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Renewable Energy Reform in Taiwan

An overview of the macroeconomic environment and cost-benefit analysis of economic viability

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List of Acronyms

CBA	Cost-Benefit Analysis
BCR	Benefit-Cost Ratio
BOE	Bureau of Energy, Ministry of Economic Affairs
ESCO	Energy Service Companies
EU	European Nations
FIT	Feed-in Tariff
GHE	Greenhouse Gas Emission
IEA	International Energy Agency
IRR	Internal Rate of Return
LNG	Liquidized Natural Gas
MOEA	Ministry of Economic Affairs in Taiwan
NEC	National Energy Conference
NPV	Net Present Value
NTD	New Taiwanese Dollar
O&M	Operation & Maintenance
REDA	Renewable Energy Development Act
RPS	Renewable Portfolio Standards
Solar PV	Solar Photovoltaic
TPC	Taiwan Power Company
TPES	Total Primary Energy Supply
UNFCCC	United Nations Framework Convention on Climate Change

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1. Executive Summary

Taiwan has a scarcity of natural resources, resulting in a strong dependence on importing fossil fuels and an energy security problem. Furthermore, the public fears and opposes the usage of nuclear power plants, forcing the government to have a serious debate that has lasted for years. As a consequence of this, the Tsai Ing-Wen administration is determined to change the status quo and reform the electricity sector. One of the new government's key goals is to increase renewable energy contributions to 20% of the overall electricity mix by 2025.

This paper aims to answer the question of whether or not the new renewable energy policy in Taiwan is economically viable. The research is integrated into a cost benefit analysis of the three main types of renewable energy outlined in this plan, which are wind power, solar power, and small hydropower, respectively. The paper adopts (1) net present value (2) benefit-cost ratio and (3) internal rate of return and (4) payback period as decision criteria to be used in appraising the monetary costs and benefits associated with this plan, from the private sector perspective. The paper also covers non-monetary costs and benefits, which are also extremely important when going through the decision-making process.

The results of the analysis contained in this report prove that both wind and solar PV are both economically viable options, while small hydropower is not. The paper concludes with some insights into how the Taiwanese government can leverage public policy and make strategic decisions that will both attract private investors into this space and bring Taiwan closer to ensuring clean and reliable access to electricity for its people.

2. Introduction

Since the beginning of the industrial revolution in the 18th century, scientists and meteorologists have found that greenhouse gas (GHG)[1] concentrations in the atmosphere have accumulated dramatically over the past few centuries. Among all the greenhouse gases, carbon dioxide (CO_2) in particular is produced through human-induced activities like fossil fuel combustion, accounting for nearly 65% of GHG emissions in 2010 (IPCC, 2014). As GHG concentrations in the atmosphere have continued to rise, the average global temperature has been climbing at the fastest recorded rate in history (See Figure 1).

With the increase in atmospheric CO_2 concentrations, changes in climate have negatively impacted both natural and human systems across the globe. Across the world, melting glaciers and rising ocean levels threaten to leave cities underwater. In the north, polar bears struggle to cope with historically low levels of sea ice and heat waves that have seen the North Pole's temperature rise above freezing (Washington Post, 2018). Furthermore, it appears that recent trends have not been promising, with 17 out of the 18 warmest years on record all having taken place since 2001 (Shaftel, 2018).

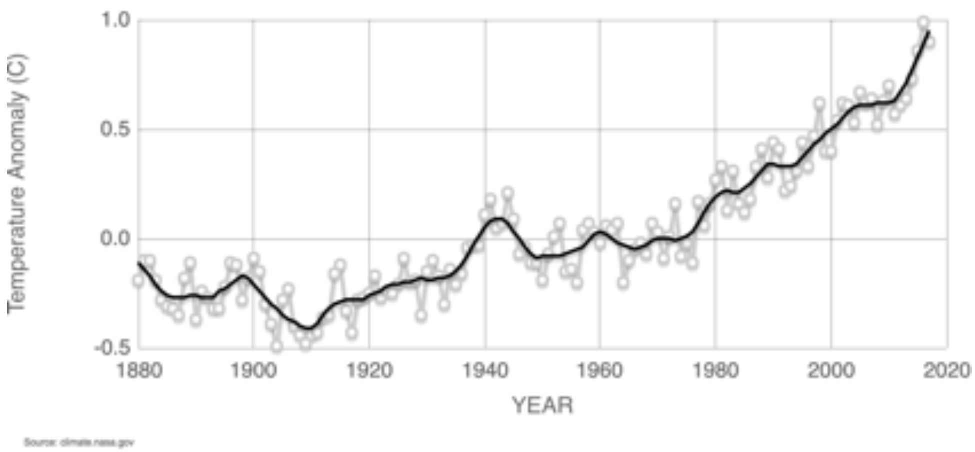

Figure 1 NASA Global Land-Ocean Temperature Index[2] (LOTI)

Source: Shaftel, 2018

[1] Greenhouse gases are heat-trapping gases, including carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and fluorinated gases (US EPA, 2017).

[2] The Global Land-Ocean Temperature Index (LOTI) is a global mean trend of global surface temperature change, which is based on the fact that ocean warming is largest near the Earth's surface and stores significant energy in the climate system (IPCC, 2014)

Continuing to emit greenhouse gases will cause further long-term changes to the climate that will endanger the ecosystem. In response to this serious realization, many governments have signed international treaties that have been entered into force. For example, The Paris Agreement, signed by 175 parties in 2015, aims to globally mitigate adverse climate change to well below 2°C. While Taiwan continues to be excluded from the UN and is thus unable to add its name to the Paris Agreement, the Taiwanese government has taken a bold stance in its fight against climate change. Through a diversified electricity mix promoted by renewable energy,[3] Taiwan hopes to source 20% of its electricity demand through renewables by 2025, in addition to curbing greenhouse gas emissions by 50% in the year 2050 (Taipei Times, 2016).

Taiwan's electricity goals may be even loftier than they appear. Due to geographical limitations and the stark scarcity of domestic resources, Taiwan imported approximately 98% of its total energy consumption (EC) in 2016, for a total of $30.1 billion USD, and electricity accounted for nearly 50% of total EC in 2016 (BOE, 2017a). To delve a bit deeper, most imported fossil fuels were acquired from politically unstable locations in the Middle East (BOE, 2017a). This further underscores the importance of domestic electricity generation for Taiwan, where a massive demand and an insufficient supply for electricity have become the norm.

The issue of energy security in Taiwan has repeatedly emerged in public forums and debates. One area that has been explored by the Taiwanese government in the past is nuclear energy, which is not renewable by definition but emits much less CO_2 than conventional fossil fuels. As Taiwan is in the Circum-Pacific seismic zone, also known as the Pacific Ring of Fire, earthquakes and tsunamis are a constant threat that makes nuclear power generation riskier. The general public has become wary of nuclear energy projects in the aftermath of the Fukushima Daiichi Accident[4] in Japan in 2011, such as the Lungmen nuclear power plant. On April 27th 2014, anti-nuclear protesters gathered to demonstrate their opposition and urge

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3 According to the International Energy Agency (IEA), renewable energy, by definition, is energy derived from natural processes (e.g. sunlight and wind) that is **replenished at a faster rate than it is consumed**. There are five common renewable energy sources that will be referred to in this thesis: hydropower, solar, wind, geothermal and biomass (IEA, n.d.).

4 On 11 March 2011, the Great East Japan Earthquake with a magnitude of 9.0 struck off Japan's northeastern shore and caused a tsunami, which devastated the Fukushima Daiichi Nuclear Power Plant. The power plant soon experienced a level-7 nuclear meltdown and released high levels of radiation. (Oskin, 2017)

the government to cease further construction and operation on the Lungmen plant. Taiwan's former president, Ma, Ying-Jeou, responded to the request by agreeing to halt the first reactor and seal the second reactor after its safety check was completed. (ABC News, 2014). Sure enough, the Taiwan Power Company (TPC), the government-owned utility, announced on 15 March 2018 that the Lungmen nuclear power plant would be permanently closed. Clearly, Tsai Ing Wen's "Nuclear-Free by 2025" presidential platform shows that for now, nuclear energy will not be an option in securing energy independence and a greener future.

Although the Taiwanese government itself has implemented various policies and developed some facilities to promote renewable energy generation, the uncertainty of the future power supply remains concerning. Without a reliable domestic power supply, Taiwan will continue to depend on importing fossil fuels from its very limited number of trade partners, which may prevent its economy from realizing its full potential. In addition, fossil fuel reliance is at the center of modern science's explanation for climate change, so the world as a whole ought to be invested in a greener Taiwan. With a strongly committed government and abundant renewable energy potential, sourcing 1/5th of energy renewably seems like it could be feasible, but a more important question remains for Taiwan.

Research Question:

Taiwan's stated goal is to be using 20% renewable energy, while also being nuclear-free, in the year 2025. Is this energy goal economically viable[5] for the private sector?[6]

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[5] Economically viable decisions must generate (sufficient) financial returns and/or make a company more competitive in the industry it participates in

[6] For purposes of this research paper, it has been assumed that reaching the 20% renewable energy figure itself is feasible, if it is considered independently of governmental financial constraints. This assumption has been bolstered by the renewable energy potential discussed in section 4.2, as well as by projections made by the Taiwanese government itself and by independent global intelligence companies.

3. Methodology

3.1 Secondary Data Collection

Secondary data, by definition, is meant to reanalyze data that has been gathered from some other prior research (Saunders, Lewis and Thornhill, 2009). In general, data collection begins with a systematic study of what is already known and what remains to be discovered about a topic by reviewing secondary sources that have been previously gathered in the specified area of interest (Johnston, 2014).

This research paper has employed many different secondary data resources, including but not limited to academic journals, government reports, and company profiles. All of these resources together provide a comprehensive overview of the current electricity situation in Taiwan that also contains crucial information for conducting the Cost Benefit Analyses, which are discussed in detail in the following sections.

3.2 Cost-Benefit Analysis

Cost-benefit analysis (CBA) is the systematic and analytical process of weighing costs and benefits in order to determine which programs or projects are worth pursuing (Mishan and Quah, 2018). As CBA is designed to compare the pros (benefits) and the cons (costs), this formal technique is often used to assess the desirability of policy or regulatory proposals. Furthermore, it can be applied across a wide variety of different areas, such as environmental projects, education, social welfare, employment objectives and more (Mishan and Quah, 2018). Although CBA has long been very popular amongst governmental project teams, it is also becoming more widespread as a method of investment appraisal in the private sector.

