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Taiwan's sustainable energy development and prospects for Taiwan - EU cooperation

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Abstract

Taiwan has made significant strides in sustainable energy development, particularly in areas like wind power and hydrogen production. The government of Taiwan has effectively utilized collaboration mechanisms by establishing partnerships with both experienced foreign companies and domestic enterprises to facilitate technology transfer. Additionally, the encouragement and formation of offshore wind industry zones and centers have been pivotal strategies, along with attracting international manufacturers during the initial deployment phase. Taiwan's partnership with the EU holds promising prospects, as the EU ranks as Taiwanss fifth-largest economic and trade partner. The EU's investment in Taiwan, especially from European offshore wind energy companies, has been rapidly growing, with significant contributions to offshore wind energy projects. Collaboration between the two entities is crucial, particularly in the development of green technologies like renewable hydrogen production. While Taiwan faces challenges in funding infrastructure and ensuring adequate renewable energy sources, EU support in sharing expertise, technology, and financial assistance could significantly bolster Taiwan's efforts. Furthermore, the EU's focus on renewable hydrogen production aligns well with Taiwan's goals, making it a suitable partner for collaborative efforts. Overall, Taiwan's sustainable energy development presents ample opportunities for cooperation with the EU, particularly in advancing green technology initiatives and addressing mutual energy challenges.

Keywords: *Taiwan – EU relations, Taiwan's renewable energy, renewable energy policy, sustainable energy*

Introduction

Taiwan, a small economy, has witnessed significant strides in economic development, not only rapid but also showcasing unique creativity, emerging as one of the four Asian Tigers. Since the industrialization efforts starting from the 1950s, Taiwan has continuously developed steadily due to crucial strategies and policies in human resource development. The most noteworthy adjustment in recent decades has been the transition towards a knowledge-based economy, focusing on producing high-value knowledge-based products (Chi, 2022). Taiwan's economic

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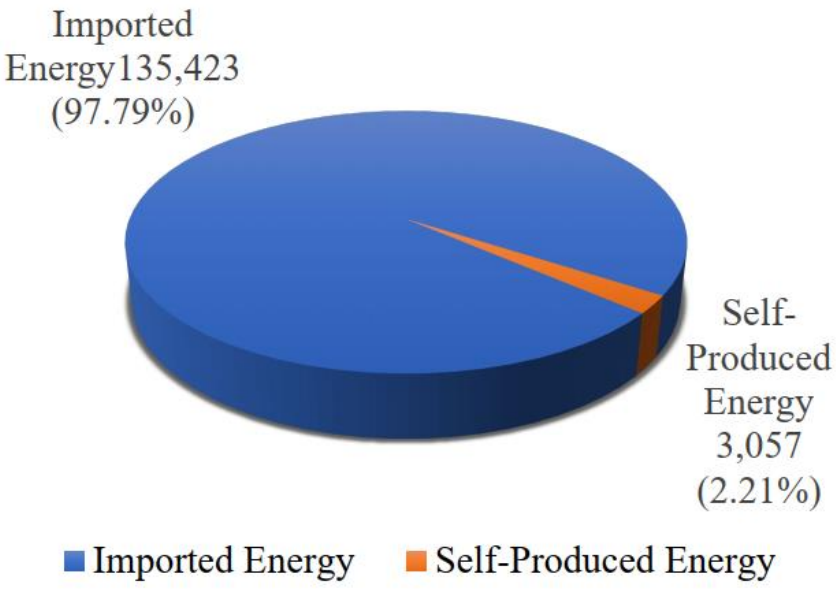
development has undergone three main stages: from an agricultural - based economy, followed by the development of import - substitution industries and labor - intensive manufacturing, and finally transitioning to domestic industries, promoting innovation and creativity. Currently, Taiwan is gradually transitioning to developing a high-value green industry, building a knowledge-based economy, yielding economic growth and addressing social and environmental issues (Phuong, T. & Tan, T., 2020). However, despite strong economic development, Taiwan still faces a major challenge in resource scarcity and energy consumption, both in primary and secondary energy.

