florida [20]	287.3	Population: 14.6 million
9	Arizona [21]	458.7	Population: 3.6 million Consider the technical feasibility of 2025's target
10	Taiwan	8,430.4	Refer Table 7
11	World	18,629	Population: 6 billion Global reserves: 111,778 GW (Table 8)

***Table 10. List of the reserves of renewable energy of the countries or regions around the world in term ofelectricity generation (kWh) per person per year*.**

Item	Country (or Region)	Renewable Energy Reserves (kWh/d/p)		Description
1	Denmark [13]	81.2		Population: 5.4 million
2	The U.K.	A.[14]	34.5	Population: 5.4 million East Region, England
		B.[1]	175.5	Population: 60.9 million The U.K.
3	Germany [15,16]	18.9		Population: 82 million Excluding ocean energy
4	China [13]	39.43		Population: 1321.29 million
5	India [17]	1.22		Population: 1,200 million Biomass: 19,500 MW Solar: 20,000 MW Wind: 47,000 MW Small hydro: 15,000 MW Marine: 50,000 MW Total: 152,000 MW
6	California [18]	6.1		Population: 38 million Potential of the total installation capacity: 24,153 MW (including 9,153 of pump storage)
7	Massachusetts [19]	61.9 (theoretical value) 13.16 (technically feasible)		Population: 6.5 million Installation potential: 41,900 MW(theoretical value) 8,700-12,900 MW(technically feasible)
8	Florida [20]	9.89		Population: 14.6 million Installation potential: 52700 GW (Consider the technical feasibility of 2020's target)
9	Arizona [21]	11.0		Population: 3.6 million Consider the technical feasibility of 2025's target
10	Taiwan	78.03 kWh/d/p		Table 14
11	World	85.47 kWh/d/p		Population: 6 billion Global reserves: 187,175 TWh (Table 8)

TAIWAN'S CURRENT STATUS OF RE DEVELOPMENT

Taiwan, Republic of China, with land area of 36,190 km^2 and population of 22.6 millions, has the world 2nd highest population density, i.e. 625 capita per km^2. Over the last two decades, the rapid economic growth has created substantial changes in the economic structure: GDP rose from US$52.4 billion to US$295.9 billion, and per capita BNP increased from US$2,832 to US$13,157, with average growth rate of 6%. 67% of GDP is now from service sector vs. 48% in 1983.

According to the data of BOEMOEA [4], also as shown in Fig. 2 and Fig. 3, the installing status of renewable energies in Taiwan for 2015 is described as followings: 2,084.9 MW (4.29%) for hydropower generation; 646.7 MW (1.33%) for wind power generation; 842 MW (1.73%) for photovoltaic system; 740.4 MW (1.52%) for biomass/waste electrification; the aforementioned data summation is 4,318.6 MW, share of which is 8.87% of the national power capacity in 2015. In the meantime, during 1995–2015, as Fig. 2 shows, the average annual growth rate for total installed power capacity is 3.59%, while average annual growth rate for power peak load is 3.2%. It is obvious that rapid economic progress is followed by higher energy demand during the last two decades in this country.

Compared the rest of Southeast Asia, Taiwan equals Southeast Asian nations in terms of developing biomass energy and hydropower. Notably, hydropower is the most popular renewable energy in the region. Geothermal energy enjoys high application in certain countries as well, such as the Philippines, Indonesia, and Japan (not shown in the table), all of which are located at fault-lines along the Pacific Rim, Taiwan should share the same geographic advantage in terms of developing geothermal energy. Furthermore, significant potential also exists in Taiwan to develop solar energy and wind power, respectively, given that it is a subtropical island adjacent to a famous "wind tunnel" in the form of the Taiwan Strait.

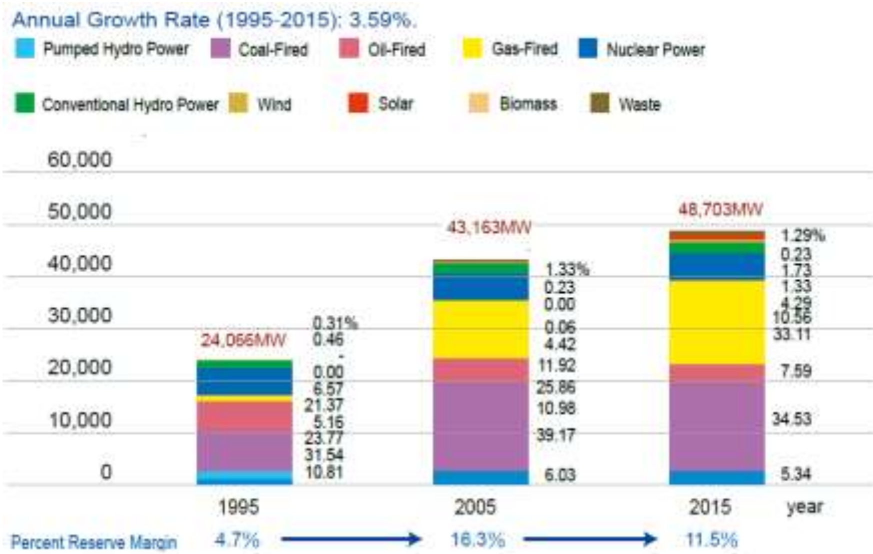

Fig. 2. Power generation installed capacity in Taiwan from 1995 to 2015

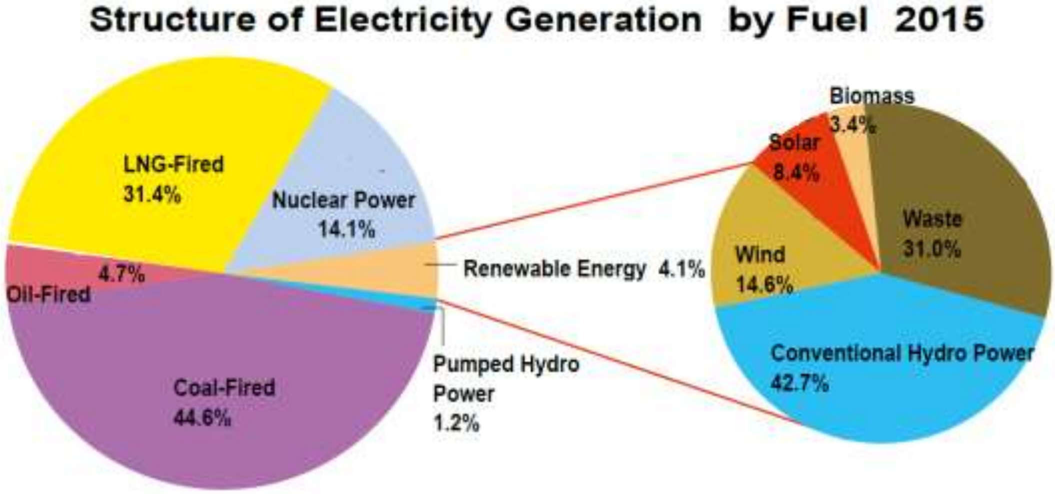

Fig. 3. Power infrastructure including RE for 2015 Taiwan

The economic realities are reflected in the status of different development strategies in Taiwan. For example, solar water heater has enjoyed successful development and achieved a strong international reputation, yet the development of PV remains very limited. On the other hand, wind power and biomass energy have been prioritized in government planning. Finally, owing to environmental considerations and the relatively high production costs, small hydro power and geothermal power projects have received little development attention.