3.2.1 Key Steps in Cost-Benefit Analysis

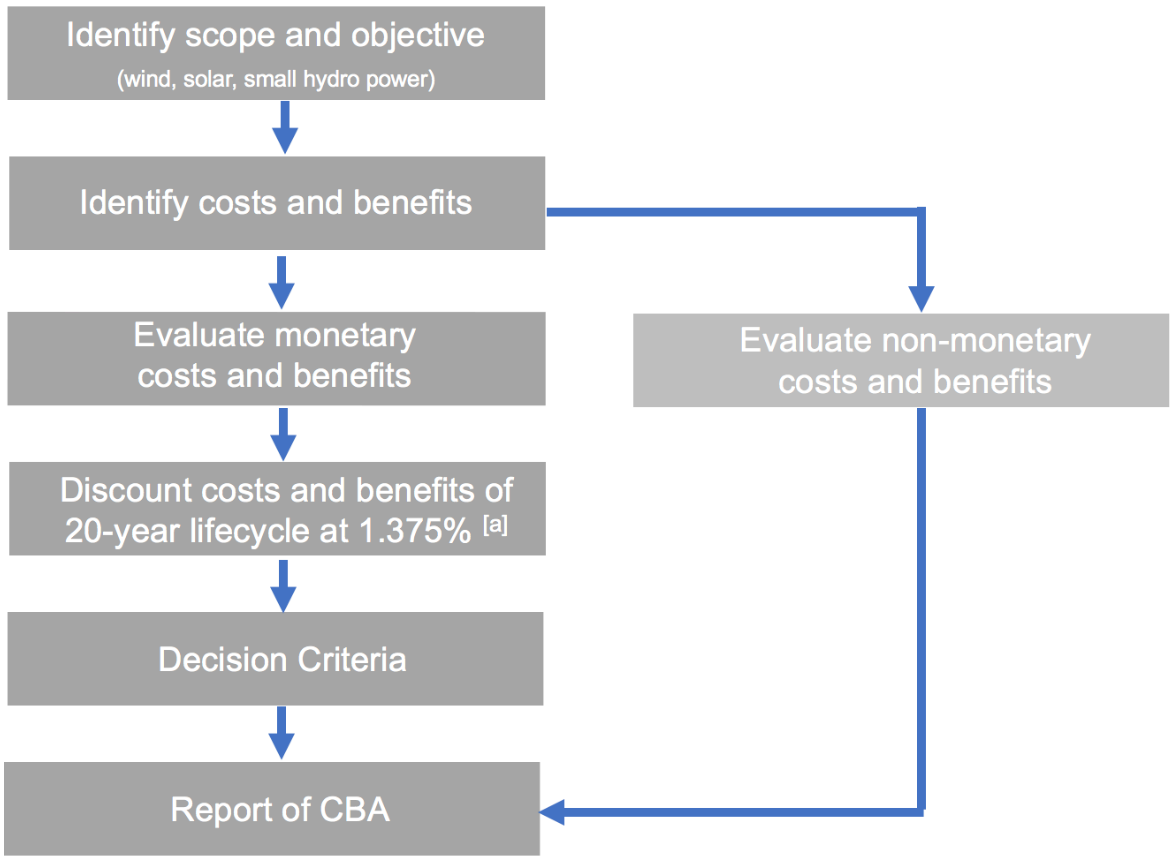
In this research paper, CBA is implemented to appraise the Taiwanese government's new electricity policy, "Nuclear-Free by 2025." However, due to the scope of our research topic and questions, the paper only conducts CBA on the new renewable energy goal from the private sector perspective. This research paper identifies four critical steps when conducting the CBA (Harris, 1991; Financial management group, 2006):

(1) Determine the scope and objective of the project.

(2) Identify all the relevant costs and benefits related to the project.

(3) Estimate the present value of a stream of future net benefits from the project

(4) Calculate equations of decision criteria to indicate whether the project is worth undertaking in order to provide an order ranking for different projects.



[a] Central Bank of the Republic of China (Taiwan), n.d.

Figure 2 CBA Flowchart

3.2.2 Monetary Cost-Benefit Analysis

The first part of CBA pertains to monetary costs and benefits, such as installation costs, operating & maintenance (O&M) costs and Feed-in-Tariff (FIT) benefits. To assist with the decision-making process and assess the viability of this policy, the paper employs four different decision criteria: (1) Net Present Value (NPV), (2) Benefit-Cost Ratio (BCR), (3) Internal Rate of Return (IRR), and (4) Payback Period. The equations of the decision criteria, shown below, refer to the same concepts presented in the Financial and Economic Analysis of Selected Renewable Energy Technologies in Botswana, written by Philips LeBel (1985).

Before introducing the criteria, it is important to establish a firm grasp of the basic concepts of a cumulative Present Value of Costs (PVC) and a cumulative Present Value of Benefits (PVB). PVC is the sum of total costs taken over a certain period of time and discounted at a predetermined rate. In the equation (1) below, C is the economic value of costs in each time period t, R depicts the discount rate and n represents the number of periods in the series.

Equation (1):

$$PVC = \frac{C_0}{(1+R)^0} + \frac{C_1}{(1+R)^1} + \frac{C_2}{(1+R)^2} \dots\dots = \sum_{t=0}^{n} \frac{C_t}{(1+R)^t}$$

On the other hand, PVB is the sum of total benefits taken over a certain period of time and also discounted at a predetermined rate. In the equation (2), B is the economic value of benefits in each time period t, R shows the discount rate and n represents the number of periods in the series.

Equation (2):

$$PVB = \frac{B_0}{(1+R)^0} + \frac{B_1}{(1+R)^1} + \frac{B_2}{(1+R)^2} \dots\dots = \sum_{t=0}^{n} \frac{B_t}{(1+R)^t}$$

Decision Criteria (1) - Net Present Value (NPV)

NPV is one of the most common ways in which the return on investment for a project is analysed (Gallo, 2014). A positive NPV indicates that the present value of benefits (cash inflows) is greater than the present value of costs (cash outflows) and, therefore, investing in the project is financially desirable for the party in question. Although NPV analysis is commonly used, it does have its disadvantages. It is highly dependent on many assumptions; for example, the discount rate that is used could be flawed or the estimates of benefits may not inherently consider the risk associated with the project (Investopedia, n.d.). With that being said, all forms of CBA require that assumptions be made, and no analysis can ever be perfect. As a result, NPV is still a very popular method in practice. See equation (3) below for a visual depiction of how NPV is calculated for a given project.

Equation (3):

$$NPV = \sum_{t=0}^{n} \frac{B_t}{(1+R)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+R)^t}$$

Decision Criteria (2) - Benefit-Cost Ratio (BCR)

The Benefit to Cost Ratio, or BCR, outlined below is another method that is often used to compare the PVC with the PVB. Instead of simply calculating the actual NPV by subtracting the PVC from the PVB, the BCR divides PVB by PVC to provide a different perspective.

Equation (4):

$$BCR = \frac{\sum_{t=0}^{n} \frac{B_t}{(1+R)^t}}{\sum_{t=0}^{n} \frac{C_i}{(1+R)^t}}$$

BCR is almost always associated with NPV. As shown below, the resulting BCR figure will be greater than one whenever the NPV figure is positive. This indicates not only that the investment is profitable, but also that it is expected to yield a greater return than the company's predetermined discount rate.[7] Hence, BCR values greater than 1 generally mean that the investment is worth pursuing for the company or business entity in question.

$$NPV > 0, then\ BCR > 1$$

$$NPV = 0, then\ BCR = 1$$

$$NPV < 0, then\ BCR < 1$$

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[7] A company uses a variety of benchmarks to determine its Weighted Average Cost of Capital (WACC), which is the prime determinant in selecting a discount rate for NPV analyses. These benchmarks, or alternative investment options, provide low-risk and low-reward returns, with the most common examples being banking interest, mutual funds, heavily diversified investment portfolios and so on.

Decision Criteria (3) - Internal Rate of Return (IRR)

As noted below, the IRR deploys the same equation as NPV, but solves for a different variable. By setting the equation equal to zero in order to solve for the discount rate, (which is already assumed and given as a constant in NPV equations), one can arrive at the minimum discount rate that a company would have to assume in order to make it worthwhile to invest capital in the project. This number is the internal rate of return, or IRR, and it is especially valuable in CBA because it helps show whether a project is worth its economic opportunity cost. The interpretation is that if IRR is greater than or equal to the opportunity cost, the project may be considered beneficial.

Equation (5):

$$IRR = \sum_{t=0}^{n} \frac{B_t}{(1+R)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+R)^t} = 0$$

Decision Criteria (4) – Payback Period

Payback period is another very popular financial metric that estimates the time required after an investment to recoup the initial costs of that investment (Investopedia, n.d.). In the equation (6) below, i is the last period with a negative cumulative cash flow, B is the benefits and C is costs (Jan, n.d.). It is worth noting that this metric does not take into account the time value of money. Therefore, it is often used in conjunction with the criteria mentioned above, especially in the case of longer projects or investments (Investopedia, n.d.).

Equation (6):

$$Payback\ Period = i + \frac{-(B_i - C_i)}{B_{i+1} - C_{i+1}}$$

3.2.3 Non-Monetary Cost-Benefit Analysis

Ideally, costs and benefits should be quantified to assess the feasibility of projects. However, in practice, it is not always easy to do so. Therefore, in addition to the monetary section, this research paper includes environmental and health effects that are difficult to value in monetary terms. One must bear in mind that these non-monetary factors should be taken into account and discussed thoroughly before making any final decision, as they are often just as important as their monetary counterparts.

3.2.4 Limitations of Cost-Benefit Analysis

Along with its advantages, CBA has a few drawbacks and limitations that are worth noting.

(1) Uncertainty & Risk

Although the two words "uncertainty" and "risk" may seem interchangeable in daily uses, they have distinct meanings when being applied to financial analysis policies and other investment situations. In the case of CBA, the greatest difference between risk and uncertainty is that risk indicates situations in which the nature of the probability distribution of future events is identifiable and measurable, while uncertainty refers to situations where the probabilities cannot be captured or determined (Hosking, and Preez, 2004).

(2) False Accuracy

CBA is sometimes criticized for quantifying intangible values in monetary term, leading to disputes of "false accuracy" in CBA results (Financial management group, 2009). On the other hand, analyses themselves can arguably be even more inaccurate when excluding intangible effects, which sometimes can be more important than the tangible ones (Financial management group, 2006). In this research paper, the tangible components of the CBA only include the costs and benefits that are purely quantifiable. The intangibles are discussed later, in their own section.

(3) Ethical Dilemmas

CBA attempts to evaluate all benefits and costs, including non-monetary ones and "externalities", which indirectly affect the project stakeholders (Harris, 1991). However, this is based on the assumption that all types of costs can be compensated by benefits (Ministerrådet, 2007). In addition, CBA recognizes value to society as a whole, but individuals who receive benefits from a project or a policy may not necessary be the ones who incur loses (Ministerrådet, 2007). Thus, it is difficult to address the inherent problem that some people may suffer negative effects while others reap the benefits. This can be a controversial topic in CBA, and it is something that will be touched on later in the paper.

4. Shifting Trends from Fossil Fuels to Renewables

4.1 Electricity Supply and Demand Trends in Taiwan

As Taiwan has one of the highest population densities in the world[8] and is a leading developer of energy-intensive industries, the electricity supply is essential for supporting the industrial and household demand. In 1996, the installed capacity in Taiwan was approximately 26,247 MW. With an annual growth rate of roughly 3.27% over the next 20 years, Taiwan's total installed capacity in 2016 reached a total of 49,906 MW (BOE, 2017a). In addition, coal-fired electricity accounted for 45.4% in the electricity generation structure in 2016, followed by 32.4% of LNG-fired, 12% of nuclear and 4.8% of renewable energy (BOE, 2017a). Although these statistics show Taiwan's consistent ability to grow domestic power production, the increasing utilization of fossil fuels and the relatively small percentage of renewable energy supply is a cause for concern.

