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Effects of Taiwan's Promotion of Solar PV on its Economy and for Net-zero Emissions

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Abstract

Achieving net-zero emissions by 2050 is a crucial issue for the global community, and countries worldwide have pledged to support and join this initiative. They have set out ambitious carbon reduction goals to combat global warming. Taiwan should actively participate in reducing carbon emissions and should discuss possible paths and actions required to achieve the 2050 net-zero emissions goal. Solar PV are a crucial technology because replacing fossil fuel energy generation with Solar PV can reduce carbon emissions. Promoting Solar PV can result in reduced carbon emissions, stimulate the development of the Solar PV industry, and establish an industrial supply chain to increase the economic growth and green competitiveness of Taiwan. Therefore, investigating Solar PV and their expected growth can facilitate formulating strategies for Taiwan to achieve net-zero emissions by 2050.

JEL classification numbers: I18, Q43, Q54, Q58.
Keywords: Solar PV, Net-zero emissions, Energy policy.

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1. Introduction

1.1 Research Background

Climate change has substantially affected Earth's environment and ecology, caused the large-scale extinction of species, and caused food crises. Extreme climate events have triggered a green revolution in industrial supply chains. The green revolution has affected the competitiveness of individual industries and the development of countries. Moreover, it has been vital for economic growth. Therefore, the global community has focused on climate issues in recent years. In 2015, the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) adopted the Paris Agreement [1], which aimed to limit global warming to at most 2 °C compared with preindustrial levels with a target of 1.5 °C. In 2018, the Intergovernmental Panel on Climate Change (IPCC) Special Report [2] indicated that to limit global warming to 1.5 °C, the world must achieve net-zero emissions by 2050. In April 2021, President of the United States Joe Biden convened 40 world leaders and hosted the Leaders' Summit on Climate; all of the attending leaders supported climate policies and promised to greatly reduce carbon emissions. The UNFCCC COP26 was hosted in United Kingdom in 2021. Climate and carbon emission issues were discussed, and the Glasgow Climate Pact was formulated [3]. The conference reached a consensus on the rules, format, and procedures of the global carbon market schemes.

More than 100 countries, including European countries, the United States, China, Japan, and South Korea, have supported climate policies and have promised to greatly reduce their carbon emissions; pursuing net-zero emissions is a shared global goal. Governments and firms have set zero carbon emissions policies, and over 130 countries have pledged to achieve net-zero emissions by 2050. The European Union plans to implement a carbon border tax by 2023, and multiple transnational corporations, such as Apple and Microsoft, have announced that they would establish carbon neutral or carbon negative supply chains and products. Taiwan is export-oriented; hence, the carbon border tax would affect the export industries of Taiwan and possibly affect Taiwan's entire economy. International firms requiring reduced carbon emissions would also affect the competitiveness of Taiwan in the international supply chain. Therefore, to respond to stricter demands for green supply chains by international firms and to overcome possible trade obstacles such as the carbon border tax, Taiwan has begun evaluating possible methods for achieving the goal of net-zero emissions by 2050. These methods include proposing strategies and specific actions in the energy, industrial, residential, transportation, agricultural, and environmental sector.

The current annual greenhouse gas emissions of Taiwan are approximately 275.039 (MtCO2e) [4], comprising carbon dioxide (95.38%) and other gases (4.62%). Carbon dioxide emitted by burning fossil fuels accounts for 90.08% of the total carbon emissions. Therefore, using renewable energy to replace conventional energy generation technologies that produce high carbon emissions is crucial. To ensure an energy transition that achieves energy security, a green economy, social

equality, and environmental sustainability, five principles are identified. These five principles are active energy saving to reduce increases in electricity usage, diverse energy generation to ensure a stable supply of electricity, smart storage to improve the responsiveness and stability of the electrical grid, acceptable electricity prices, and using mature technologies with cost–benefit oriented and phased developments to stimulate industrial development. The energy transition is gradually changing the energy sources used in Taiwan, and Taiwan aims to achieve an energy supply with 20% renewable energy sources, 30% coal and other sources, and 50% gas sources by 2025. To achieve this goal, renewable Solar PV systems with an installed capacity of 20 GW and wind power generation systems with an installed capacity of 6.9 GW should be constructed. Solar PV systems include Solar PV roof systems with a capacity of 8 GW and Solar PV ground systems with a capacity of 12 GW, and the wind power generation systems include onshore wind turbines with a capacity of 1.2 GW and offshore wind turbines with a capacity of 5.7 GW. Renewable energy sources can lower carbon emissions and can support the development of local industrial supply chains and for economic growth.

1.2 Research Motivation and Objective

Net-zero emissions is a shared global goal. Although Taiwan is not a member of the United Nations, Taiwan should still fulfill its duty as a member of the global community by actively formulating mitigation and adaptation plans to respond to climate change and to demonstrate its determination to contribute to the world. The effects of promoting Solar PV in Taiwan on the net-zero emissions goal and on the economy is a topic worth investigating. This study compiled the most recent information regarding net-zero emissions published by governments and international companies worldwide and included related past studies to investigate hypothetical scenarios in which Taiwan achieves net-zero emissions by 2050. This study used the Long-range Energy Alternatives Planning system (LEAP) to perform empirical analysis and to understand the benefits of promoting Solar PV for reducing carbon emissions and on the economy. The results can serve as a reference for related sectors to formulate the strategies and paths required to achieve net-zero emissions by 2050, boost the development of the economy, and realize the goal of net-zero emissions.