Solar Thermal Energy

In Taiwan, the only commercially available solar thermal product is solar water heater (SWH), of which 98% is used for domestic purpose. Taiwan is a subtropical island located between the latitudes of 22 and 25° North and the longitudes of 120 and 121° East. Annual sunshine is in the range of 1,500~2,200 hours for most parts of the island, and even reaching 2,500 hours in the southernmost region. The average solar irradiance in Taiwan is 716~1,027 kJ/day·m^2, and thus solar energy resources in Taiwan are so abundant as to make the development of solar energy extremely practical compared to most location around the world.

To encourage more people to install solar water systems, according to "Solar Water Heaters Incentives" implemented by the BOEMOEA for 2016. The subsidizing rate is based upon type and area of collectors installed in a solar hot-water system, as follows:

- ■ Glazed Flat-Plate Collector: 2,000 NT dollars per square meter;
- ■ Evacuated-Tube Collector: 2,000 NT dollars per square meter;
- ■ Unglazed Flat-Plate Collector: 1,250 NT dollars per square meter;

These rates are applicable to users on the main island of Taiwan. On the smaller islands there is an additional subsidy of 1,000 NT dollars per square meter owing to the additional transportation expenses. Generally, the subsidy covers 15%~20% of the total cost of a solar hot-water system (including installation cost). Since the launch of this incentive scheme, the number of SWHs installed has increased markedly. The accumulated area of solar collectors installed reached 2.37 million square meters at the end of 2013. Approximately 560 thousand families have installed SWH in Taiwan, representing an installation rate of around 6.65%; that is, 6.65% of families have installed SWH. Solar water heaters thus are the most notable success story in RE development in Taiwan. According to International Energy Agency (IEA) data for 2013, Taiwan was ranked the 19^{th} market with 85 MWth of annually newly installed capacity, the 19^{th} country with 1,082 MWth of cumulated installed capacity, and the 20^{th} country with glazed collector installation density of 46.4 W/p for SWH in the world [22]. According to BOEMOEA, the collector installed density is 52.63 square meters per square kilometer of land area, ranked fifth in the world. The annual energy and environmental contributions of SWH for Taiwan are 940GWh in energy generation, 101,082 toe in energy saving, and 326,767 tco_2 in GHG emissions reduction [22].

Currently, Taiwan has a sophisticated SHW industry, comprising: 30 manufactures, 200 retailers, and 1,000 employees, with annual sales of 100 thousand square meters, equivalent to 20 million US dollars or ten thousand new users. Notably, 96% of qualified installers/dealers are located in western Taiwan. Out of the 241 qualified products, 148 are assembled by installers themselves. As shown in Fig. 4, metallic (stainless or copper) flat-plate solar collectors account for 78% of SWHs, with the remaining 22% being evacuated-tube collectors. Almost all metallic flat-plate solar collectors are produced domestically, while some evacuated tube absorbers are imported. Most SWHs are permanently connected to an auxiliary electric heater.

***Fig. 4.* Solar hot-water systems in Hualien County Hualien Academy for 115 students (Metallic collector installation area: 77 square meters)**

Solar Photovoltaics

Taiwan is located in a subtropical region. Sunlight can be considered one of the most abundant resources in the country. The Tropic of Cancer passes through Central Taiwan; therefore, with long hours of sunlight and a small angle of sunlight deflection, sunshine is plentiful.In recent years, the standard of living of the Taiwanese people has increased, and the peak load during summer months has been increasing annually. This has caused a potential supply shortage crisis in Taiwan's power market, leading to policies of brownouts or rolling blackouts. If the power generation characteristics of PV systems could match the peak demand in the Taiwan area, this would assist in alleviating peak loads.

In recent years, the requirements for reducing CO_2 emissions and ensuring energy security have driven Taiwan government to move forward in promoting the development of renewable energy. Relying on the unquestionable benefits of solar PV systems and Taiwan's geographical location in a low-latitude zone, Taiwan's government is strongly promoting the development of solar PV energy. In particular, Taiwan's government has actively implemented a variety of policies, laws, regulations, projects, and subsidy operations for promoting solar PV energy development since 2000.

"Nuclear-free Homeland" is the primary energy policy of the new government in Taiwan. It is estimated that the installed capacity of solar energy will be as high as 20GW(73%) in the plan of 20% renewable energy power generation in 2025. The PV installation capacity target was established as 842MW, 1,342MW, 8,776MW, and 20,000MW in 2015, 2016, 2020, and 2025, respectively, as shown in Table 11.

***Table 11.* Actively promote the objectives of installed capacity (MW)**

Energy sources/year	**2015**	**2016**	**2020**	**2025**
Solar PV	842	1,342	8,776	20,000
Wind power (on shore)	647	747	1,200	1,200
Wind power (off shore)	0	8	520	3,000
Geothermal	0	1	150	200
Biomass	741	742	768	813
Hydropower	2,089	2,089	2,100	2,150
RE in total	**4,319**	**4,929**	**13,514**	**27,363**

Data source: BOEMOEA

In order to promote PV installation capacity and foster the development of PV industry, Taiwan's government has actively implemented a variety of policies, laws, regulations, projects, and subsidy operations. In the late 1990s, Taiwan's government started to subsidize the application of PV and large applications of PV in public infrastructural projects (Fig. 5, Fig. 6), with tax exemptions, financial assistance and subsidies for purchasing electricity.

To cooperate with local governments to promote solar photovoltaic (PV) cluster system in the community, MOEA released the "MOEA Subsidy Directions for the development of Solar Community" on March 5, 2013. This program aims to stimulating local government to develop solar PV community with local characteristics by providing cables, grid connection and promotion subsidies, and building up PV cluster demonstrations to achieve the vision of the "Million Rooftop PVs project."