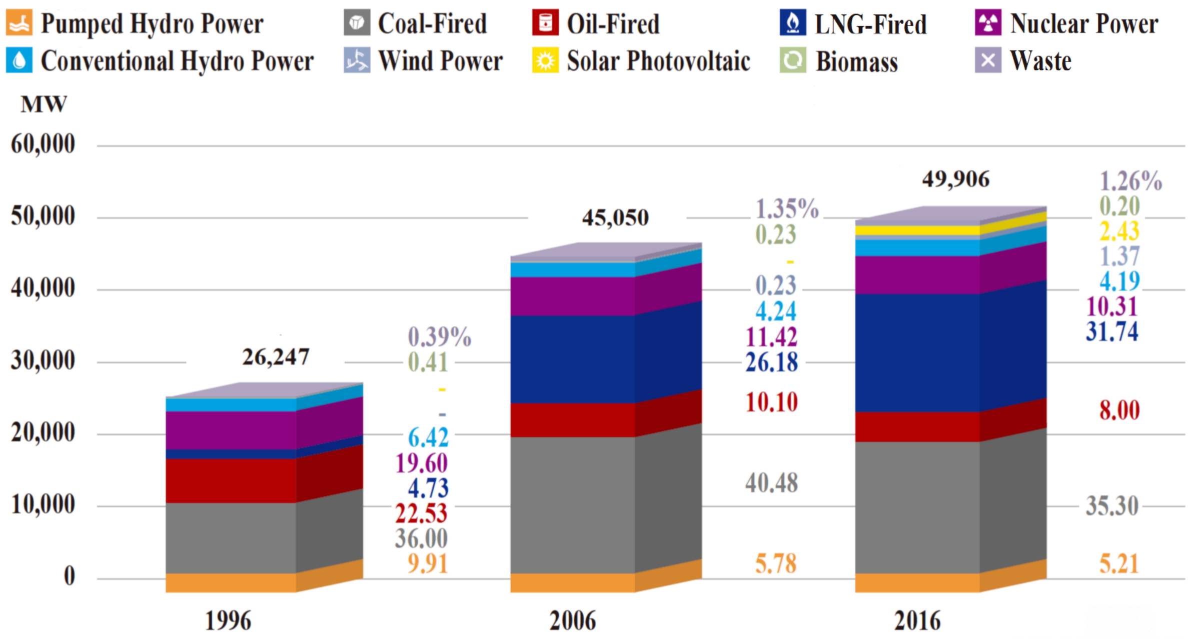

Figure 3 Installed Electricity Capacity in Taiwan 1996 - 2016

Source: BOE, 2017a

[8] Taiwan is a densely populated island with a land area of 36,190 km^2 and a population of 23.1 million.

In 1996, the total electricity consumption in Taiwan was approximately 134,307 GWH, with 46.86% industrial, 20.53% residential, 20.14% service and 10.62% energy sector own use[9] (BOE, 2017a). 2016 demand nearly doubled 1999 demand to a total of 255,381 GWH and the annual growth rate of per capita electricity consumption is 2.81% (BOE, 2017a). The main concern now for the Taiwanese government and the public is the availability of sufficient electricity generation capacity. Figure 5 on the following page shows the planned retirement of the three remaining nuclear power plants (six nuclear reactors in total will be closed) in Taiwan, which will lead to a severe reduction in the domestic power supply unless alternate forms of energy (i.e., renewables) can make up the difference. With increasing demand expected in the years to come as well, electricity generation capacity is quickly becoming a time-sensitive issue for Taiwan.

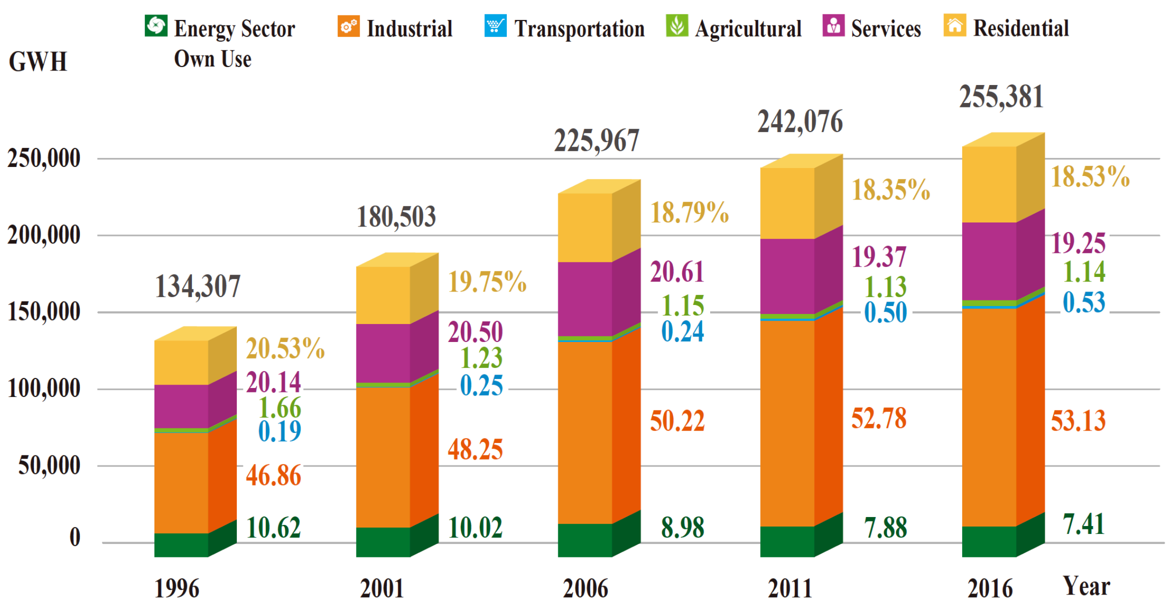

Figure 4 Electricity Consumption in Taiwan 1996 - 2016

Source: BOE, 2017a

[9] During the electricity generation process, there are many parts of the power plant itself that consume electricity simultaneously while it is being generated, such as motors, lighting, ventilation and other protection devices and controls.

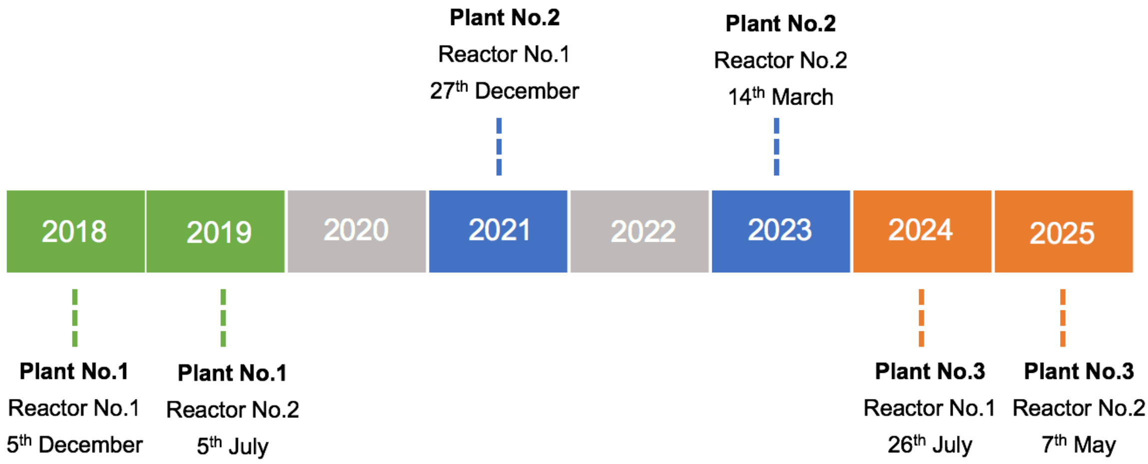

Figure 5 Timeline of Three Existing Nuclear Power Plant Retirements

Source: Atomic Energy Council, 2018

There is a critical topic to address when discussing electricity demand and supply, and that is the reserve margin (also known as reserve capacity). Electricity is a unique necessity that can hardly be stored on a large scale[10] and therefore must be consumed the moment it is generated, meaning that electrical grids must maintain a balance between demand and supply, second-to-second. Given this idea of "just-in-time" electricity delivery, utilities employ a simple principle for securing reliability: always have more supply available than projected demand. However, one significant limitation of this principle is that it is difficult to predict future demand and often takes years to build new facilities and plants.

To prevent electricity shortages, utilities adopt reserve margins that serve as a buffer for unexpected fluctuations, such as power plant emergency outages or unplanned sudden increases in demand (especially during peak hours and seasons). Furthermore, reserve margins can apply not only to real-time operating, but also long-term planning (from a month ahead to years) (California Energy Commission, n.d.). The formula below shows how the reserve margin is calculated. The "capacity" is the expected maximum available supply, and the "demand" is expected peak demand (EIA, 2012b).

[10] The most mature technology to store electricity on a large scale is pumped-storage hydropower (PSH). It has geographical constraints; however, and other electricity storage technologies haven't fully developed for full-scale implementation.

$$\text{Reserve Margin} = \frac{\text{Capacity} - \text{Demand}}{Demand}$$

In Taiwan, the reserve margin was up to 25% before 1985 and then dropped down to 20% after 1985. Since 2006, the public has often questioned the necessity of having a high reserve margin of 16%, as maintaining an extra 1% of reserve margin requires extremely high costs. After examining the historical power data, the government decided to adjust the reserve margin from 16% to 15% in 2012; after not having any electricity shortages in the past 16 years (TPC, 2017). However, the heat wave and other natural catastrophes in 2016 and 2017 led to a supply emergency, where the daily operating reserve margin often decreased to 6% or even lower. Moreover, on 15 August 2017, Taiwan suffered a massive electricity blackout for about 5 hours, causing millions of dollars in losses (Time, 2017).

Although the outage in 2017 was a result of a human technical error, it prompted criticisms and questions about Tsai Ing-wen's energy policy and its reliability, especially the nuclear-free policy. After these human-induced accidents, the government decided to keep a 15% reserve margin in effect during off-peak hours and a 10% daily operating reserve margin in peak periods to ensure the public and investors a reliable electricity supply (TPC, 2017).

4.2 Renewable Energy Potential in Taiwan

In this research paper, renewable energy, by definition, is derived from sources that can be regenerated and sustained indefinitely. For purposes of our research, some resources that emit little or no carbon footprint during use will be excluded, such as nuclear plants and any other conventional power plants that are equipped with carbon capture and storage facilities.

Compared to fossil fuels, renewable energy sources have three main characteristics (Brown and Whitney, 2011):

(1) *Renewable energy sources are diverse and numerous:* such as the sun, wind, flowing water in streams and tidal channels, waves in oceans, natural heat from the earth, organic biomass material, and so on.

(2) *Some renewable energy sources have relatively low energy densities*[11]*:* Although different fossil fuels have different energy densities, they have in general much higher energy densities as compared to renewables. What this means for many renewable energy types, is that they often require a drastically greater special land than fossil fuels in order to produce comparable amounts of energy. This can make it very difficult for renewable energy generation to meet modern demand.

(3) Installation capacity of renewable energy sources can vary greatly in size

As we think about the different characteristics that separate renewable energy from fossil fuels, it is very important for our purposes to understand the renewables potential in Taiwan before attempting to replace fossil fuels too quickly, as this could lead to energy shortages. Thankfully, Taiwan is endowed with substantial renewable energy potential, as depicted in Figure 6 on the following page. This diagram shows an overview of the optimal geographic locations within Taiwan of various types of renewable energy generation. Although Taiwan has substantial ocean energy, the current immaturity of the necessary technology prevents Taiwan from taking full advantage and generating massive amounts of electricity in this domain (Hu and Mathews, 2016; Hannon et al., 2018). Therefore, this section will focus primarily on solar, wind, hydropower, biomass and geothermal. Furthermore, Figure 7 on the following page shows that there are four different dimensions of potential assessment: resource, technical, economic and market. The market potential, which is of course most important in terms of policy and regulatory perspectives, will be discussed more in the following sections and chapters.

[11] Energy density refers to the quantity of energy that can be contained in a given unit of volume, area, or mass (Hanania et al., n.d.).