Regarding primary energy, Taiwan currently imports about 98% of its energy sources and over 80% of its electricity from fossil fuels, including approximately 43% from coal and 39% from natural gas (Gavin, 2023), making Taiwan the 24th country in terms of greenhouse gas (GHG) emissions (Shan, S. K., Hailing, L., and Chih, C. K., 2023). Specifically, in 2015, Taiwan had to import 141.9 million kiloliters of energy equivalent to a cost of $36.7 billion, accounting for 7% of the total gross domestic product (GDP) (Lu, 2016, p. 400). The import of fossil fuel raw materials increased significantly in 2022, with Taiwan consuming 84.21 billion liters of oil, of which the three largest energy-consuming sectors were industry (27 billion liters), non-energy use[1] (22 billion liters), and transportation[2] (13 billion liters) (figure 1).

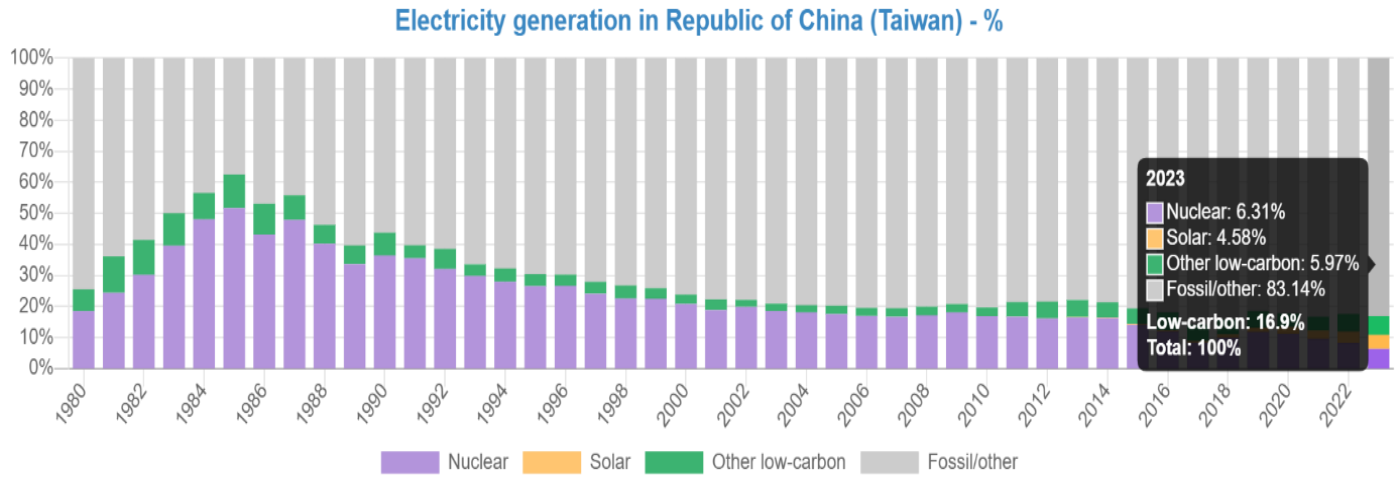
Figure 1: Overview of energy supply in 2020 (unit: kL)



Soure: Bureau of Energy, drawing by TIER

Electricity generation produced 239 TWh of electricity for Taiwan in 2023, with over 80% of it coming from coal and natural gas almost equally in this framework. Low-carbon combined energy sources accounted for only 18% of total electricity consumption. This includes nuclear energy, accounting for over 6%, while solar and wind energy accounted for nearly 4.7% and 1.6% respectively. Hydropower generated nearly 2.5% of electricity, and renewable energy of undetermined origin accounted for the remainder of consumption. Therefore, fossil fuels, mainly coal and natural gas, contribute the majority of Taiwan's electricity, while low-carbon sources play a much smaller role (LowCarbonPower, 2024) (figure 2).

Figure 2: Electricity generation in Taiwan (%)



[1] Non-energy use refers to lubricating oil, asphalt and solvent oil consumption.