2. Literature Discussion

2.1 International Trends and Developments of Net-Zero Emissions

In December 2015, 195 members of the United Nations, including Palestine and Vatican City, adopted the Paris Agreement at the UNFCCC COP to replace the Kyoto Protocol. In the Paris Agreement, countries pledged to limit global warming to 2 °C before the turn of the 21st century and endeavored to limit global warming to 1.5 °C. In 2018, the IPCC Special Report indicated that to limit global warming to 1.5 °C, the world must achieve net-zero emissions by 2050. In April 2021, the United States hosted the virtual Leaders' Summit on Climate, convening 40 leaders

of countries and international organizations. At the summit, the challenges of climate change faced by the global community and potential responses were discussed. Europe and the United States proposed the Carbon Border Adjustment Mechanism (CBAM). In 2019, the European Commission proposed the European Green Deal [5] and planned to impose a carbon tax for on products imported into the European Union or demand that non-European countries purchase a reduced quota for greenhouse gas emissions specified by the European Union. The European Green Deal can reduce the risk of carbon leakage and was projected to be implemented by no later than 2023. The climate policy proposed by the United States also included carbon adjustment fees or quotas. Bill Gates published How to Avoid a Climate Disaster in 2021 [6] and argued that nothing is more essential than the equal transition to net-zero emissions and responding to climate change. He promised that his climate investment fund would commit US $1.5 billion to the United States government to help respond to climate change.

Carbon emissions and energy usage are highly correlated. The International Energy Agency (IEA) published a report explaining how the world can achieve net-zero emissions by 2050 [7]. The IEA argued that the world should not make new investments in fossil fuels on its path toward net-zero emissions, and concrete actions included governments worldwide terminating the approval of new coal mines or oil fields by 2021, planning to close all current coal mines and oil fields, banning the installation of gas furnaces in new buildings by 2025, and banning the sale of petrol or diesel cars by 2035. Other concrete actions included increasing the installation of solar power plants and reducing the carbon emissions of the electricity sector worldwide to almost zero. The aforementioned methods and approaches can create more employment opportunities and economic growth. In addition, reductions in air pollution can reduce disease. To achieve net-zero emissions by 2050, various countries have proposed specific milestones and approaches and have passed laws to achieve such goals. Table 1 presents the goals and schedules for net-zero emissions as pledged by various countries; Table 2 presents carbon reduction goals and approaches as pledged by international firms.

Table 1: Net-zero emissions goals and schedules pledged by major countries

State	Main policy
United States	The United States pledged to become a net-zero emissions economy by 2050 and reduce greenhouse gas emissions by 50%–52% by 2030 compared with emissions levels in 2005.
European Union	The European Union pledged to reduce carbon emissions by 55% before 2030, achieve net-zero emissions by 2050, and implement a carbon border tax in 2023.
United Kingdom	The United Kingdom aims to achieve net-zero emissions by 2050 and to reduce carbon emissions by 78% before 2035 compared with emissions levels in 1990.
China	China is committed to reaching its maximum carbon emissions before 2030 and then rapidly reduce carbon emissions by 2045. China pledged to achieve net-zero emissions before 2060.
Japan	Japan aims to achieve net-zero emissions by 2050 and to reduce carbon emissions by 46% by 2030 compared with emissions levels in 2013.
Brazil	Brazil is committed to terminating illegal deforestation, reducing carbon emissions by 50% before 2030, and achieving net-zero emissions before 2050.
Canada	Canada promised to reduce carbon emissions by 30% by 2030 compared with emissions levels in 2005 and to increase its carbon reduction to 40%–45% to achieve net-zero emissions by 2050.
South Korea	South Korea aimed to achieve net-zero emissions by 2050 and to reduce carbon emissions by 40% by 2030 compared with emissions levels in 2017.
Australia	Australia pledged to achieve net-zero emissions by 2050. However, Australia will rely on consumers and firms to reduce carbon emissions instead of passing laws.
India	India aimed to achieve zero carbon emissions before 2070, but demanded that developed countries should contribute an additional US $1 trillion to assist India in reaching its goals.
Saudi Arabia	Saudi Arabia endeavored to achieve net-zero emissions by 2060 and to reduce carbon emissions by 0.28 billion metric tons of carbon annually.
Taiwan	Taiwan has formulated possible approaches to achieve net-zero emissions by 2050, such as promoting energy transitions in the production, transportation, residential, and agricultural sectors, and by proposing systematic carbon reduction strategies.