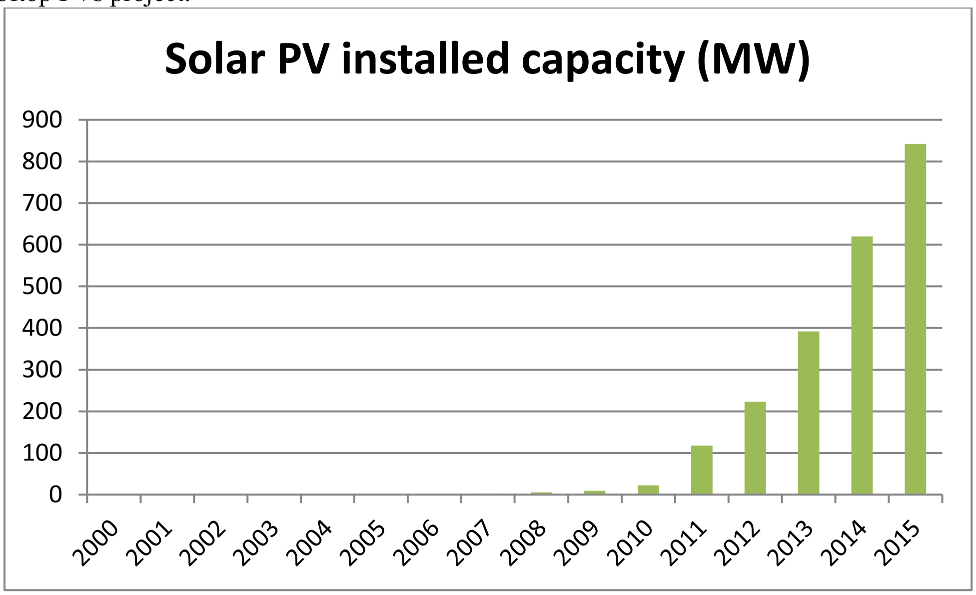

***Fig. 5** Installed capacity of solar PV for Taiwan from 2000 to 2015*

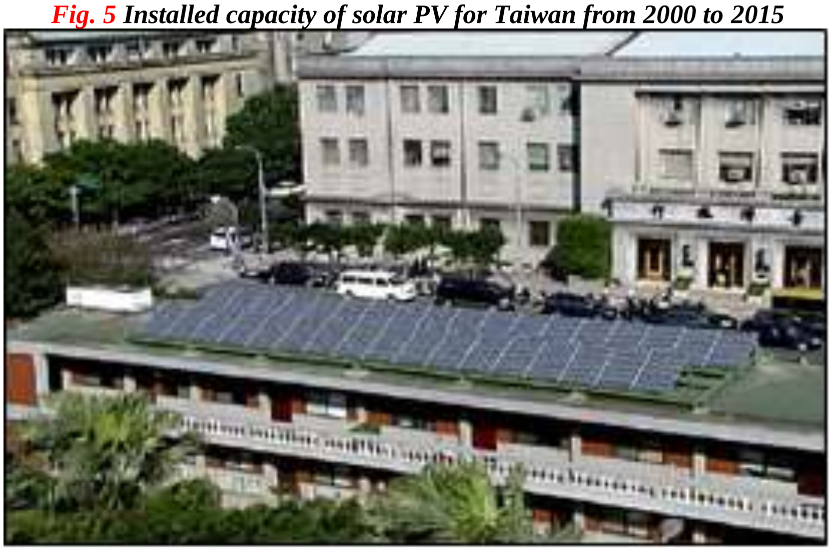

***Fig. 6** Presidential Hall demonstration system (10.5 kW)*

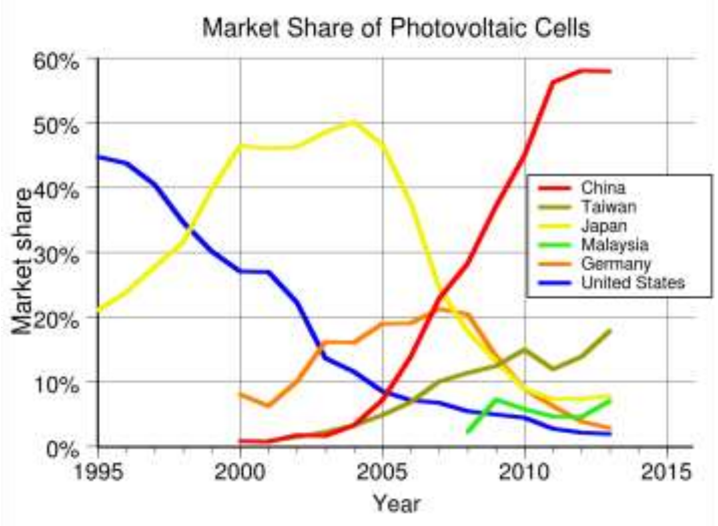

Fig. 7. Global market share of PV cells by major countries
Sources: IEA-PVPS and Earth Policy Institute

Since Taiwan has a strong foundation in semiconductor production, it was not surprising when the government announced that it would prioritize the development of solar power, which utilizes semiconductors in its solar cells. Regarding the PV industry, there are several internationally famous companies focused on different products in Taiwan, including Sino-American Silicon Products Inc. for silicon wafer, Gintech (660MW), Motech (470MW), E-Ton Solar (320MW), and Neo Solar Power (240MW) as the top 4 solar cell manufactures based on capacity in 2015, and Photonic Energy Semiconductor Co. Ltd. for modular packagee. The global maket shares of PV cells by major countries are shown in Fig. 7. These companies have constructed a complete manufacturing chain for the PV industry in Taiwan.

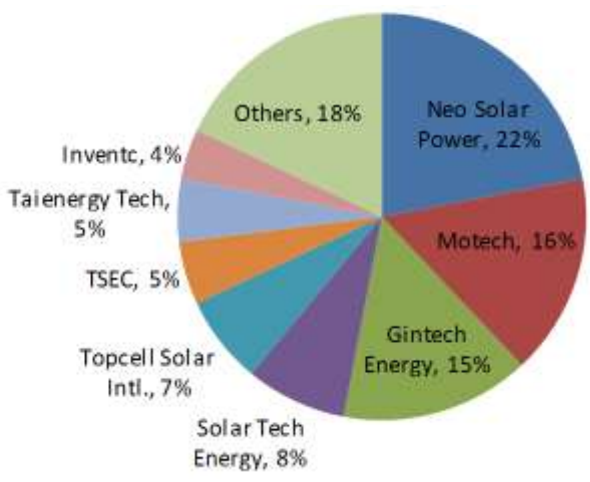

Fig. 8. Breakdown of production volume by Taiwanese solar cell manufacturers in 2014.

From data of Energy Trend [23], Taiwan PV industry ranks number two worldwide with PV solar cell production volume over 10GW with 20% annual growth rate in 2014. Taiwan has a complete PV industry supply chain. Developing high efficiency and low cost technology is the key strategy to increase competiveness. As shown in Fig. 8, the top 3 solar cell manufactures account for 53% of Taiwan production volume in 2014. The important indicators of Taiwan PV industry is shown in Table 12.

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Table 12. The important indicators of Taiwanese PV industry (2012-2016)

Item	Unit	2012	2013	2014	2015	2016(e)
Number of manufacturers	Manufacturer	92	90	89	86	89
Output value	Million USD	3,255	4,598	5,607	5,332	5,632
GDP Contribution	%	0.03	0.19	0.17	0.16	0.18
Number of employees	Employee	12,500	17,000	18,400	18,500	19,000

Data sources: IEK, ITRI, Taiwan.

Wind Energy

As described in Table 7, Taiwan is estimated to have wind power potential of 4,000 megawatts on land and 73,500 megawatts at sea. Wind energy has been aggressively promoted in Taiwan since 2000. Through resource survey, technical guideline, research and investigation, demonstration and subsidies, both the Taipower and IPPs had invested onshore wind farms construction in the last decade. As depicted in Fig. 9, by the end of July 2016, with 30 windfarms on land, a total of 341 large-scale onshore wind turbines had been erected with a total installed capacity of 670.6 MW (BOEMOEA, http://www.twtpo.org.tw/).