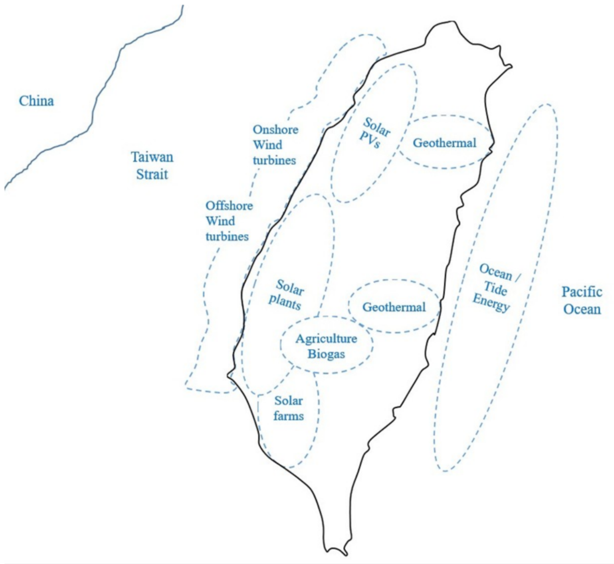

Figure 6 Geography of Targeted Green Energy Development in Taiwan

Source: Hu and Mathews, 2016

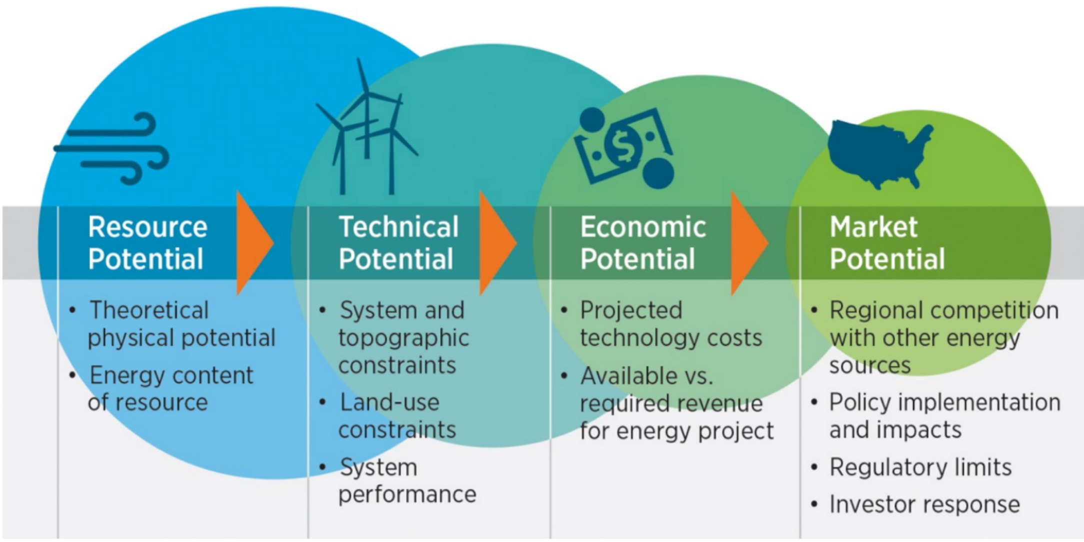

Figure 7 Types of Renewable Generation Potential

Source: Brown et al., 2016

(i) Solar

Solar energy is more widely used in Taiwan than other renewable energy sources, as it does not bring much social resistance. Due to its subtropical weather climate, Taiwan has very high annual solar radiation. Figure 8 below shows the Taiwanese map of annual average radiation, which is categorized into the following three zonings: (1) Rich solar radiation that is greater than 4500 (MJ/m^2), (2) High solar radiation that is between 4000-4500 (MJ/m^2) and (3) Medium solar radiation that is less than 4000 (MJ/m^2) (Ko et al., 2015). Among all the cities and areas, Pintgtung County has the highest annual average solar radiation, at 6,146.6 (MJ/m^2), followed by Chiayi City, Kaohsiung City and Taitung County (Ko et al., 2015).

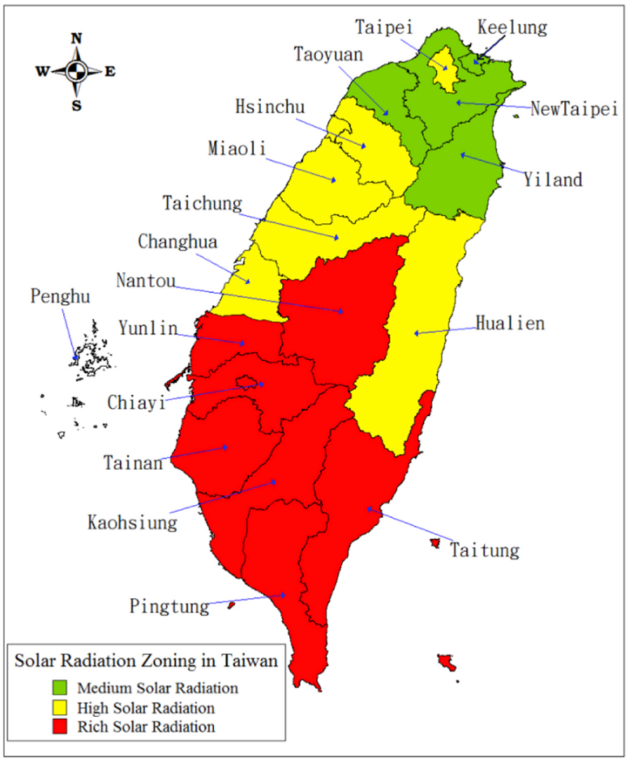

Figure 8 Solar Radiation Zoning in Taiwan

Source: Ko et al., 2015

(ii) Wind

As Taiwan is located in the monsoon[12] zone, it has northeastern monsoons in the winter and southwestern monsoons in the summer. The geographic environment and its substantial wind sources provide Taiwan with a great opportunity to develop renewable wind energy. Figure 8 illustrates the annual average wind speeds on Taiwan, with an annual average of 80 m/sec. As we can clearly see, there is a great deal of wind both on the Taiwanese mainland and in

[12] A monsoon is a seasonal wind change in a region and causes wet and dry seasons. (National Geographic Society, n.d.)

its surrounding waters, with some of the greatest potential occurring on the west coast of Taiwan (Wu et al., 2016). However, building wind turbines requires advanced technology, especially in offshore situations, and Taiwan currently lacks the relevant technology and strong domestic supply chain to manufacture enough turbines to take full advantage of the potential. This lack of technological advancement has made construction and maintenance costs extremely high. Moreover, scarcity of land and high population-densities across the island constrain the onshore wind potential, which can often lead to noise complaints and landscape changes that impact various stakeholders.

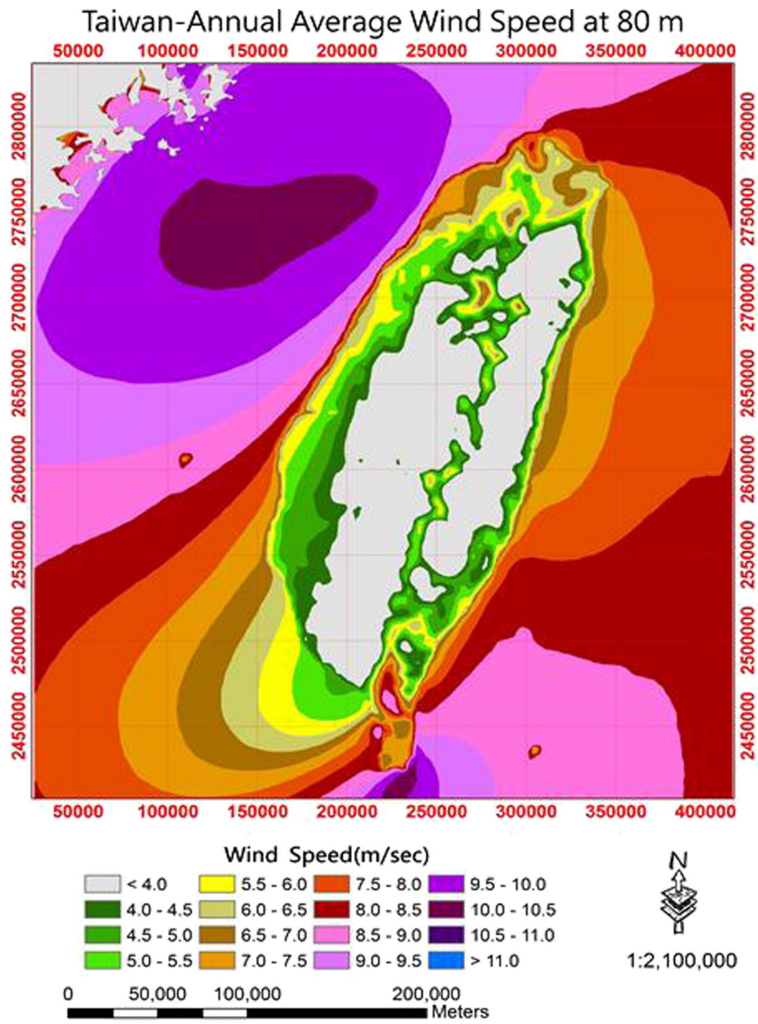

Figure 9 Taiwan Annual Wind Speed

Source: Wu et al., 2016

(iii) Hydropower

Before other renewable energy types began to catch-up technologically, hydropower had been the dominant contributor to clean energy in Taiwan (BOE, 2017a). Due to its position within the subtropical and typhoon (also called hurricane) zone, Taiwan receives approximately 800 million tons of rainfall per year, with hydropower potential estimated at about 25,700 MW annually (Chen and Lee, 2014). Most promising locations have already been exploited, with a total installation capacity of 2089 MW in 2016. As a result, there has not been much expansion of large-scale dams in the past few years and it is difficult to anticipate significant growth in the future; however, small hydropower (SHP) has shown potential and may be the answer to continued growth going forward. There is no agreed definition of SHP across the globe, as it differs in countries and international agencies. The TPC has its own definition:

(1) Small: < 20,000 kw
(2) Mini: < 1,000 kw
(3) Micro: < 100 kw

4.3 Background of Taiwanese Energy Policy

In the 1960s, Taiwan was going through a period of rapid industrialization and economic growth. To respond to increasing electricity and energy demand, the Taiwanese government established the Energy Development Group (now known as the Bureau of Energy, or BOE) and passed the first energy policy - "Principles for Taiwan Area's Energy Development" to pave the way for industrial development with reliable and low-cost electricity in 1968.

Due to two oil crises in 1973 and 1979, the government announced the "Taiwan Energy Policy" and "Taiwan Energy Policy Act" to seek stability and diversify its energy resources. Furthermore, liquidized natural gas was encouraged as a partial replacement for petroleum products, which historically have made up a large portion of Taiwan's EC.

Prior to 2000, the government had mainly focused on research, education, and demonstration purposes, instead of expanding installed renewables capacity. As a result of this lack of capacity, there was merely 3% – 4% of power generated by renewable energy during the 1990s as the majority came from conventional hydropower in addition to a slight proportion from biomass and waste (BOE, 2017a). Not until 2000 did some wind power and solar photovoltaic (solar PV) start contributing to renewable energy production (BOE, 2017a).

Global warming and climate change have been referred to as one of the world's greatest threats to our environment and society for quite some time. In 1997, the Kyoto climate change conference was held to discuss reductions in GHG footprint amongst countries whose economies rely on industry and manufacturing. With a highly industrialized economy that depends on international trade and imported fossil fuels, the carbon dioxide emissions of Taiwan ranked 25th in the world in 2015 (International Energy Statistics, n.d.). As one of the world's largest contributors of harmful GHG emissions, it would appear rather obvious to the average person that Taiwan should be included as a key part of the solution. However, due to political pressure exerted by China on the United Nations, the Taiwanese government was excluded from the Kyoto climate change conference. As a result, Taiwan was not placed under regulation of the United Nations Framework Convention on Climate Change (UNFCCC)[13] when the Kyoto Protocol[14] later entered into force in 2005.