Sources: compiled by this study

Table 2: The net-zero emissions goals and approaches pledged by international firms

Firm	Main policy
Apple	In 2020, Apple promised to become carbon neutral before 2030 and to use recycled materials to design and manufacture products using clean energy sources.
Google	Google announced in 2021 that it would achieve zero carbon emissions by 2030. To accomplish this goal, Google planned to use geothermal power, solar power, and wind power to supply electricity for its servers and operations.
Microsoft	In 2020, Microsoft pledged to become carbon negative by 2030 and remove all of its emitted carbon by 2050.
McDonald	In January 2021, McDonald's announced that it would achieve net-zero emissions by 2050.
Walmart	Walmart pledged net-zero emissions by 2040 without the use of carbon offset measures. Walmart also pledged to use 100% renewable energy before 2035 and electric vehicles before 2040. They also intend to implement refrigerants with low global warming potential and electrical heating equipment to reduce carbon emissions.
Netflix	In 2021, Netflix proposed the goal Net Zero + Nature and planned to achieve and maintain net-zero emissions by 2022.
Coca-Cola	Coca-Cola aimed to reduce its greenhouse gas emissions by 30% compared with its emissions levels in 2019 and to achieve net-zero emissions by 2040.
TSMC	TSMC pledged to achieve net-zero emissions by 2050 and reported climate-related financial disclosures. TSMC took actions to realize its environmental sustainability goals.
UMC	UMC announced that it would enter the global renewable energy initiative RE100 and aimed to obtain 15%, 30%, and 100% of its energy from renewable sources by 2025, 2030, and 2050, respectively. UMC took concrete actions to support its low-carbon energy transition.
Starbucks	In 2020, the leaders of nine companies, including Starbucks and Nike, cooperated to establish the Transform to Net Zero initiative to reduce the carbon emissions of their supply chains with the goal of net-zero emissions by 2050.

Source: compiled by this study

KPMG [8] committed to investigating issues related to net-zero emissions and published the Net Zero Readiness Index 2021, evaluating the readiness of 32 countries worldwide to achieve net-zero emissions (Figure 1). The countries were ranked according to their preparedness and ability to achieve net-zero emissions before 2050; the two indices used to evaluate the countries were national

preparedness and sector readiness. The three indices of national preparedness were carbon reduction commitments, past carbon reduction performance, and the carbon reduction environment. Sector readiness was an evaluation of five high-carbon sectors, namely electricity and heat, transportation, buildings, industry and agriculture, and land use and forestry. The three indices of sector readiness were current industrial carbon reductions, governmental actions, and carbon reduction capability. The statuses of the 25 top-performing countries are listed in Table 3.
PWC [9] published the Net Zero Economy Index and reported that the coronavirus pandemic reduced global carbon emissions in 2020. The global decarbonization rate was 2.5% in 2020. However, the global decarbonization rate must reach 12.9% annually to halve global carbon emissions by 2030, limit global warming to within 1.5 °C, realize the goals in the Paris Agreement, and avoid the disasters caused by extreme climate events. In other words, the current decarbonization rate must be quintupled. Although the growth of the global economy slowed in 2020, none of the Group of Twenty (G20) countries were able to reach the decarbonization rate of 12.9%; only a few countries successfully achieved a double digit decarbonization rate. Although most G20 countries have established ambitious climate goals, these goals have not yet resulted in specific policies or actions, as demonstrated in Table 4.