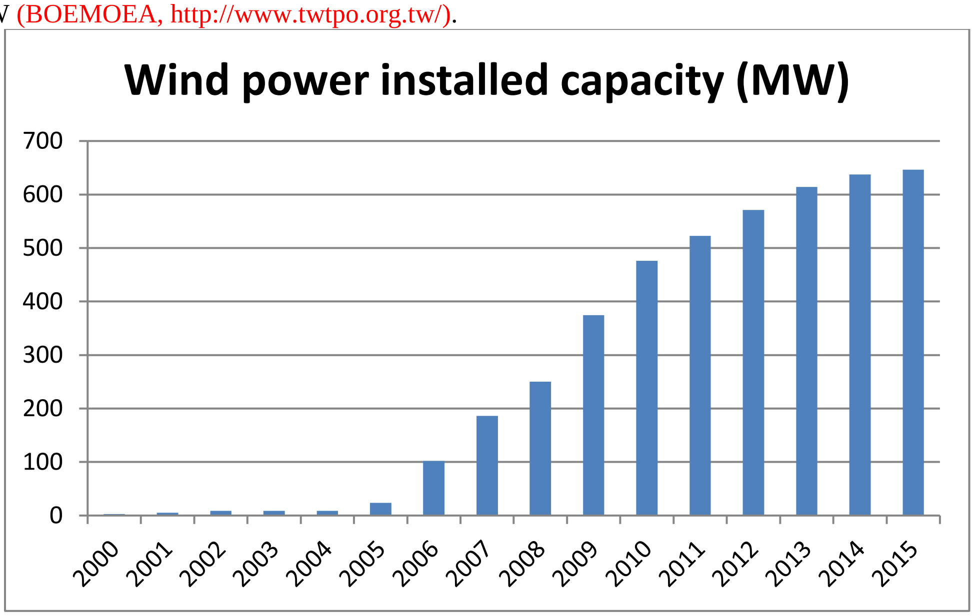

Fig. 9. Installed capacity of wind power for Taiwan from 2000 to 2015.

To accelerate the development of offshore wind power industry in Taiwan, MOEA announced the "Directions for Encouraging Offshore Wind Power System Demonstration Measures" in July 2012. Two IPPs (Fuhai Wind Farm Corp. and Formosa Wind Power Co. Ltd.) and a state-owned power company (Taipower, Fig. 10) were selected as main forces to execute the measures in January 2013. The output value of Taiwanese wind power industry was increased to 515.6 million USD in 2016 from 247.9 million USD in 2012. After years of development, the industrial chain in Taiwan's wind power industry has been gradually completed with about 70 suppliers from up- to down-streams. There are dozens of raw materials and parts/components suppliers. TECO is the only large-scale wind turbine manufacturer in the domestic, while a dozen or so manufacturers supply small and medium wind turbines. The important indicators of Taiwanese wind power industry is shown in Table 13.

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Fig. 10. ***Taiwan Power Company Penghu wind power (Installed capacity: 600kW x 8)***

Table 13. The important indicators of Taiwanese wind power industry (2012-2016)

Item	Unit	2012	2013	2014	2015	2016-e
Number of manufacturers	Manufacturer	47	50	55	65	70
Output value	Million USD	247.9	289.2	366.5	476.0	515.6
GDP Contribution	%	0.007	0.009	0.01	0.018	0.018
Number of employees	Employee	700	750	780	800	820

Data sources: IEK, ITRI, Taiwan.

After the government began promoting offshore wind power development since 2013 as shown in Fig. 11, an increasing number of enterprises have been planning and involving in the offshore wind power services, including, wind farm development, submarine cable and offshore infrastructure construction, and wind turbine installation and maintenance.

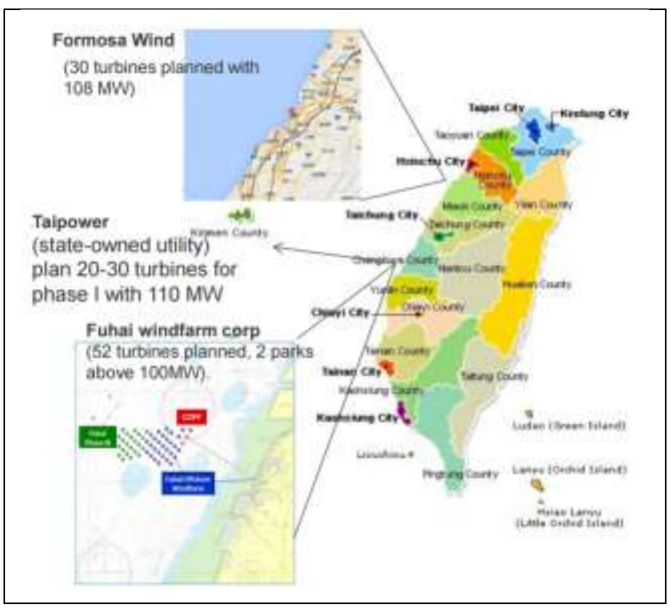

Fig. 11. ***Planned locations for the offshore wind farms along the western costs of Taiwan.***

Looking into the future, under the execution of "Thousand Wind Turbines Project", a market scale up to 500 billion NTD is expected in 2030. The strategies to develop Taiwanese wind energy including the short-, medium-, and long-term targets: (1) introduce foreign technology to complete a first demo offshore wind power system in Taiwan Strait; (2) implement the wind power system independently developed by Taipower to establish the local marine engineering capacity and accomplish the demo offshore wind farm; (3) with a cumulative 1,200 MW and 520 MW installed wind power capacity respectively for onshore and offshore by 2020; (4) by 2025 with accumulated installed capacities of 3GW and 1.2GW respectively for offshore and onshore wind farms, and over 1,000 wind turbines installed with 4.2GW capacities, by then, more than 15.35% of Taiwan's renewable energy installation will be shared by wind turbine; and (5) build Taiwan's wind power manufacture and service industries to construct the down-, middle-, and up-stream chain by 2030.

Biomass Energy

Biomass energy is widely used in Taiwan, including biogas (methane) from animal waste and fuel energy from the burial, gasification, breaking-down, and fermentation of household, industrial and agricultural garbage. Since biomass energy makes a dual contribution to energy supply and environmental protection, it is generally recognized as one of the most popular renewable energies in the world, comprising approximately two thirds of total renewable energy use. The development potential of biomass energy in Taiwan is approximately 3 Mtoe, representing approximately 40% of total RE potential.