Despite these international political challenges, the Taiwanese government took action to establish its own National Energy Conference (NEC) to examine future electricity structures and policies. The NEC has been held four times thus far: in 1998, 2005, 2009 and 2014. In the first NEC (1998), the government outlined its goal to reach 3% of Total Primary Energy Supply (TPES) from renewables by 2020, through promoting renewable energy with incentive mechanisms and potential funding sources (Chen, Kim and Yamaguchi, 2014). As the Kyoto Protocol came into effect in 2005, the second NEC agreed to increase the renewable energy goal from the original objective, 3 percent, in 1998 to 4-6 percent by 2020 and 10-12 percent of total electricity capacity by 2025 (Chen, Kim and Yamaguchi, 2014). In 2009, the BOE organized the third NEC to supervise the execution of renewable energy polices and further diversify the electricity mix through various policy mechanisms which are outlined in detail in the following chapter) (BOE, 2009). Finally, the 4th and most recent NEC was held in 2014 and hosted under the public pressure of the previously mentioned anti-nuclear power plant protest. The main topic of the conference, simply put, was: "Where

[13] To respond to problems stemming from global warming, members of the United Nations adopted the UNFCC in 1992. Later, the convention entered into force officially in 1994.

[14] The Kyoto Protocol is an international agreement associated with the UNFCCC that was adopted in 1997. It legally required 37 industrialized countries to reduce GHG emissions.

will future electricity come from?” As nuclear power plants are being replaced, which accounted for 6.25% of the electricity supply in 2016 (BOE, 2017a) and large-scale hydropower appears to be reaching its capacity due to land constraints, the most feasible answers to that question right now appear to be solar power, wind power, and small-scale hydropower (with geothermal and biomass likely contributing a bit as well). In the following chapters, it will provide a cost-benefit analysis of the 3 main options listed above in order to identify Taiwan’s best path forward towards a more sustainable future.

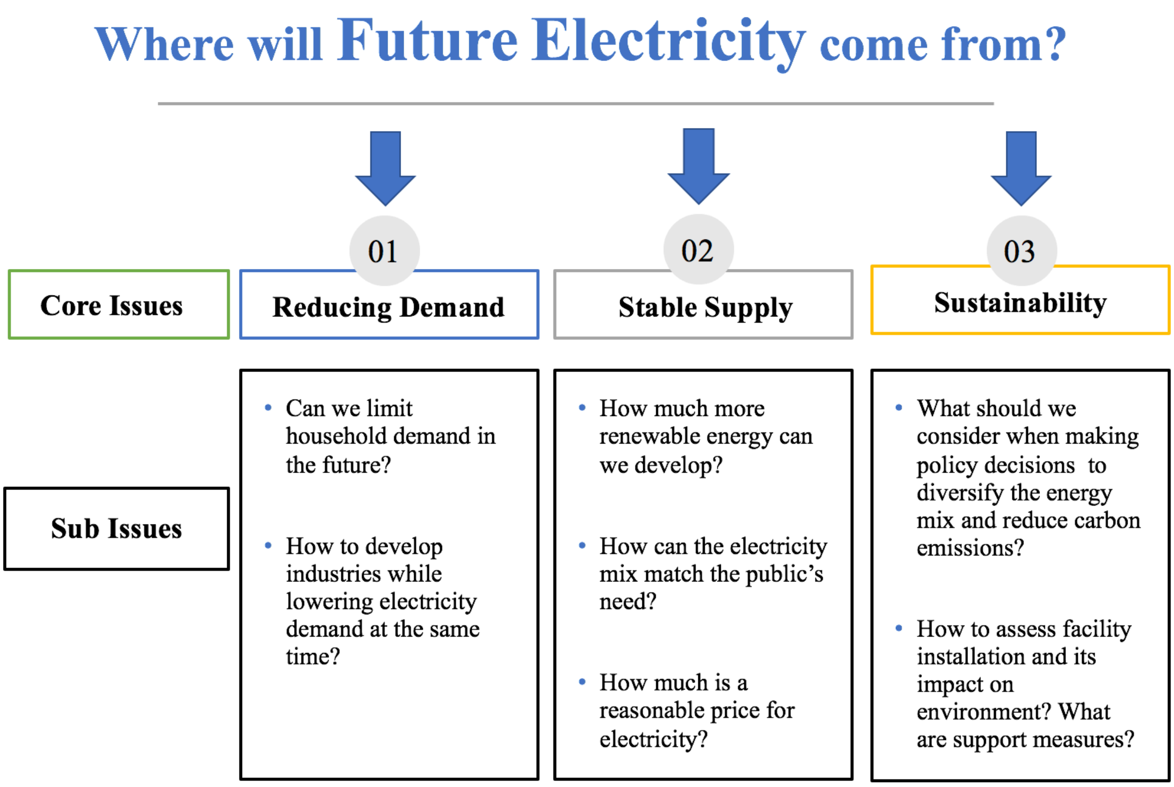

Figure 10 Agenda of the 4th NEC

Source: Monthly TPC Nuclear, Issue 383

5. "Nuclear-Free by 2025" Policy

5.1 "Nuclear-Free by 2025" Policy Roadmap

A sustainable electricity policy and regulatory environment should be able to cover three main dimensions, in order to prevent an imbalance that could lead to a series of problems and failures. These three main areas: "Energy Security," "Environmental protection" and "Economics considerations," are the foundation of the 3E framework, which is often used by the Taiwanese government as a basis for designing public electricity policy. Figure 11 below shows how the government has attempted to adopt the 3E framework and apply it to their new electricity policy, "Nuclear-Free by 2025."

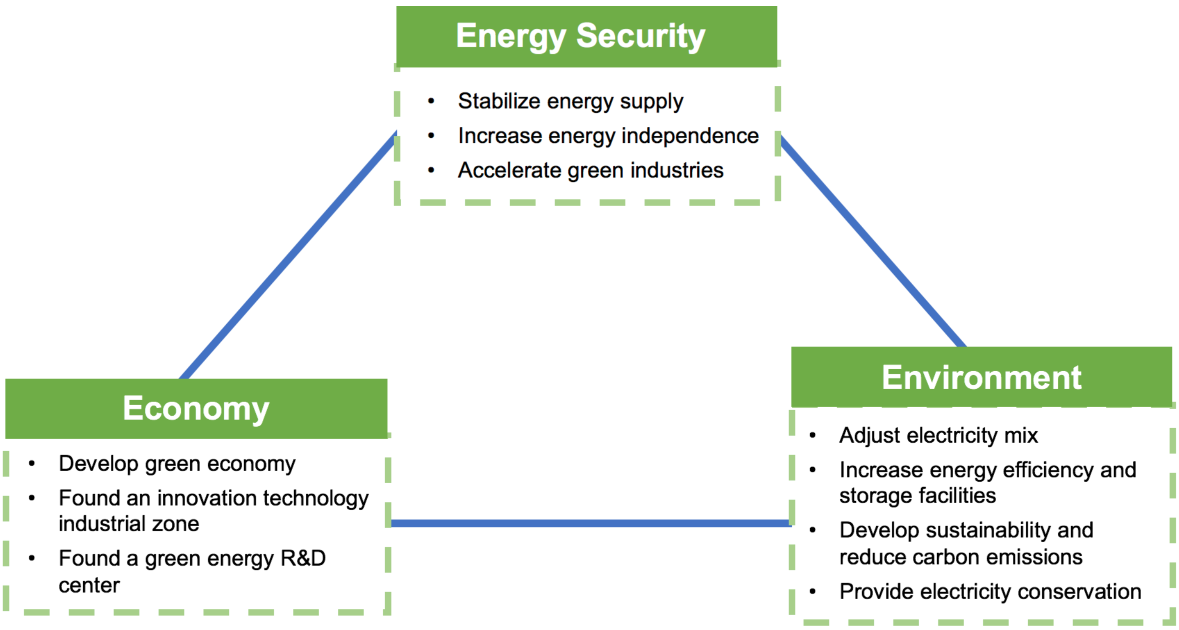

Figure 11 The 3E Framework of "Nuclear-Free by 2025"

Source: Chang and Lee, 2016

According to TPC's future electricity projections, the total demand for electricity in Taiwan will reach approximately 319.17 GWH (gigawatt hours) in 2025 and will require 331.16 GWH to secure a reliable supply (BOE, 2013). Installation capacity of the existing nuclear power plants is 5,144 MW (megawatt), which accounted for 10.31% of total capacity in 2016 (BOE, 2017a). In response to the ambitious goal of "Nuclear-Free by 2025", the Taiwanese government has proposed a new electricity mix of 50% liquidized natural gas

(LNG)-fired energy, 30% coal-fired energy and 20% renewable energy in 2025. One thing to be aware of is that this roadmap is based on five assumptions (MOEA, 2017a):

1. GDP will grow at an average of about 2.56% annually
2. Demand for electricity will grow at an average of 0.8% annually (based on the implementation of maximum electricity-saving projects in all industries)
3. The third (and last) nuclear power plant will close on 17 May 2025
4. It is based on the TPC long-term electricity planning (Nr.10510)
5. Gas-fired power generation will be prioritized

Solar PV and wind turbines will contribute the majority of installation capacity, at 73% and 15%, respectively, according to the Nuclear-Free by 2025 policy. The roadmap below shows how the government will gradually adjust the carbon-intensive electricity mix and strive to reach a more environmentally friendly electricity generation structure by 2025. However, as many fossil fuel and nuclear power plants are facing retirements and construction of renewable energy facilities will not be fully completed, the coal-fired electricity generation in 2020 will increase up to nearly 50% (TPC, n.d.; Huang and Chen, 2017).