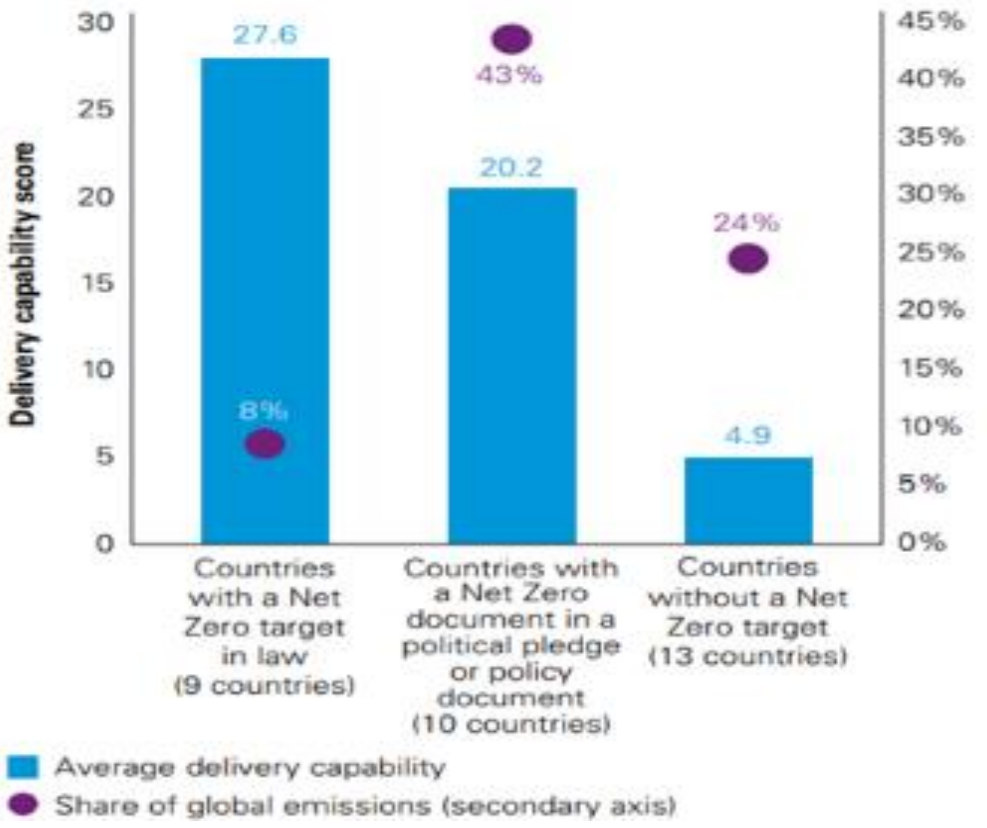

Figure 1: Average delivery capability by net zero commitment status

Table 3: Net zero readiness index

Country	Net Zero Readiness Index	National preparedness	Sector readiness
Norway	49.2	82.1	60.0
United Kingdom	48.4	86.3	56.1
Switzerland	44.7	83.8	53.4
Denmark	43.8	79.3	55.2
Germany	40.4	72.1	56.0
France	39.8	78.9	50.5
Japan	37.6	67.1	56.0
Canada	34.2	74.9	45.7
New Zealand	32.1	66.5	48.3
Italy	29.9	62.5	47.8
South Korea	29.1	57.3	50.7
Spain	28.0	61.2	45.8
Hungary	28.0	66.3	42.3
United States	27.9	61.5	45.3
Singapore	25.6	57.2	44.7
Chile	24.2	58.5	41.4
Australia	23.5	57.1	41.1
Brazil	22.5	58.2	38.8
Poland	20.0	46.5	43.1
China	19.4	46.7	41.5
Malaysia	16.5	45.1	36.5
Argentina	15.7	46.1	34.2
Mexico	14.6	42.9	34.1
Turkey	13.5	42.6	31.7
United Arab Emirates	12.8	43.1	29.7

Source: KPMG [8]

Table 4: Carbon reduction of G20 countries

Country	Change in carbon intensity 2019-2020	Annual average change in carbon intensity 2000-2020	Annual average change in carbon intensity 2016-2020 post Paris Agreement	Change in energy related emission 2019-2020	Real GDP growth (PPP) 2019-2020	Carbon intensity (tCO2/Sm GDP 2020)
World	−2.5%	−1.5%	−2.3%	−5.6%	−3.3%	262
G7	−5.7%	−2.4%	−3.3%	−10.5%	−5.1%	202
E7	−0.8%	−1.6%	−2.4%	−2.2%	−1.5%	337
China	−1.0%	−2.8%	−3.6%	1.3%	2.3%	434
US	−7.2%	−2.8%	−3.6%	−10.4%	−3.5%	236
EU	−6.3%	−2.5%	−4.2%	−12.1%	−6.2%	140
India	1.6%	−1.4%	−1.2%	−6.5%	−8.0%	274
Japan	−3.5%	−1.5%	−3.0%	−8.2%	−4.8%	221
Germany	−5.7%	−2.6%	−5.0%	−10.3%	−4.9%	147
Russia	−4.0%	−2.7%	−1.9%	−6.8%	−3.0%	389
Indonesia	−10.6%	−1.5%	−1.1%	−12.5%	−2.1%	171
Brazil	−1.9%	−0.5%	−1.9%	−5.9%	−4.1%	145
France	−6.1%	−2.7%	−3.7%	−13.7%	−8.1%	95
UK	−6.5%	−3.9%	−4.9%	−15.7%	−9.8%	112
Italy	−3.8%	−1.9%	−2.3%	−12.3%	−8.9%	125
Mexico	−12.4%	−1.4%	−5.5%	−19.6%	−8.2%	154
Turkey	−5.8%	−1.6%	−3.3%	−4.1%	1.8%	162
Korea	−6.0%	−1.7%	−3.0%	−6.9%	−1.0%	341
Canada	−4.4%	−2.2%	−2.0%	−9.5%	−5.4%	321
Saudi Arabia	2.9%	1.0%	−0.6%	−1.3%	−4.1%	432
Australia	−6.9%	−2.5%	−3.0%	−7.2%	−0.3%	279
Argentian	2.8%	−0.3%	−1.4%	−7.4%	−9.9%	178
South Africa	0.9%	−1.4%	−1.1%	−6.1%	−7.0%	574

Source: PWC (2021)

The UNFCCC COP26 (2021) Glasgow Climate Pact was the first international plan that specifically aimed to reduce coal usage and promised to provide funds to developing countries to help them respond to climate change. The COP26 included on five consensuses. The first consensus was that global warming must be limited to within 1.5 °C. Although most countries have proposed their own carbon reduction plans, these plans should be inspected annually and more actions are required to limit global warming. The second consensus was the gradual elimination of coal mining. However, for developing countries such as India and China, using subsidies to completely eliminate coal power generation is difficult; thus, the final consensus was a gradual reduction of the use of coal. The third consensus was assisting poorer countries in combating global warming. The Copenhagen Accord was adopted by

COP15 in 2009; developed countries promised to provide US $100 billion to developing countries annually to help them adapt to the effects of climate change and transition to clean energy sources. The accord was intended to be fulfilled by 2020 but has failed; hence, COP26 continued to urge developed countries to provide funds to developing countries by 2025 to help them cope with climate change. The fourth consensus was validating the carbon market and its regulations. Consensus was reached for the mechanism, format, and procedures of the global carbon market. Countries could trade carbon emission allowances in the global carbon market to create financial incentives for carbon reduction. The fifth consensus was promoting the reduction of methane emissions. The United States and the European Union spearheaded the global methane reduction initiative. Approximately 100 countries pledged to reduce their methane emissions by 30% by 2030 compared with emissions levels in 2020 to reduce the greenhouse effect.