As described in Table 7, the total reserves and equivalent power generation of Taiwan's biomass are 5.08 GW and 15,278.90 GWh/year. Both energy productions account most supply of the national renewables. As shown Fig. 12, the main biomass energy resources are landfill gas and waste incineration, which have total electricity generation capacity of 629.1 MW (at the end of 2015) in more than 70 installed sites. A "Waste Energy Application Technology Development and Promotion Project" was initiated from 1999, in which the priorities of RD&D are waste energy applications, such as landfill gas, gasification, liquefaction and refuse derived fuel (RDF). Currently, the installed biomass power is total 740 MW in Taiwan, with municipal solid waste incineration 625 MW, biogas 19MW, and waste from industry and agriculture 97MW, as shown in Table 14. Meanwhile, the technical development of RDF is gradually matured. Solid RDF (Fig. 13) made from waste has the following advantages: high thermal value, uniform-and-stable property, ease of control and low pollution when burning, ease of transportation and storage, able to be used in boilers of power generation and co-generation, small environmental impact, high energy recycling efficiency, *etc*. RDF technology currently has been transferred from ITRI to industry to establish factories to convert ordinary waste into useful fuel. Furthermore, a demonstration urban RDF system was established in ITRI for the purposes of research and promotion. On the other hand, technologies of waste liquefaction and gasification have also been developed to convert waste into compound fuel or syngas (e.g., H_2, CO, and CH_4, *etc*.) that may be provided as the fuels of boiler and generator to generate steam and electricity, such that the goals of environmental protection, waste self-management and clean production may be fulfilled. Presently, specific technologies of solid waste energy have been developed successfully in ITRI, for example rice husk gasification and waste Styrofoam liquefaction, which have been granted as patents and transferred to industry.

In the future, more aggressive promotion of goals will focus on developing more advanced technologies, including alcohol gasoline, organic hydrogen production, energy crop, forest resource, bio-diesel, *etc*. As shown in Fig. 14, the current biomass power capacity in Taiwan is about 111.3 MW.

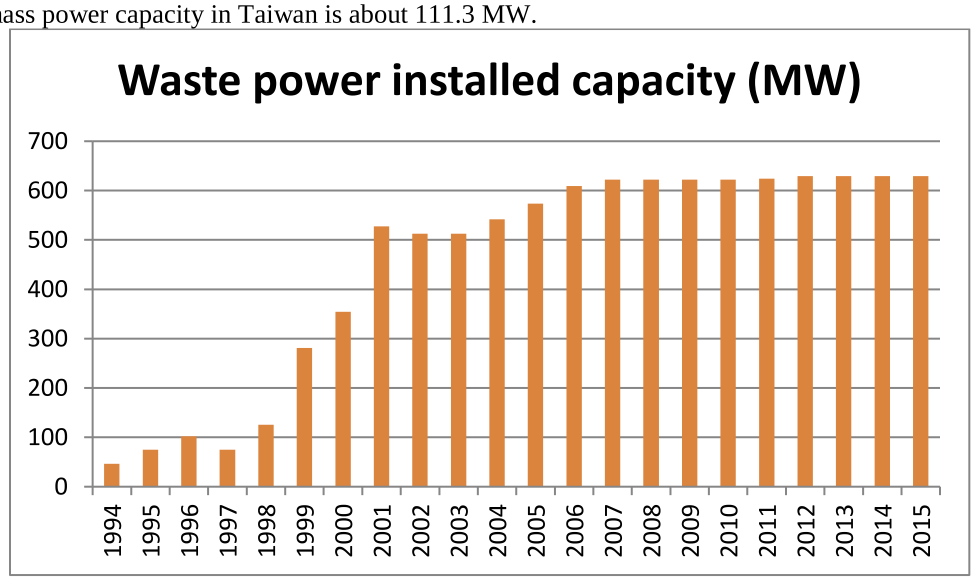

Fig. 12. Installed capacity of waste for Taiwan from 1994 to 2015.

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Table 14.Agricultural and livestock wastes in 2014

	Total production	Unit of waste	Total waste
Rice	1,600 tonnes	86 kg/tonne	137.6 tonnes
Sugar	500 tonnes	250 kg/tonne	125 tonnes
Pig	8 millions	2.4 kg/head/day	7 million tonnes
Poultry	370 millions	0.15kg/head/day	20.2 million tonnes

Source: [24]

Fig. 13.Solid waste derived fuel manufactured by ITRI
(1 cm in diameter, 5 cm long; calorific value of approximately 6,200 kcal / kg)

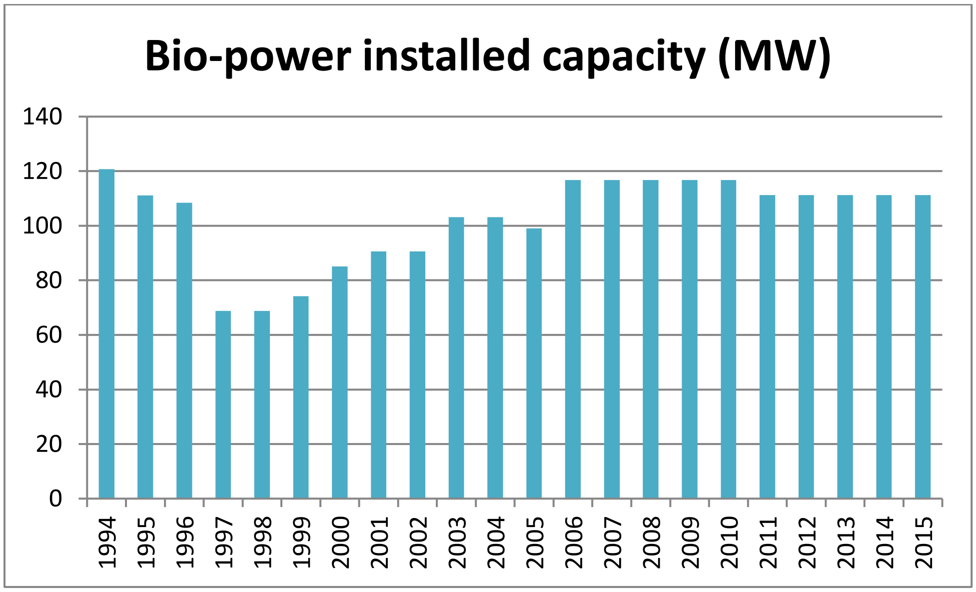

Fig. 14. Installed capacity of biomass for Taiwan from 1994 to 2015.

Geothermal Energy

Taiwan lies on a major geological fault-line along the Pacific Rim, and has abundant geothermal resources. A comprehensive exploration estimates that Taiwan has total geothermal potential of up to 714 MW. However, most of the geothermal resources in Taiwan are located in remote areas, making their exploitation difficult. The economically and technically feasible exploitation potential is only about 150 MW. The target for geothermal utilization is 200 MW by 2025.

Unlike solar energy and wind power, the application of geothermal energy is not influenced by weather conditions and its stable output can provide a base load for power generation. Nowadays, the main application of geothermal energy is electricity generation, the cost of which is still higher than that of traditional generation methods. However, following electricity generation, the remaining hot water may be further utilized for multiple functions, including recreational spas, swimming pool, greenhouse horticulture and agriculture, air conditioning and so on, thus extracting additional economic value from the process. On the other hand, to avoid the gradual depletion of geothermal resources due to excessive extraction, most hot water after being used may be injected back to geothermal reservoirs, thus prolonging the operating life of the resource.