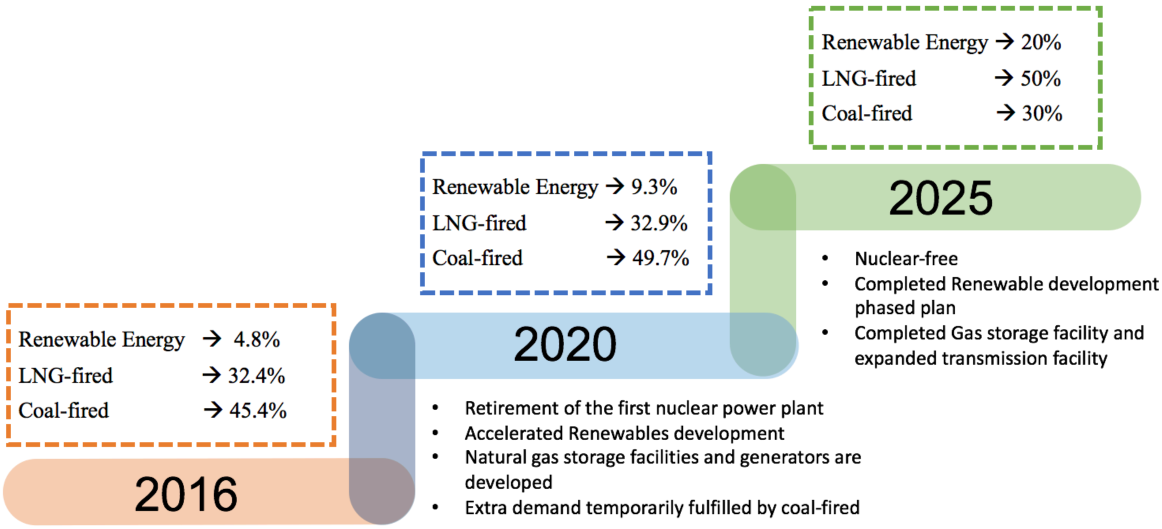

Figure 12 "Nuclear-Free by 2025" Roadmap

Source: MOEA, 2017a

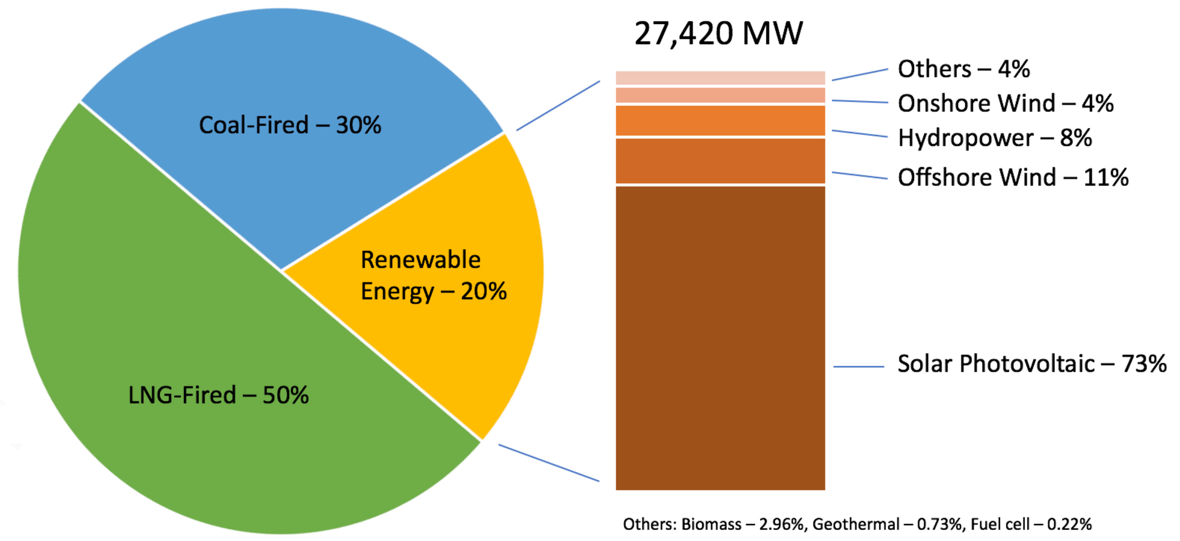

Figure 13 2025 Renewable Energy Mix Breakdown

Source: BOE, 2017b

The installation capacity of solar PV is estimated to grow to 20 GW in total by 2025, and it can be split into two categories: roof-mounted solar power and ground-mounted solar power. Roof-mounted solar panel installation can be applied on resident houses, government-owned buildings, factories, and agriculture facilities (such as greenhouses), and it is expected to make up 3 GW (or 15%) of solar capacity in 2025. On the other hand, ground-mounted solar panel installation refers to artificial salt evaporation ponds, land subsidence[15] areas, landfills, and water areas (dams, ponds etc…), with a vast majority of 17 GW (85%) of solar installation capacity planned in this area (BOE, n.d).

On a related note, the government in 2016 set a short-term goal called the, “Two-year Solar PV Promotion Project”, which aims to reach 1.52 GW of total solar installation capacity by June, 2018 (BOE, n.d). To incentivize private sector installation, the government has actively promoted a combination of the PV-ESCO (energy service company) business model[16], and a feed-in-tariff (FIT) mechanism. The model and the mechanism will be discussed in more detail in the following section.

[15] Land subsidence refers to a gradual sinking of the Earth's surface (Groundwater, n.d.). As Taiwan has many freshwater fish farms, which extract tons of underground water annually, some areas have suffered from severe subsidence problems.

[16] Consider adding footnote here to briefly introduce/ describe PV-ESCO business model

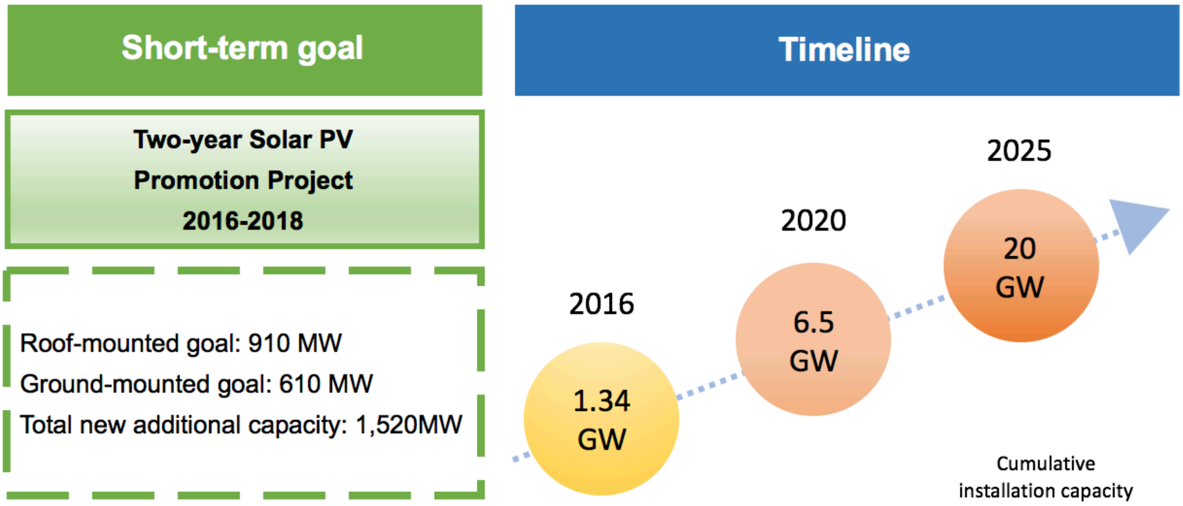

Figure 14 Roadmap of Solar PV Objective

Source: Executive Yuan, 2017

In addition to solar PV, the government aims to implement wind turbines with 1.2 GW total capacity of the onshore variety and 3 GW total capacity of the offshore variety in 2025. Furthermore, Taiwan plans to initiate another short-term project called the: “Four-year Wind Generation Promotion Project” (Executive Yuan, 2017). Although offshore turbines often benefit from more consistent wind speed and direction, building wind farms in the water carries higher capital risks and requires refined techniques and substantial equipment. As a result, the Taiwanese government prioritizes the development of onshore wind farms and only develops offshore farms in water that is less than or equal to 20 meters deep. Lastly, offshore wind farms will not begin to be constructed until the government and turbine developers gain sufficient experience and improve their methods. The government also encourages wind turbine development by employing FIT schemes, which is the focus of our analysis in the next section.

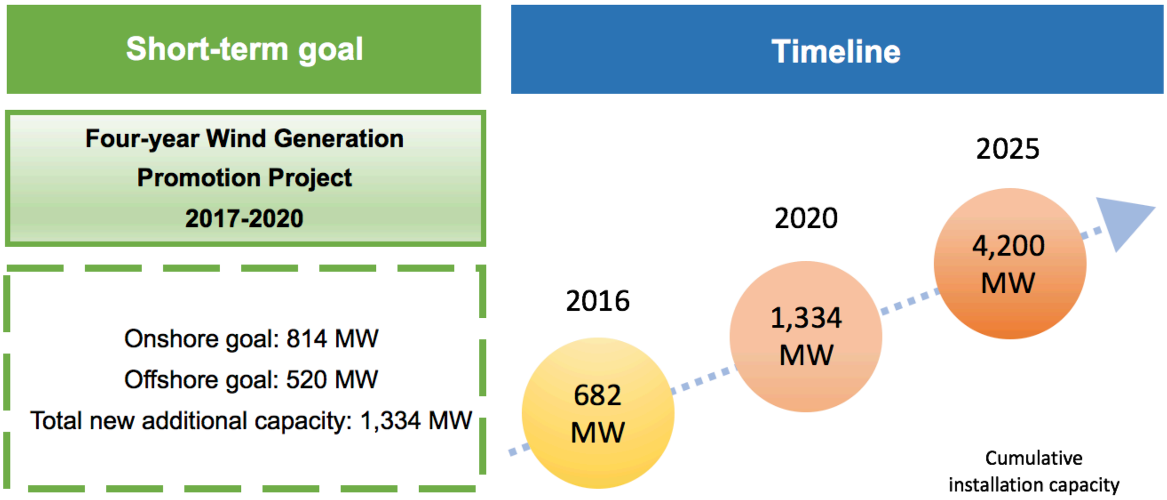

Figure 15 Roadmap of Wind Power Objective

Source: Executive Yuan, 2017

5.2 Policy Mechanisms and Incentives

In most cases, renewable energy mechanisms can be categorized as quantity-based and price-based. Renewable Portfolio Standards (RPS) are quantity-based schemes that require electricity generators within a given jurisdiction to produce a specified proportion of their electricity from renewable energy sources (EIA, 2012a). This mechanism has been commonly applied in many European countries and in the US, with 29 states and Washington D.C adopting it as of 2012 (EIA, 2012a). Though RPS are relatively simple to understand and arguably easier to implement than many other schemes (discussed later), price-based mechanisms have been generating a lot more buzz amongst Taiwan's policymakers.

The Taiwanese government has attempted to replicate the successes of Germany's Feed-in Tariff (FIT) model in order to promote renewable energy utilization in Taiwan and support the "Nuclear Free by 2025" initiative. FITs are price-based mechanisms that promote the development of renewable energy and have been commonly employed across the globe, especially in Germany. There are two different kinds of FIT policy, fixed FIT and premium FIT, which are often included in long-term contracts that ensure profitability for renewable energy producers. Fixed FITs allow producers to sell electricity that is generated from renewable energy sources at a **fixed price** above the market price for a certain period of time. On the other hand, premium FIT policies allow producers to sell renewably generated electricity at a **percent premium** above the market price, often allowing producers to capture additional value as compared to fixed FIT situations (Lin et al., 2014). Although, both FIT and RPS have their pros and cons, one can be assured that renewable energy sources have difficulty competing with conventionally generated power without support schemes such as these.

Recently, many policy leaders in Taiwan have been supporting the introduction of a Feed-In Tariff to the economy, which has led to some progress in the legislative branch of government. In Taiwan, The BOE submitted a draft of the Renewable Energy Development Act (REDA)[17] to the Legislative Yuan[18] in 2002. After seven grueling years of debate, the REDA was passed in June 2009 and went into effect the following month. The act contains 23 articles and the main objective is to diversify the energy mix by promoting renewable energy and offering a legal framework for fixed FIT (BOE, 2009). The REDA has selected fixed FIT as the main mechanism to actively encourage renewables development over RPS for the following three reasons (Huang and Wu, 2011):[19]

(1) Renewable energy has huge potential in Taiwan, but in order to stimulate investment in renewable energy facilities, a well-balanced support scheme must be introduced to place renewables on equal competitive footing with other types of energy like gas and coal, which frequently win on cost

(2) FIT is suitable for Taiwan's highly regulated electricity market because TPC owns the entire grid system in Taiwan and is familiar with this type of the scheme.

(3) FIT schemes align with Taiwan's legal environment, because RPS schemes require competition between energy utilities, and TPC's role as a monopoly makes such a scheme currently impossible (or at least extremely difficult to implement).

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[17] The REDA defines renewable energy as solar energy, biomass energy, geothermal energy, ocean energy, wind power, non-pumped-storage hydropower, waste conversion and other sustainable and renewable energy approved by central government.

[18] The Legislative Yuan is the legislative parliament in Taiwan.

[19] The REDA is also the legal framework for the establishment of the Renewable Energy Development Fund. This fund is meant to subsidize utilities when they produce or purchase renewable electricity. Funding sources come from the state-owned TPC and are allocated according to self-usage power generation equipment that reaches a specified level of capacity.