2.2 Tasks Required to Achieve Net-zero Emissions for Taiwan

Taiwan passed the Greenhouse Gas Reduction and Management Act in 2015 [10], and proposed national greenhouse gas emissions phased reduction goals using 2005 as the base year; emissions in 2050 are targeted as 50% lower than the emissions in 2005. The goal of the first phase (2016–2020) is to reduce emissions in 2020 by 2% compared with the base year, that of the second phase (2021–2025) is to reduce emissions in 2025 by 10% compared with the base year, and that of the third phase (2026–2030) was to reduce emissions in 2030 by 20% compared to the base year; the plan was a rolling plan. Taiwan began planning possible approaches for achieving net-zero emissions by 2050, such as systematic carbon reduction strategies and promoting energy transitions in the industrial, transportation, residential, and agricultural sectors. In addition, Taiwan proposed amending the Greenhouse Gas Reduction and Management Act and changing it to the Climate Change Response Act with the goal of net-zero emissions by 2050. Taiwan aimed to respond to climate change and achieve carbon reduction by using stronger regulations. According to the IEA World Energy Outlook 2020 [11], current technologies cannot achieve net-zero emissions by 2050, and more research, development, and investment in innovative technology is necessary. Taiwan has investigated the technologies required to achieve net-zero emissions by 2050 and established a long-term energy vision. Taiwan has aimed to introduce new low-carbon technology to achieve the goal of zero carbon emissions. Taiwan can promote solar and wind power to achieve its carbon reduction goals and can integrate the advantages of its manufacturing industry to commercialize technological innovations and industries. Taiwan can then enter the global carbon reduction market, increasing its economic growth. The European Union planned to implement CBAM by 2023, yet Taiwan has not implemented any carbon pricing system. If Taiwan does not accelerate the implementation of carbon pricing measures, its trade competitiveness will be affected. Green energy industries, such as photovoltaics, provide Taiwan the opportunity to create substantial green energy

investments before 2050.

In 2021, Taiwan began to discuss amending the Greenhouse Gas Reduction and Management Act and changing it to the Climate Change Response Act. Some proposed changes include mandating net-zero emissions by 2050, increasing the level of climate risk management, adding an additional section for climate change adaptation, strengthening emissions regulations and incentive mechanisms to reduce emissions, and collecting specific carbon funds for special purposes. In terms of the industrial sector, the Taiwan Institute for Sustainable Energy was launched and the Taiwan Alliance for Net Zero Emission was established with almost 20 firms. The Taiwan Alliance for Net Zero Emission is a communication platform for the public sector, private sector, and nongovernmental organizations. The firms also promoted the net-zero emissions initiative to respond to the international 2030/50 carbon reduction and net-zero emissions goals proposed by the United Nations. The Industrial Technology Research Institute [12] has proposed that Taiwan can achieve its net-zero emissions goals by 2050 through five approaches. First, in terms of supply, Taiwan should pursue a zero carbon emissions energy supply and should establish next generation renewable energy sources such as hydrogen fuel or geothermal energy. To stimulate the development of new electrical service industries, Taiwan should accelerate its energy transition, develop new low-carbon energy technologies, use virtual power plants for electricity dispatch, and establish the electricity loading order. Second, in terms of demand, consumption behaviors must be changed. Taiwan should use transportation electrification to improve its energy usage efficiency and should create shared low-carbon innovative business models or new economic models. Third, low-carbon manufacturing is also crucial aspect, particularly for high-carbon-emissions industries such as the steel, petrochemical, and cement industries. Fourth, for the environment, Taiwan should actively develop carbon capture and carbon cycle technologies and should research negative carbon emissions technologies for directly capturing and reusing carbon. These new technologies can create diverse high-value products, use biological carbon fixation, or create green fuels to reestablish healthy carbon cycles. Fifth, in terms of economic trade and regulations, countries worldwide are formulating carbon border taxes. Taiwan should use international trade measures to respond to climate change and to assess the effects of carbon reduction trade measures. Taiwan should also amend its laws and participate in international economic and trade negotiations.

2.3 The Energy Policy of Taiwan and the Promotion of Solar PV

Approximately 98% of Taiwan’s energy is imported; hence, increasing energy independence is crucial. To achieve its nuclear-free goal and fulfill carbon reduction commitments, Taiwan is actively promoting the integration of energy generation, energy saving, and energy storage systems to boost the development of the green energy industry. Taiwan began its energy transition in 2016 with the goal of transitioning while ensuring energy security, green economy, social equality, and

environmental sustainability. Taiwan is actively reducing increases of electricity usage, using diverse energy generation methods to ensure a stable supply of electricity, and implementing smart storage to increase the power dispatch and stability of the electrical grid. The energy sources of Taiwan are thus gradually changing, and an energy supply with 20% renewable energy sources, 30% coal and other sources, and 50% gas sources is the goal for 2025. Five principles were listed for the energy transition, namely feasible and mature technology, cost–benefit orientation, phased and equal developments, stimulation of industrial development, and acceptable electricity prices. The current main renewable energy sources are solar energy, wind energy, hydropower, and biomass energy (Table 5) [13]. The efficiency of solar energy has increased, and solar is gradually becoming one of the main sources of renewable energy. Taiwan has used incentives and regulations to promote solar projects such as solar fisheries, ground Solar PV, and roof Solar PV. The installed Solar PV capacity can be increased by implementing Solar PV industrial parks and by expanding and promoting the use of Solar PV on rooftops and in agriculture, fisheries, and animal husbandry.