Geothermal resources can be classified into volcanic and non-volcanic types, with the former being hotter but more acid than the latter. Domestic geothermal resources are mostly non-volcanic, and are located in mountains and on small islands, making access difficult. Geothermal resources with easy access and high potential will be prioritized for development. The most promising one is the Chinsuei geothermal energy project (located at Yi-Lan County, as shown in Fig. 15), which will be developed by the local government using a BOT (Build, Operate, and Transfer) method, and for which technical planning and research will be provided by experienced R & D groups authorized by BOEMOEA. Besides electricity generation, the hot water will be further utilized to make the project become a demonstration system with multiple functions. The project has planned capacity of 1,000 kW, sufficient to supply electricity for about 340 families.

***Fig. 15.* Chinsuei geothermal energy project, 3MW, single flash-steam**

Hydropower

Presently, most hydropower plants with large water dams are operated by the Taiwan Power Company. At the end of 2015, the total installed capacity of hydropower in Taiwan was approximately 2,089.4 MW, of which 1,745 MW is contributed by plants with capacity exceeding 20 MW (excluding 2,602.0 MW pump storage hydropower). According to a survey, Taiwan has about 5,160 MW of technically feasible hydropower potential, about half of which is considered economically viable. Hopefully around 2,502 MW can be exploited by 2030, with approximately 300 MW being small hydropower (SHP) plants, each with capacity of less than 20 MW; that is, they can be considered renewable energy, for example, flow-through type hydropower, as shown in Fig. 16. Currently, the total installed capacity of operational SHP plants is around 166 MW.

In Taiwan, the application of large-scale dam is concentrated in agricultural irrigation and domestic water supply, with electricity generation generally regarded as an auxiliary use. For example, in 2015, the total generation output of hydropower in Taiwan was just 7,505.1 million kWhs, equivalent to 1,603 hours of full-loading time. That is, the full-loading efficiency of hydropower in Taiwan is only 18.3%, much lower than the 60~70% average efficiency of nuclear or fossil fuel electrification. Most of the cost of hydro plant establishment goes to civil engineering for dam construction. Furthermore, most plants are located in remote mountain areas, which have high development costs and investment risks. However, a large-scale hydropower plant may have a useful lifetime of over 30 years,

something unachievable by other generation methods. Considering the benefits in terms of both water supply and electricity generation, large-scale hydropower plants are actually the cheapest renewable energy option.
Hydropower is a clean, indigenous energy resource. However, due to disputes involving the ecological and environmental issues created by large-scale dam construction, the development of large-scale hydropower is inevitably difficult. However, SHP plants are also worth developing, and besides having less environmental impact also offer such advantages as short set-up time, easy maintenance, and low investment and operational costs. In Taiwan, most SHP resources are located in national parks, so careful evaluation is necessary and solutions must be sophisticatedly prepared before exploring and exploiting these resources.

***Fig. 16.* Low head flow-through hydro power demonstration plant in Houli, Taichung**
(Photo Source: Taiwan Provincial Taichung Irrigation Association)

PROMOTION STRATEGIES FOR REWABLE ENERGIES IN TAIWAN

Although the results of the assessment point out that Taiwan has abundant renewable energy resources, the four inherent shortcomings-low energy density, high cost of power generation, instability of power supply, and current cost of renewable energy being still higher than that of fossil energy-have to be overcome first, before renewable energy is actually formed as a main component in national energy mix. The measures executed by government to break through these barriers further include the upgrade of the technological level, the formulation of the necessary policies, and the work together from all levels for the overall promotion.
Based on Energy Statistics Manual in 2015 published by Bureau of Energy of Ministry of Economic Affairs, the national energy structure in supply side is still mainly comprised of fossil fuels, such as coal and coal products (29.33%), crude oil and petroleum products (48.18%), natural gas (13.29%), *etc*. Produced by burning fossil fuels, greenhouse gases (mainly carbon dioxide) have been identified as the main cause for global climate change, while emissions in Taiwan in 2015, a total of approximately 250.50Mt (million tonne) of carbon dioxide, accounting for about 0.78% of global emissions, with annual growth rate of 3.37% since 1990, is really shocking. Renewable energy is considered non- or less-polluting sustainable energy, but the proportion of renewable energy on supply side in Taiwan is still very low only 1.92%, in which, 1.39% for biomass and waste, 0.29% for conventional hydro power, 0.16% for PV and wind power,and 0.08% for solar thermal. In addition, since most of fossil fuels are imported from abroad, and mostly from the political instable countries in the Middle East or Southeast Asia, security of energy supply is a major worry for Taiwan. To solve above problems, the development of renewable energy may be the necessary measures.
Prior to the Renewable Energy Development Bill enacted in 2009, the central competent authority in Taiwan has adopted subsidiary incentives to promote renewable energy development. However, accelerating the sustainable energy in a time-table way is the vital aim of the Bill, which mandates the Feed-in Tariff (FiT) policy for renewable electricity generated from specified sources, especially in solar PV power and wind power. The FiT policy prescribed by the Bill contains four implementation elements, including subsidy target for renewable electricity, FiT rate setting mechanism, government procurement by state-owned power company, and mandatory grid connection. In Taiwan, the calculation formula of FiT for renewable electricity are based on the relative factors of generation

equipment, including installation cost, operation and maintenance (O&M) cost, operating years, annual power generation, capital recovery factor, reasonable profit rate, and other factors such as inflation rate and insurance fee. Based on the levelized cost approach, the central competent authority announced the calculation formula for setting FiT rates in each year:

$$\text{FiT}=\frac{\text{Initial installation cost}\times\text{Capital reduction factor}+\text{Annual operation and maintenance cost}}{\text{Annual electricity sale}}$$

wherein:

$$\text{Capital reduction factor}=\frac{\text{Average cost of capital}\ \times\ (1+\text{Average cost of capital})^{\text{Purchase period}}}{(1+\text{Average cost of capital})^{\text{Purchase period}}-1}$$

Annual operation and maintenance cost = Initial installation cost × ratio of annual operation and maintenance cost in initial installation cost

In Table 15, the feed-in tariffs (FiT) for various categories of renewable electricity production in Taiwan effective in 2016 was listed.