The Taiwanese government has provided a legal framework and FIT model for renewable energy sources, and there is also a business service model that they are encouraging to promote solar PV energy. The Taiwanese government has incentivized the formation of solar PV "Energy Service companies," (PV-ESCOs) that operate by installing solar panels on the rooftops of private sector buildings and sharing electricity profits (or even paying rent) for the property owners. The government encourages this business service model to reduce the costs of renewable energy installation, operation and maintenance for their customers, who are very often end-users of electricity. As rooftops in the private sector are one of the targeted locations for policymakers to boost solar generation, 60-80% of total solar PV installation has occurred through ESCO's business model (BOE, 2016a). Figure 16 below illustrates how PV-ESCOs function and their relationship between rooftop owners, banks and utilities.

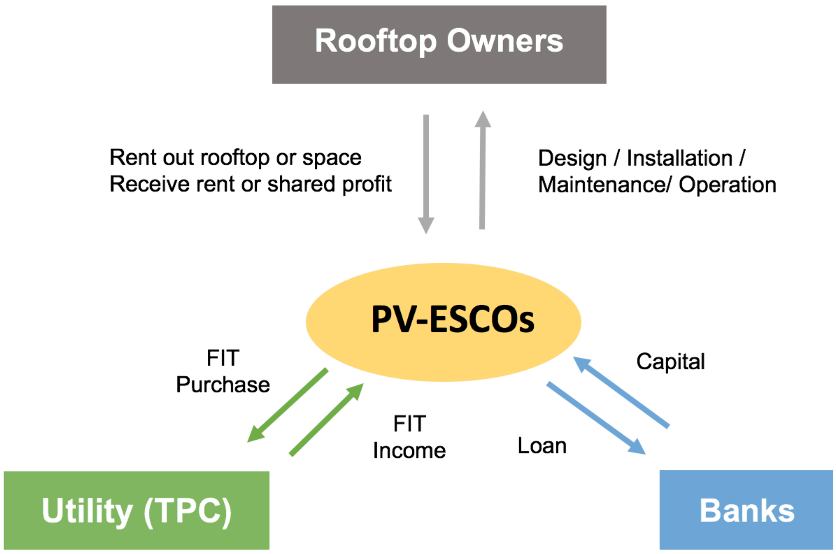

Figure 16 PV-ESCOs

6. Cost-Benefit Analysis of “Nuclear-Free by 2025” Policy

6.1 Cost-Benefit Analysis Assumptions and Definitions

The cost-benefit analysis shown in this section will focus exclusively on solar power, wind power, and hydropower. Although other forms of renewable energy like biomass and geothermal have potential and are certainly relevant, wind, solar, and hydropower are widely expected to account for well over 90% of all renewable energy generation in the year 2025, as discussed in Chapter 5 of this thesis.

The goal of our research is to determine whether or not the Taiwanese government’s 2025 renewable energy goals are economically viable. For our purposes, we define economic viability as the existence of sufficient financial returns to incentivize rational firms or individuals to participate and/or invest in this segment of the renewable energy sector. What is very important to highlight here is that the following CBA takes the perspective of firms and individuals in the private sector, which means that costs and benefits from the government’s point of view are not taken into account. Please see table 1 below for a depiction of the cost and benefits pertaining to firm-level perspectives across each of these renewable energy segments in the private sector. The detailed calculation is shown in Appendix.

Cost	Benefit
Total capital costs + Total operation & maintenance costs (O&M costs) * 20 years of lifecycle	Renewable Energy Generated * FIT price * 20 years of lifecycle

Table 1 Costs and Benefits Calculations

Since the Taiwanese government’s renewable energy programs revolve heavily around subsidies and private sector participation, our research will focus on the economic returns (benefits) and costs that are incurred by private sector participants across these three segments of the renewable energy sector. To support this position and maintain the integrity of the analysis, two key assumptions have to be made:

1. The government will have sufficient funds to afford and complete all FIT payments to relevant private sector participants, for the length of the investment horizon.
2. Private sector firms and individuals will act rationally according to economic principles – that is, they will only consider those renewable energy investments that generate positive financial returns

6.2 Monetary Costs and Benefits

Presenting the economic outcome of the renewable energy options in monetary terms makes it easier to judge whether the current FIT scheme and its prices are able to attract enough private sector investors in order to reach the 20% renewable energy goal by 2025. As solar PV, wind turbines and SHP account for about 96% of the renewable energy goal of the "Nuclear-Free by 2025" policy (BOE, 2017b), this CBA will not include biomass, geothermal and fuel cell energy, in order to focus on the most critical areas.

6.2.1 Monetary Costs and Benefits Breakdown

The costs outlined in Tables 2, 4 and 6 include both non-recurring and recurring costs, installation capital costs and O&M costs. The benefits shown in Table 3, 5 and 7 are FIT prices.[20] The exchange rate used is 1 US Dollar (USD) to 30 New Taiwanese Dollars (NTD).

Solar

Given that Taiwan is prone to typhoons, which cause massive destruction, it is necessary that solar PV have the structural stability to withstand extreme winds, resulting in higher installation costs (MOEA, 2017b).

[20] These are the benefits received by private sector companies and citizens, paid for by the government, in return for their installation of solar PV technologies

Solar PV	Cost (USD/kw)
Roof-mounted: 150 W/ m^2	
Installation Capital Cost[a]	$2,367
O&M Cost[a]	2.55% of capital cost per year
Ground-mounted: 150 W/ m^2	
Installation Capital Cost[a]	$1,803
O&M Cost[a]	2.31% of capital cost pear year

[a] *MOEA, 2017b*

Table 2 Solar PV Costs

Solar PV	Benefit (USD/kwh)
Roof-mounted: 150 W/ m^2	
1 kwh - 20 kwh FIT[21] [b]	0.203
Ground-mounted: 150 W/ m^2	
Consistent across all output[b]	0.152

[b] *MOEA, 2017c*

Table 3 Solar PV Benefits

Wind

As mentioned earlier in the paper, costs and benefits vary greatly between offshore and onshore wind turbines, due to differences in average wind speeds, as well as the logistical challenges of installation in very different areas.

Wind Turbine	Cost (USD/Turbine)
Offshore - 5 MW Turbine	
Capital Cost[c]	
Turbine Capital Cost	$7,000,000
Other Facility Capital Cost	$4,112,000
Land Purchase	$90,000
BOS Cost	$5,137,444
O&M Cost	3.48% of facility capital cost in first year[d] 1-10 years: increase by 1% each year[e] 11-20 years: increase by 2% each year[e]

[21] For purposes of this CBA, we will assume a low-end output of 1-20kwh for roof-mounted solar PV, due to the fact that the vast majority of citizens living in Taiwan have very small roofs, due to the nation's high population density.

Onshore - 2 MW Turbine	
Capital Cost[f]	
Turbine Capital Cost	$3,966,667
Other Facility Capital Cost	$3,216,667
Land Purchase	$4,200
BOS Cost	$200,667
O&M Cost[e]	2.72% of facility capital cost in first year 1-10 years: increase by 1% each year 11-20 years: increase by 2% each year

[c] *BOE, 2016b*
[d] *MOEA, 2017b*
[e] *Wen et al., 2014*
[f] *Yang, Kan and Su, 2018*

Table 4 Wind Turbine Costs

Wind Turbine	Benefit (USD/kwh)
Offshore - 5 MW Turbine	
20 years fixed FIT[g]	$0.20
Onshore - 2 MW Turbine	
1 kwh - 20 kwh[g]	$0.30

[g] *MOEA, 2017c*

Table 5 Wind Turbine Benefits

Small Hydropower

Hydropower facilities mainly adopt automatic controls; therefore, the differences in O&M costs are small. However, the smaller the installation capacity is, the higher the O&M cost is relative to the facility's output.

SHP	Cost (USD/kw)
Installation Capital Cost[h]	$3,248.43
O&M Cost[h]	5% of the installation capital cost

[h] *Taiwan Joint Irrigation Association*

Table 6 Costs of 6MW Small Hydropower

SHP	Benefit (USD/kwh)
FIT[i]	$0.098

[i] MOEA, 2017c

Table 7 Benefits of 6MW Small Hydropower

6.2.2 Decision Criteria

As discussed earlier, decision criteria are variables that are used to determine the feasibility of projects throughout the decision-making process. In the CBA setting, there are four decision criteria that we will be using, namely: Net Present Value (NPV), Benefit-Cost Ratio (BCR), Internal Rate of Return (IRR), and Payback Period. This analysis is assessed from an investor's perspective to provide a strong decision rationale. The CBA analysis uses 20 years as an investment lifecycle.

Decision Criteria (1) - Net Present Value (NPV)

As mentioned earlier, a project is generally worth pursuing as long as its NPV is greater than 0. The equation (3) introduced in Chapter 3 is used to calculate NPV and Table 8 below illustrates what NPV results represent in different situations.

When	Economic Viability	Action
NPV > 0	Viable	Project may be accepted
NPV < 0	Not Viable	Project may be rejected
NPV = 0	No gain or loss	Decision makers should consider other criteria, such as intangible benefits

Table 8 Decision Criteria (1) – NPV

Decision Criteria (2) – Benefit-Cost Ratio (BCR)

When the BCR is greater than 1, it means that the project is most likely acceptable. The equation (4) introduced in Chapter 3 is used to calculate BCR and Table 9 below illustrates what BCR results represent in different situations.

When	Economic Viability	Action
BCR > 1	Viable	Project may be accepted
BCR < 1	Not Viable	Project may be rejected
BCR = 1	No gain or loss	Decision makers should consider other criteria, such as intangible benefits

Table 9 Decision Criteria (2) – BCR

Decision Criteria (3) – Internal Rate of Return (IRR)

Based on the equation (5) in Chapter 3, Table 10 below shows the interpretation of IRR results in different scenarios. One must note that R in the table refers to the interest rate.

When	Economic Viability	Action
IRR > R	Viable	Project may be accepted
IRR < R	Not Viable	Project may be rejected
IRR = R	No gain or loss	Decision makers should consider other criteria, such as intangible benefits

Table 10 Decision Criteria (3) - IRR

Decision Criteria (4) – Payback Period

The final decision criteria, payback period, evaluates a project based on the amount of time it will take for the PV of benefits to offset or "pay back" the PV of the costs. A general overview of how projects are evaluated with the payback period criterion is provided below.

(1) For a project to be at least considered, it would need to have a maximum payback period within the lifecycle of the project.

(2) If there are two or more competing projects with payback periods within the acceptable range, the decision maker should select the project with the shorter payback period.

6.2.3 Result of Cost-Benefit Analyses

The overall viability of each option adopts the four decision criteria, as earlier discussed, in the interpretation of the CBA results. Table 11 reveals that the FIT prices of both solar PV and wind turbines will be economically attractive for investors. However, given the nature of the solar PV business, household rooftop owners may not be able to bear the long-term payback period of 12.34 years. Furthermore, the CBA outcome indicates that SHP is not economically viable, with a negative NPV, 0% IRR, low BCR and no achievable payback period. The consequences of this analysis will be covered in more detail in the following chapter: "Recommendations and Conclusions."

DESCRIPTION	Solar PV	Wind Turbine	SHP
Total Cost (USD)	$22,156,636,651	$55,646,746,667	$389,812,000
Total Benefit (USD)	$77,075,583,267	$53,023,329,575	$306,507,382
Present Value of Total Cost (USD)	$53,314,163,419	$21,072,160,770	$364,299,518
Present Value of Total Benefit (USD)	$67,168,987,199	$33,607,743,050	$266,386,688
NPV (USD/life cycle)	$13,854,823,780	$41,008,755,613	$(97,912,830)
IRR (%)	4.85	8.94	0.00
BCR	1.26	1.59	0.73
Payback Period (yrs)	12.34	9.07	> Lifecycle
Discount Rate (%)	1.38	1.38	1.38
Life Cycle (yrs)	20	20	20
Viability	**Viable**	**Viable**	**Not viable**

Table 11 Feasibility of the Renewable Energy Goal

6.3 Non-Monetary Costs and Benefits

6.3.1 Non-Monetary Costs

Negative Environmental Impact

Some offshore wind turbine projects have been controversial as they may have negative consequences for the environment. For example, the Zhong Neng Offshore Wind Turbine Development Project aims to build turbines in an area that is only about one kilometer away from a significant habitat for the Taiwanese humpback dolphin (also called White Dolphin, or sousa *chinensis taiwanensis*). According to the IUCN Red List (n.d.), this marine mammal is a critically endangered species, with an estimated population of less than 100. As these dolphins rely heavily on sonar to navigate the oceans, they are very sensitive to the underwater noise from offshore wind turbines, which may cause temporary and permanent hearing loss and other behavioural problems (Wang et al., 2012).