The public is concerned about problems related to the promotion of Solar PV, such as the environmental and ecological effects of the installation of Solar PV, real estate agents raising land prices and affecting the right of the public to purchase land, and the loss of agricultural land due to the installation of Solar PV. Solar PV Energy Service Company is a new business model used in Taiwan to promote Solar PV. Installers do not have to pay for the installation costs. Instead, they only have rent their roof or site and permit photovoltaic technology services to install, finance, operate, and maintain photovoltaic equipment. The installers may receive rent according to their contracts and the profits from the electricity sold.

The development of the Solar PV industry relies on the supportive national policies. Therefore, reasonable electricity price changes are a cornerstone for the sustainable development of the industry. Only the implementation of national policy goals, national land use planning, and friendly environmental regulations can attract investment and funds from the private sectors to boost the development of the industry. The main obstacle currently faced by the government in its promotion of solar power plants is a lack of land. Solar power plants are only allowed to be installed in lands unsuitable for agricultural use, lands with land subsidence, and polluted lands. These regulations have limited the installation of solar power plants. Solar PV systems do not emit greenhouse gases or noise and can provide clean, renewable energy for up to 20 years. Solar PV energy is currently the main source of renewable energy. In this study, solar power plants were expected to update their solar modules to more efficient and high-performance modules after 20 years.

Table 5: The current renewable energy development of Taiwan

Energy source	Installed capacity of renewable energy (MW)			Generation of renewable energy (100 million kWh)		
	2019	2020	2025	2019	2020	2025
Solar PV energy	4,150	6,500	20,000	40	81	256
Onshore wind energy	717	814	1,200	17	19	28
Offshore wind energy	128	520	5,667	2	19	204
Geothermal energy	0.3	150	200	0	10	13
Biomass energy	709	768	813	38	38	43
Hydro energy	2,093	2,100	2,150	55	64	66
Fuel cell	0.3	22.5	60	0	2	5
Total	7,796	10,875	30,090	152	233	615

Source: Bureau of Energy, Ministry of Economic Affairs

3. Empirical Analysis

This study investigated the effects of Taiwan's renewable energy policies and promotion of photovoltaics on carbon reductions and on the economy. Factors such as gross domestic product (GDP) growth, changes in electricity usage, installed photovoltaic capacity, technological growth, and supply and demand for electricity were considered. LEAP was used to perform the empirical analysis to understand whether photovoltaics substantially contributed to carbon reduction.

3.1 LEAP

In general, the global community believes that promoting renewable energy and to replace fossil fuels can facilitate carbon reductions. Taiwan has clearly formulated policies to promote photovoltaics. Therefore, understanding the benefit of Taiwan's promotion of photovoltaics is crucial. This study used LEAP to perform empirical analysis. LEAP is an energy and environmental accounting tool that uses scenario analysis and was codeveloped by Stockholm Environment Institute in Sweden and Boston University in the United States. LEAP has been used by more than 200 organizations and scholars across 60 countries. It includes demand analysis, statistical differences, transformation analysis, stock change, resource analysis, and non-energy sector effects analysis. The energy demand analysis in LEAP includes energy supply, energy transition, and terminal energy demand. LEAP is mainly used for mid- and long-term energy planning for countries and cities. It can predict the mid- and long-term energy supply and demand under the effects of different factors. In addition, it can calculate air pollutants and greenhouse gas emissions during the transmission and consumption of energy.

3.2 Benefits of Taiwan's Promotion of Solar PV on the Economy and Carbon Reduction

Taiwan began the development of its Solar PV industry since 1999. After Germany passed the feed-in tariff system in 2004, the Solar PV industry of Taiwan began to grow rapidly. Since 2005, the industry has boomed in the European market, mainly due to purchases by Germany. In 2009, the financial crisis slowed the growth of the industry for the first time, and the industry peaked in 2010 due to European policy changes and the end of rapid installation of Solar PV. The industry hit its lowest point from 2011 to 2012 due to the European debt crisis; European manufacturers went bankrupt or they moved their production overseas; thus, Asian manufacturers, such as in China and Taiwan, became production centers for Solar PV. At the end of 2016, the Solar PV industry chain again moved production lines overseas to diversify the export market. Solar PV systems on the market were divided into centralized systems and distributed systems in 2017. The demassification of Solar PV systems also improved. In 2018, midstream and upstream manufacturers gradually developed downstream solar modules and systems because Solar PV systems created higher profit opportunities and these systems could stimulate the demand for other products. In 2019, silicon wafer manufacturers exited the market and major firms changed their operations to enter the domestic market. The Solar PV industry chain of Taiwan was briefly affected by the COVID-19 pandemic in 2020. However, after the restoration of the supply chain and due to the support of government policies, some companies have again begun to generate profit and have continued to expand their capital expenditures on large silicon wafer products. The Solar PV industry has had a substantial impact on the economy of Taiwan, and its projected output is presented in Table 6 [14].