Table 15. RE FiT for 2016 Taiwan

<table>
<tr><th>RE category</th><th>Classification</th><th>Capacity grade</th><th colspan="3">FiT (Yuan[1]/kWh)</th></tr>
<tr><td rowspan="5">Solar photovoltaic</td><td rowspan="4">Roof type</td><td>Between 1 kW and 20 kW</td><td colspan="3">6.4813</td></tr>
<tr><td>Between 20 kW and 100 kW</td><td colspan="3">5.2127</td></tr>
<tr><td>Between 100 kW and 500 kW</td><td colspan="3">4.8061</td></tr>
<tr><td>More than 500 kW</td><td colspan="3">4.6679</td></tr>
<tr><td>Ground type</td><td>1 kW or above</td><td colspan="3">4.6679</td></tr>
<tr><td rowspan="6">Wind</td><td rowspan="3">Land type</td><td>Between1 kW and 20 kW</td><td colspan="3">8.5098</td></tr>
<tr><td rowspan="2">20 kW or above</td><td colspan="2">With LVRT[2]</td><td>2.8099</td></tr>
<tr><td colspan="2">Without LVRT</td><td>2.7763</td></tr>
<tr><td rowspan="3">Offshore type</td><td rowspan="3">Without distinction</td><td colspan="2">Fixed 20 Years FiT</td><td>5.7405</td></tr>
<tr><td rowspan="2">Cascade FiT</td><td>First 10 Years</td><td>7.1085</td></tr>
<tr><td>Last 10 Years</td><td>3.4586</td></tr>
<tr><td>Stream-type hydraulic</td><td>Without distinction</td><td>Without distinction</td><td colspan="3">2.9078</td></tr>
<tr><td>Geothermal energy</td><td>Without distinction</td><td>Without distinction</td><td colspan="3">4.9428</td></tr>
<tr><td rowspan="2">Biomass</td><td>Without anaerobic digestion equipment</td><td rowspan="2">Without distinction</td><td colspan="3">2.7174</td></tr>
<tr><td>With anaerobic digestion equipment</td><td colspan="3">3.9211</td></tr>
<tr><td>Waste</td><td>Without distinction</td><td>Without distinction</td><td colspan="3">2.9439</td></tr>
<tr><td>Other</td><td>Without distinction</td><td>Without distinction</td><td colspan="3">2.7174</td></tr>
<tr><td colspan="6">1. 32.5 NTD = 1 USD
2. LVRT (Low Voltage Ride Through)</td></tr>
</table>

Source: organized by the study.

To meet aforementioned targets set for the development of RE in Taiwan in both near and long terms (Table 11), BOEMOEA has addressed three executive principles as following:

(1) Building up the framework for renewable energy development

- Establishing a sustainable environment based on the enactment of “Renewable Energy Development Bill”.
- Adjusting the premium tariffs for renewable energies and rationalizing prices of fossil fuels by counting their external costs.
- Removing the obstacles in grid connection and power transmission to promote the power generation from

renewable energy sources.

(2) Assisting the development in renewable energy industries

- Enlarging the renewable energy market to encourage related industries and improve technology capability.

(3)Strengthening R&D

- Accomplishing the targets by improving renewable energy technologies.

According to the framework and contents of "Renewable Energy Development Bill" enacted by Executive Yuan, the essence of promotion strategies for renewable energies in Taiwan can be summarized as follows.

(1) In the medium term, the renewable energies shall contribute 20%, in terms of national power by 2025.
(2) Wind and solar PV technologies are relatively mature and will be the major renewable energies in the near and long terms. Meanwhile, the government shall continue to promote other renewable energies such as geothermal, biomass, hydropower and ocean energy to utilize renewable resources in all aspects.
(3) Solar photovoltaic (PV) product is booming in current energy market worldwide. The promotion of PV shall focus on strengthening R&D capability and developing related industries for cost reduction.
(4) Taiwan has greatest potential in developing offshore wind power. Its capacity will be established from zero to 3GW in the next 10 years.
(5) In the long term, the ratio of renewable energy to total power supply is projected to increase from 5.24% in 2015 to 20% in 2025.

Since 2000, sustainable power generation in Taiwan remarkably increased in response to the trends of global warming mitigation and renewable electricity development. One of the significant milestones in the reform of the electricity industry in Taiwan could be said to have been implemented in 2009 when the central government promulgated the Renewable Energy Development Bill. Under the authorization of the Bill, the FiT scheme was adopted to encourage the deployment of renewable electricity systems for the purpose of selling their surplus electric power at a profitable rate to the local power company. During the period of 2000–2015, the renewable electricity from PV power and wind power systems in terms of total installed capacity in Taiwan have rapidly increased from 2.7 MW in 2000 to 1,488.7 MW in 2015.

However, the growth rate of renewable electricity systems in terms of total installed capacity seemed to show a steady increase since 2008, mainly due to the decreasing trend in domestic investments by the industrial and energy sectors. As a result, the central competent authority in Taiwan has adopted subsidiary programs starting from 2013 to promote the development of renewable electricity technologies, including rooftop-type PV power, off-shore wind power and biogas-to-power.

To encourage the investment in renewable electricity system as an emerging industrial development and a measure for the reduction of greenhouse gases emissions, and also achieve the government goal (i.e., total installed capacity reached 27,363MW in 2025, as compared to 4,319MW in 2015), the following measures are recommended and enhanced:

(1) Actively promote renewable energy development, serve to enhance energy independence, reduce carbon dioxide emissions, and enhance energy supply resiliency. Set more aggressive targets, including specific measures to promote "Thousand Wind Turbines" and "Million Rooftop PVs", to achieve the goal of 27,363 MW installed capacity of renewable energy by 2025, accounting 20.0% of national total power generation from 5.24% in 2015.
(2) Learn from Japan's Fukushima nuclear disaster experience, and examine the domestic nuclear safety and energy policy by increasing the amount of renewable energy and reducing dependence on nuclear power. Forecast to 2025, renewable energy power generation will be increased to 20.0% national power generation by 2025 from 5.24% in 2015.
(3) The promotion of all types of renewable energy depends on the ministries that will actively assist the relevant regulations and administrative procedures, simplify administrative operations, improve overall system and create a favorable environment for RE development.
(4) Continue to carry out research and development of renewable energy to enhance the development of renewable energy technologies and reduce set-up costs; and develop large-scale smart grid and energy storage systems, strengthening the power grid building, to reduce the impact of energy on the grid of the regeneration setting.
(5) Establish a review mechanism from the implementation date of renewable energy development regulations up to 20 years, a review every two years, depending on the technology development process, and regularly adjust the percentage of each class of renewable energy development goals.

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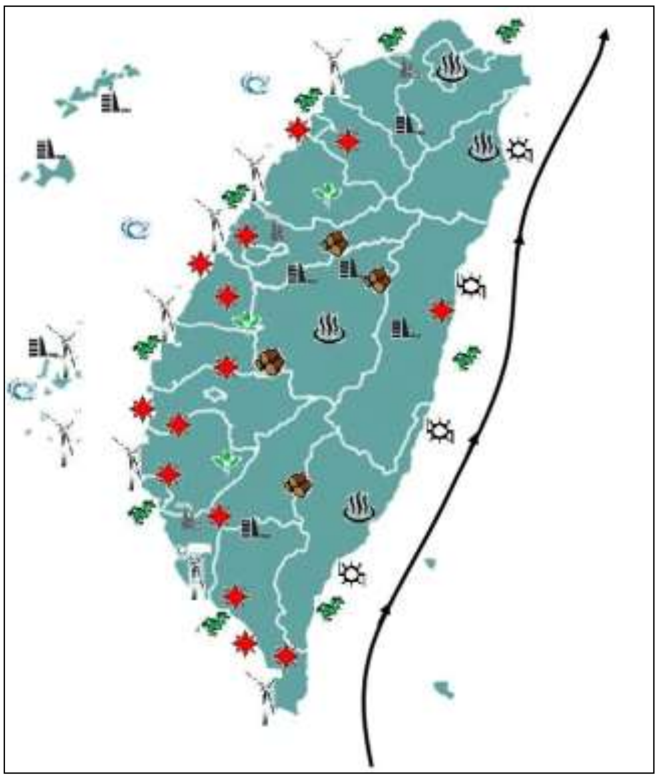
SUMMARY

All in all, the theoretical reserves, current status, and promotion strategies for RE in Taiwan are summarized in Fig. 17, Table 16, and Table 17. In Table 16, the corresponding electric energy reserves are listed, wherein the total reserved power generation 655.06 TWh/year is 2.54 times of 258.02TWh, the national power generation in 2015 [4].