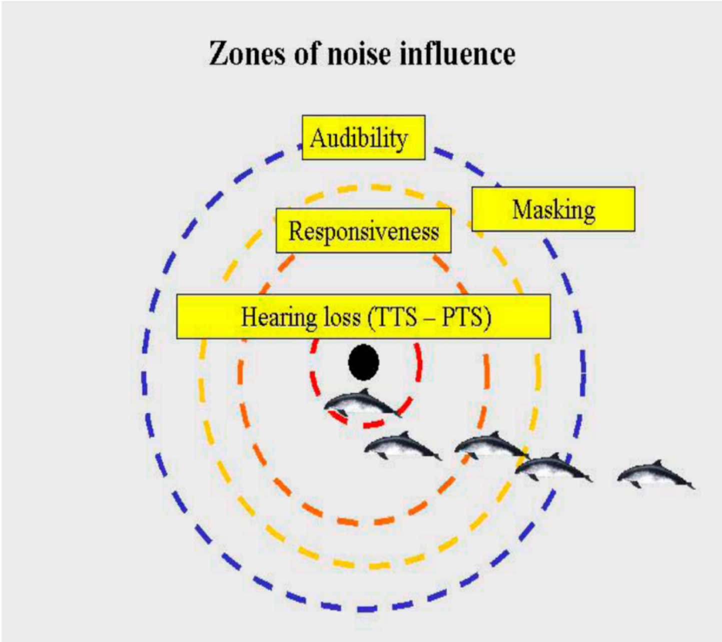

Figure 17 Underwater Noise and Its Impact on Dolphins

Source: Wang et al., 2012

Another issue that wind farm projects have encountered is algal reefs. Dead calcareous algae produce crystalline calcium carbonates that form algal reefs, which usually expand at an extremely slow rate of 0.1 – 0.2 centimeters in thickness per year and are the home of many important fish, shrimp and shell species in the marine ecosystem (Taiwan Today, 2008). The construction of wind turbines will cause silt and sand, which would in turn cover and kill the algal reefs. This would put the health of the marine life in the region in jeopardy, as many food sources would lose their habitat and potentially leave the region or die out entirely.

For private sector organizations, these non-monetary considerations are critical because they affect arguably their most important stakeholder – the general public. Without careful consideration, mistakes in these areas could lead to a significant loss of profitability, as well as issues with recruiting future talent.

6.3.2 Non-Monetary Benefits

Positive Public Health

In 2016, the fossil fuel power plants accounted for approximately 81.99% of electricity generation in Taiwan (BOE, 2017a). This facet of the electricity sector is a huge source of air pollutants, such as sulphur dioxide (SO_2), which for the most part are not produced by clean energy technology. Having 20% renewable energy will certainly help the air quality, which could help generate positive publicity for companies that are being part of the solution.

The main benefit of the improvement of air quality lies in its contribution to human health, as air pollution results in cardio and respiratory diseases, and even cuts life expectancy. However, healthcare costs and their relationship to improved quality of life are often very difficult to measure and not directly reflected in market prices. As a result, these benefits are often not taken into account when conducting quantitatively focused electricity planning.

Reduction of CO_2 Emissions

Combustion of fossil fuels, like coal and natural gas, is the main source of CO_2 emissions for the Taiwanese economy. Electricity produced from natural gas releases from 0.27 to 0.91kg of carbon dioxide equivalent per kilowatt-hour (CO2E/kWh) and coal-produced electricity is responsible for releasing 0.64 to 1.63kg of CO2E/kWh (Union of Concerned Scientists, 2017). In Taiwan, about 60% of CO_2 emission (15,365,000 tonnes) in 2016 came from the electricity sector (BOE, 2017c).

Unlike conventional power plants, most renewable energy sources emit negligible amounts of CO_2. Wind emits only 0.0091 to 0.018kg of CO_2E/kWh on one lifecycle, solar releases 0.032 to 0.091 kg of CO_2E/kWh and hydroelectric releases between 0.045 and 0.23 kg of CO_2E/kWh (Union of Concerned Scientists, 2017). Clearly, these numbers show just how drastically Taiwan could reduce its CO_2 emissions by replacing some of its conventional power plants with renewable energy production.

7. Recommendations and Conclusion

This research thesis set out to understand and analyze the feasibility of Taiwan's renewable energy policy by taking a holistic view of Taiwan's geopolitical landscape and conducting a CBA of the projects necessary for achieving this nation's electricity goals. In economics, we tend to assume that people in a market economy act rationally of their own free will in order to better themselves in the world and achieve maximum utility for themselves. Whether you look at a government body or the private sector, people tend to gravitate towards investments that make sense financially, and this has been the rationale behind the methodology and evaluation of this electricity proposal. At the core of our discussion has been a single research question that we have been looking to answer:

Taiwan's stated goal is to be using 20% renewable energy, while also being nuclear-free, in the year 2025. Is this electricity goal economically viable for the private sector?

When revisiting this question after a lengthy and comprehensive analysis, the short answer that comes to mind is "Yes, and No."

Let us begin with the positives. As was discovered during our CBA in the previous section, we see that both wind and solar-powered renewable energy are financially feasible with positive NPVs and promising results for the other decision criteria, though small hydropower is not yet profitable at its current level of maturation. Taken altogether, this is promising news for Taiwan, as wind and solar are to make up the vast majority of its renewable energy output in the years going forward. With that being said, it is entirely possible that Taiwan can achieve its electricity goals by staying its current course and maintaining the status quo. However, there are several specific actions that can be taken to upgrade this mission from "probable" to "possible", and these will be outlined shortly after looking at some of the less optimistic details that necessitate them.

Taiwan's renewable energy plans for solar and hydropower energy going forward leave much to be desired. In terms of rooftop solar energy, the current state of this area is only economically viable if private citizens are willing to accept a payback period of around 12 years for their investment. While this is certainly possible for people who can wait a long time to see their capital returned and for people who simply place a high value on being sustainable in their own lives, this is a concerning fact. On the hydropower side of things, the situation is even bleaker. Large-scale hydropower operations, as discussed earlier, have largely reached maximum capacity, and small-scale hydropower operations have been proven through our CBA to be significantly unprofitable. Fortunately, both the private sector and government can play a role in resolving these issues.

One potential solution for the long payback periods in rooftop solar is rooted in the PV-ESCOs discussed in Chapter 5. To briefly recap, these companies' business model consists of paying individual Taiwanese citizens for the rights to build solar panels on their roofs and receive FIT revenue from the government for the power that is generated. By being able to do this on a larger scale, these companies can leverage their buying power with suppliers of solar panels to reduce purchase and installations costs, and thus lower the payback period to more reasonable levels. One thing that is key for these companies is their ability to secure enough financing from banks to make these purchases on a large scale. As a result, it is important that the federal Taiwanese government creates a positive banking landscape that helps enable these companies to keep securing the financing they need to make rooftop solar panels that are economically viable for them, when they might not be economically viable for individual people.

While there does not seem to be a quick fix for the profitability issues associated with SHP, there are some promising uses for this segment of renewable energy that could still save Taiwan a great deal of money in the long run. SHP has been used effectively by the government as a "last resort" of sorts for generating power when the supply is running low, and it seems likely that using SHP in this capacity going forward is the right decision. Of course, as technology advances there is a possibility that SHP will become profitable and thus be undertaken by more and more private sector and government entities, but until that happens it makes sense to utilize this form of electricity as an additional buffer against the costly power outages. As mentioned earlier in the paper, weather-dependent renewable energy and a declining reserve margin open up Taiwan to increased risk of power outages, so finding additional (and renewable) ways to prevent this from happening is economically in the country's best interest. Consequently, it likely makes sense for the Taiwanese government to continue to invest in SHP operations and infrastructure in order to insure against shortcomings that arise in the domestic electricity supply.

In conclusion, the analysis has shown that Taiwan's electricity policy for 2025 is indeed economically viable, but it is not as economically promising as it could be with a few small tweaks by the government. By creating a promising business landscape for PV-ESCO's to operate in the Solar PV space, in addition to investing further in SHP operations, Taiwan will put itself in the best possible position to achieve its goals and move rapidly towards a greener future for its people and the people in the region.

8. Limitations and Further Research

Like any research paper, this thesis encounters some limitations in the CBA results that have been presented. In addition, through the process of attempting to pose and answer the research question shown in the introduction, one new question arises that needs to be explored through further research on this topic.

For the limitation aspect of things, firstly, the paper only considers current technology and its cost when conducting the CBA. However, renewable energy technology is continuously evolving and all projects differ in scope and size. In the future, Taiwan may have access to more advanced and cost-effective techniques, which could improve efficiency, installation, reduce costs or speed up the time it takes to reach the electricity goal in some other way.

Secondly, although the CBA assumes an investment lifecycle is 20 years, many renewable energy technologies are still relatively young and newly installed when compared to conventional power plants. Therefore, it is difficult to predict the real investment lifecycle, as it could turn out to be much different than what is currently predicted. The facilities may still be running smoothly after the 20-year time horizon or they could be facing retirement earlier than expected. Lastly, although offshore wind turbines have 20 years of fixed FIT price, other companies or governments may achieve a decrease in future prices, which could lead to a very different result in the pursuit of this goal.

Most importantly, the 2025 Nuclear-Free policy is meant to reform the total electricity mix, and its success will have a critical impact on the stability of the electricity supply and the overall economy in Taiwan. However, it is important to note that this research paper focuses exclusively on renewable energy. To add to the discussion and continue to illuminate the path forward for the Taiwanese government, more research should be done in the form of complex analyses and models that dive into the monetary and non-monetary feasibility of this policy as it pertains to the remaining 80% of electricity that will come from fossil fuels.

Appendix

Power to Energy Conversions

$$P(kW) = \frac{E(kWh)}{t(hr)}$$

$\mathrm{E(kWH)} = P(kW) \times t(hr)$

Power (P), Energy (E), Time (t)

Standard Metric conversions

1MW=1,000 KW

1W=0.001KW

1 year (yr) = 8,760 hours (hrs/yr)

Renewable Energy Generated with Offshore Wind Power with 5MW Turbine at 36.52% Capacity (Zhou and Sun, 2013)

5 (MW) * 1,000 (KW/MW) * 8,760 (hrs/yr) * 36.52% = 15,995,760 KWh/yr

Renewable Energy Generated with Onshore Wind Power with 2MW Turbine at 22.83% Capacity (Zhou and Sun, 2013)

2 (MW) * 1,000 (KW/MW) * 8,760 (hrs/yr) * 22.83% = 3,999,816 KWh/yr

Renewable Energy Generated with Solar Power with 150W Panel at 14.26% Capacity (Zhou and Sun, 2013)

150 (W) * 0.001 (KW/W) * 8,760 (hrs/yr)* 14.26% = 187.3764 KWh/yr

Renewable Energy Generated with Small Hydro Power with 6MW at 29.64% Capacity Factor (Zhou and Sun, 2013)

6 (MW) * 1,000 (KW/MW) * 8,760 (hrs/yr) * 29.64% = 15,578,784 KWh/yr

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