To investigate the benefits of Taiwan's promotion of Solar PV for carbon reductions, this study designed the following scenario: If Taiwan is to achieve the goal of net-zero emissions by 2050, Taiwan must implement an energy transition project. Its renewable energy supply must reach 20% by 2025, and its carbon emissions in 2030 must be 30% less than in 2005. Solar PV in Taiwan had an installed capacity of 4.15 GW in 2019 and 5.82 GW in 2020; capacity is planned to reach 20 GW in 2025. After other installation locations are made available, Taiwan could achieve an installed capacity of 25 GW by 2030. The entire photovoltaic industry chain in Taiwan will continue research and development. Although the current efficiency of solar modules is only 20%, this efficiency is expected to reach 30% by 2040 as technology improves. Moreover, Solar PV firms will have higher demands in 2040 and thus will have updated their modules with newer and more efficient modules. Therefore, as the efficiency increases, the installed capacity within the same area could reach 30 GW by 2040 and 35 GW by 2050. Photovoltaics are promoted and are used to replace current coal and gas power plants. The built-in parameters of LEAP and other parameters were set to calculate the electricity carbon emission factor of Solar PV in the basic scenario and in the carbon reduction scenario. Next, the electricity carbon emission factor was used to calculate the carbon reduction performance.

Table 6: The expected output value of the photovoltaic industry of Taiwan

Year	2019	2020	2021	2022	2023	2024	2025
Output value (US$ 100 million)	21.6	20.2	24.2	23.8	24.5	23.2	31.6

Source: Industry, Science and Technology International Strategy Center, Industrial Technology Research Institute

3.3 Establishment of the Basic Scenario

3.3.1 GDP growth

According to the National Development Council [15], economic growth from 2020 to 2030 is expected to be 2.7%–3.0%, and the percentage of older adults in Taiwan in 2030 is expected to reach 25%, limiting the growth of the labor supply. In this study, average GDP growth from now until 2050 was assumed to be 2.4%.

3.3.2 Growth in electricity use

According to the 2019–2020 National Electrical Energy Supply and Demand Report (NEESDR) [16] published by the Bureau of Energy, Ministry of Economic Affairs, electricity usage in 2020 was 271.1 billion kWh; usage increased by 2.1% compared with 2019. The Bureau of Energy estimated that, on average, electricity usage would increase by 2.5% annually. To achieve net-zero emissions by 2050, electricity usage cannot keep increasing without bound. In this study, the average annual growth of electricity usage in the basic scenario was assumed to be below 0.5% by 2050.

3.3.3 Installed photovoltaic capacity

The current installation goals for photovoltaics are 20 GW by 2025 with an increase of 1 GW per year from 2026 to 2030; thus, by 2030 Taiwan would have an installed capacity of 25 GW. Due to technological improvements in solar modules and higher energy generation efficiency, Taiwan could have an installed capacity of 30 GW by 2040 and 35 GW by 2050.

3.3.4 Technological growth

The efficiency of current solar modules is 20%, but as technology advances this efficiency is expected to reach 30% by 2040.

3.3.5 Electricity supply and demand

In the basic scenario, the electricity sector was hypothesized to be driven by economic behaviors; hence, the Taiwan's GDP growth rate was used to estimate the growth of electricity demand in the basic scenario. The carbon reduction scenario included the improved performance from the energy source plan from 2019 to 2027 as specified in the NEESDR. Energy generation was estimated by using the Long-

term Energy Development Project published by Taiwan Power Company and the energy source plan from 2019 to 2027 specified in the NEESDR [17]. The simulation parameters were set to predict the renewable energy of Taiwan in 2050 as presented in Table 7.

Table 7: The expected situation of renewable energy in Taiwan by 2050 (MW)

Renewable energy	2025	2030	2035	2050
Hydropower	2,150	2,150	2,150	2,150
Geothermal energy	0.3	0.3	0.3	200
Solar energy	20,000	25,000	30,000	35,000
Onshore wind energy	814	814	814	814
Offshore wind energy	5,700	10,700	15,700	25,700
Biomass energy	85.7	85.7	85.7	85.7
Waste energy	631.93	631.93	631.93	631.93

Source: compiled by this study

3.3.6 Carbon pricing and carbon fees

Carbon pricing refers to the pricing of exhaust gases, carbon dioxide, and greenhouse gases. A carbon pricing system uses economic incentives to reduce emissions and is a globally approved carbon reduction strategy. The UNFCCC COP26 validated the carbon trade market and its regulations and reached a consensus on the regulations, format, and procedures of the global carbon market. Currently countries are still discussing pricing standards for carbon, and the scenarios are divided into high carbon fees and low carbon fees. A list of firms emitting carbon compiled by Greenpeace from 2019 data was referenced, and the opinions of major carbon emitters in Taiwan on carbon pricing were surveyed; thus, a metric ton of carbon dioxide was priced at US $10 [18].