Table 16.**Statistics of power potential of the renewable energies reserved in Taiwan (unit: TWh/year).**

	Solar*	Wind	Biomass	Marine	Geothermal	Hydro	Total
Reserves	203.75	251.01	15.28	38.45	5.62	140.95	655.06
Proportion	31.3 %	38.3 %	2.3 %	5.9 %	0.8 %	21.5 %	100%

*include: rooftop, 1% public land, reclamation land.



	Solar (76.48)		Hydro (25.7)		Garbage incineration (0.21)
	Agricultural and forestry waste (3.15)		Algae oil (13.8)		Wind (77.5)
	Kuroshio (30)		Ocean thermal (10.0)		Wave (8.2)
	Geothermal (15.54)		Biomass crop (6.38)		Tide (0.24)

(Unit: GW)

Fig. 17 ***Distributions of various types of renewables reserves in Taiwan area (including 2nd generation biomass, deep geothermal, algae oil, ocean thermal, Kuroshio, etc.)***

Table 17. Current status, targets and promotion strategies for RE in Taiwan

	Current status (2015)	Targets	Promotion strategies
1.Solar PV	842 MW (1.73%)	8,776MW(2020), 20,000MW (2025)	"Million Rooftop PVs Project" • Gradual expansion/incentivizing roof-tops prior to ground installations; • Set target each year through FiT to promote and guide various types of PV construction.
2.Wind power	647 MW (1.33%)	1,720 MW (2020), 4,200MW (2025): • Land: 1,200 MW (2020) • Offshore: 520 MW (2020), 3,000MW (2025)	"Thousand Wind Turbines Project" • Complete 520 MW shallow water windfarms by 2020; • Complete 3,000 MW offshore wind farms between 2021-2025; and • No case and experience in offshore; economic incentives and financial risk reduction are needed.
3.Biomass	111.3 MW (0.23%)		According to "Renewable Energy Development Bill", "the use of fallow land for energy crops as incentives and subsidies for the production system of biomass fuels" has been drafted.
4.Waste	629.1 MW (1.29%)	• 925 MW (2020) • 1,369 MW (2030)	• Municipal waste (622.5 MW): use waste heat to generate electricity; • Agricultural and industrial waste (167.5 MW): on the bases of electricity generation and thermal applications; and • Biogas thermoelectric applications (8.5 MW): on the bases of landfill gas power generation.
5.Hydro power	2,089 MW (4.29%)	2,150 MW (2025)	• The currently planned projects are the priorities of development, approximately 168 MW (Taipower); and • Encourage private industry and irrigation and water conservancy to develop running-through-typed hydropower, about 100 MW.
6.Geothermal	0 MW	200 MW (2025)	• Short-term: establish 1 MW demonstration plant in Chinsuei geothermal area. • Mid-term: expand geothermal plant capacity of Chinsuei plant, and develop Mt. Tatun volcanic area and other geothermal area. • Long-term: continuously develop Mt. Tatun volcanic area, and begin to develop deep geothermal power in 2025.
7.Ocean energies	0 MW	600 MW (2030)	• According to the potential of ocean

			energy, marine energy target and volume are planned; • Based on the maturity and international development trend, the development schedule of ocean energy is planned; and Build 4 MW demonstration plant by 2016; and, • Build commercial-type power plant by 2020.
8.Solar water heating system	Installed collector area: 2.37 million square meters (2013)	Installed collector area: 4.09 million square meters (2025)	Expand the scope of incentives to building integrated solar water heating systems and large-scale application technology.

Source: organized by the study.

CONCLUSIONS AND PROSPECTS

Since Taiwan relies on imports for 97% of energy supply, energy security constitutes the most important topic of national energy policy. The development of renewable energy resources not only can contribute the independence and autonomy of energy supply, but also can achieve the effectiveness of economic development and environmental protection-the so-called "3E".

According to the estimation, the reserve of wind energy, up to 251.01 TWh/year, is the largest one among all kinds of renewable energies in Taiwan, followed by 203.75 TWh/year of solar energy, 38.20 TWh/year of biomass, 38.45 TWh/year of ocean energy, 0.56 TWh/year of geothermal energy and 140.95 TWh/year of hydro power. If regarding biomass as a primary energy, and assuming 40% being the average efficiency to convert primary energy into electricity, the total power of the all kinds of renewable energy reserves is about 655.06 TWh/year, which is equal to 2.54 times of 258.02 GWh, the national power generation in 2015, so we can say that the reserves of renewable energies in Taiwan are quite abundant. However, if intending to fully develop these reserves of energies, in addition to the requirement to overcome the various difficulties of technique and implementation, the most optimistic time for the completion will be as late as 2050. However, by then, the energy supply needed may be four folds of the present's, based on the estimation of ETP 2008 of IEA, and the total reserves of renewable energies still importantly account for about 70% of national energy supply then.

Based on the latest national energy policy, "Nuclear-free Homeland", the RE power installed capacity in 2025 will reach 27,363 MW. With the promotion policies of carbon reduction and energy diversification, while in response to energy security issues, Taiwanese government accelerates the development of renewable energy potential and expands various types of renewable energy promotion goal from 4,929MW in 2016 to 13,514MW in 2020, ten years ahead to achieve the ordinance goal of 12,502 MW for 2030 set by BOEMOEA in 2012. Further, a goal of 27,363 MW in 2025 is set to show determination of actively promoting the policies.

Under suitable planning and promotion, significant growth in new and renewable energy utilization can be expected. The promotion of renewable energies would, however, require breakthrough in various regulations (e.g. land-use, building codes, grid-connection standards etc.), which require inter-agency coordination mechanism to overcome multiple barriers. To speed up the utilization of RE and deregulation of electric utilities, and the commitment on the execution of “Renewable Energy Development Bill” and revision to the “Electricity Law” are among the most important actions to be undertaken by the government. In today, a clear and definite commitment to RE development has been given, with good progress. Taiwan is hoping that by actively implementing these action plans mentioned above, the energy diversity shall be promoted, the environmental quality shall be improved and the development of industries shall be triggered. The ultimate goal is to achieve environmental protection, energy security and economic growth, namely the so-called “triple-win” situation.

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