3.4 Analysis Results Using LEAP

(1) Electricity carbon emission factor: The overall electricity generation of Taiwan directly affects total greenhouse gas emissions. Therefore, the electricity carbon emission factor was used to evaluate the greenhouse gas emission reduction goals of the energy sector. The recorded statistics included the amount of publicly sold electricity and the amount of renewable energy either directly or indirectly transformed to electricity. After the energy transition and with the active promotion of renewable energy, the net-zero emissions by 2050 scenario and LEAP were used to calculate the electricity carbon emission factor from 2020 to 2050 in the carbon reduction scenario (Table 8). The results revealed that Taiwan must reach 0.278 kilograms of carbon dioxide equivalent per kWh (kgCO2e/kWh) by 2030; reaching this goal requires substantial improvement from Taiwan's current emissions efficiency.

(2) Carbon reduction benefits of photovoltaics: Current Taiwanese energy policies aim for renewable energy to account for 20% of all energy by 2025 and to promote green energy to reduce carbon emissions. The electricity generation of

photovoltaics in Taiwan is presented in Table 9. The LEAP analysis indicated that promoting Solar PV and using them to replace some coal and gas power plants from 2025 to 2050 can increase carbon reductions from 13.8 million metric tons to 37.15 million metric tons (Table 10). Increases in photovoltaic installation has contributed to carbon reduction efforts.

Table 8: Electricity carbon emission factor (kgCO2e/kWh)

Year	Basic scenario	Carbon reduction scenario
2020	0.502	0.502
2025	0.394	0.393
2030	0.424	0.278
2035	0.417	0.243
2040	0.412	0.201
2045	0.408	0.199
2050	0.404	0.176

Source: computational outcomes deriving from application of LEAP in the study

Table 9: Electricity generation from photovoltaics (billion kWh)

Year	Basic scenario	Carbon reduction scenario
2020	7.3	7.3
2025	35.0	35.0
2030	35.0	43.8
2035	35.0	52.6
2040	35.0	84.1
2045	35.0	89.4
2050	35.0	92.0

Source: computational outcomes deriving from application of LEAP in the study

Table 10: Carbon reduction benefits of photovoltaics (MtCO2e)

Year	Carbon reduction in the basic scenario	Carbon fee (US$)	Carbon reduction in the carbon reduction scenario	Carbon fee (US$)	Performance of the carbon reduction scenario compared with the basic scenario
2020	3.65	36,500,000	3.65	36,500,000	0.00
2025	13.80	138,000,000	13.80	138,000,000	0.00
2030	14.84	148,400,000	18.55	185,500,000	3.71
2035	14.63	146,300,000	21.94	219,400,000	7.31
2040	14.45	144,500,000	34.67	346,700,000	20.22
2045	14.29	142,900,000	36.44	364,400,000	22.15
2050	14.15	141,500,000	37.15	371,500,000	23.00

Source: computational outcomes deriving from application of LEAP in the study

4. Conclusion

The energy policy of Taiwan has become more comprehensive, and Taiwan is actively promoting energy transitions and participating in global initiatives for reducing carbon emissions. Taiwan has discussed possible paths and actions to achieve net-zero emissions by 2050. Taiwan is implementing its energy transition policies by increasing natural gas and green energy production and by reducing coal use. The promotion of renewable energy, the improvement of energy-saving technologies, widespread energy storage, and the installation of carbon capture and fixation technologies can all benefit carbon reduction efforts. The promotion of Solar PV is crucial for achieving the goal of 20% renewable energy in 2025. If Taiwan promotes photovoltaics with its current policies from 2020 to 2050, Taiwan could reduce carbon emissions by approximately 3.65–14.15 million metric tons (Table 10). Under the carbon reduction scenario for achieving net-zero emissions by 2050, if carbon emissions in 2030 are 30% less than emissions levels in 2005, carbon emissions would be reduced by 3.65–37.15 million metric tons (Table 10); this would greatly benefit Taiwan's effort to achieve net-zero emissions. The promotion of Solar PV can reduce carbon emissions and stimulate the development of the Solar PV industry, and Taiwan could establish an industrial supply chain and enter the Asian photovoltaics market. Widespread installation of Solar PV can increase investment and form industrial clusters. Taiwan can also use market incentives to attract international Solar PV firms to come to Taiwan and cooperate with domestic businesses, thereby forming an industrial supply chain and increasing the economic growth and green competitiveness of Taiwan.

The European Commission proposed the European Green Deal in December 2019 (European Commission, 2019) and aimed to lead Europe in achieving carbon neutrality by 2050. The European Green Deal stated that the European Union would propose CBAM for specific sectors in 2021 to reduce the risk of carbon leakage due to industries within the European Union moving overseas. CBAM stated that industries of European Union members must follow carbon reduction regulations, and a carbon border tax on products from regions without carbon pricing could be imposed when these products are imported into the European Union. The world is promoting carbon emission trading and carbon border taxes; these would both have enormous effects on Taiwan because Taiwan is an export-oriented economy. Although Taiwan has actively discussed responses to carbon fees or carbon taxes, Taiwan should still reference international carbon tax prices and discuss a reasonable carbon tax. In 2025, 20% of the energy in Taiwan will be renewable energy. Future studies can investigate the relationship between photovoltaics and carbon taxes.

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