[2] https://www.statista.com/statistics/322426/taiwan-energy-consumption-by-sector/#:~:text=In%202022%2C%20residential%20sector%20energy,of%20oil%20equivalent%20that%20year.

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Source: lowcarbonpower.org

Consumption of secondary energy, particularly electricity, is closely related to the economic growth of Taiwan. The Directorate-General of Budget, Accounting and Statistics estimated that Taiwan's economy grew by 6.09% in 2021, slowed to 4.15% in 2022, and is projected to maintain an annual growth rate of about 4% in the coming years. If electricity consumption grows in parallel with the economy, the growth rate could reach 2.93% in 2022; in the near future, the annual growth rate is unlikely to decrease below 2.82% (Kwangyin, L. & Li, H. T., 2022). Furthermore, Taiwan is a manufacturing-based economy with an export - oriented direction, especially in the semiconductor component sector. According to the Bureau of Energy of Taiwan, the industrial sector accounts for 56% of Taiwan's total electricity consumption. Electronic product manufacturing alone accounts for a whopping 37%. Therefore, Taiwan will face energy constraints (Duyen, 2023).

The energy security situation Taiwan currently faces domestically is the shortage of fossil energy supply to fuel domestic economic growth. Overdependence on foreign supply sources would undermine Taiwan's advantages in foreign policy and hinder autonomy in times of global instability. More than half of Taiwan's fossil energy is supplied by Middle Eastern countries. Historical evidence from crises in this region, such as the oil crises of 1973 and 1979, which led to skyrocketing oil prices, have had short- and long-term impacts on global politics and economics, still considered the largest in history. Moreover, the transportation routes for oil and coal from the Middle East to Taiwan are vulnerable to damage if political instability in the Middle East and conflicts in the Taiwan Strait occur. Despite recent improvements in cross-strait relations due to the signing of the Economic Cooperation Framework Agreement (ECFA), the increasing presence of the Chinese navy poses a future security concern. If cross-strait relations deteriorate, Taiwan's energy security will be compromised and not guaranteed (Benjamin, 2011, p. 217).

Additionally, carbon emissions in Taiwan are also a significant concern. According to statistics from the Bureau of Energy, MOEA, Taiwan emitted a total of 267 million metric tons (MTs) of CO_2 in 2021. The energy sector contributes the most to CO_2 emissions in Taiwan (71%), followed by transportation (13%), manufacturing (12.96%), households (2%), services (1%), and agriculture (less than 1%). However, when both direct and indirect emissions are combined, the manufacturing sector becomes the leading emitter, accounting for over 50% of Taiwan's total CO_2 emissions (Kenneth, 2023). Furthermore, Taiwan is a region vulnerable to global climate change, with hurricanes, floods, and sea level rise posing significant risks to the densely populated western coastline. Therefore, transitioning to greener and more sustainable energy policies is crucial for Taiwan to protect itself and collaborate with other nations in the global CO_2 reduction efforts discussed at the COP26 climate conference.

For these reasons, developing independent renewable energy is a top priority for the Taiwanese government. The path of renewable energy development, along with energy technology, not only helps Taiwan leverage its technological strengths, reduce dependence on foreign supply, but also aligns with the commitment to a sustainable Zero Carbon economy at the 26th Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC COP26), promoting the slogan "Taiwan + Green Energy – Power the Planet for a Green Future". Moreover, Taiwan's geographical location offers many advantages for developing various renewable energy sources, with approximately 70% of its land area being hills and mountains, primarily concentrated along the western coastal area, an island lying at the intersection of subtropical and tropical climates, boasting a relatively rich and diverse natural landscape and ecosystem, making it very suitable for developing renewable energy, such as solar energy, bioenergy, wind energy, geothermal energy, hydropower, etc. It is estimated that Taiwan's total renewable energy reserves are about 194 GW, equivalent to four times the national installed capacity in 2015, for example, 48.7 GW, so Taiwan indeed has abundant renewable energy resources. However, due to the importance of traditional fossil energy in producing cheap electricity, renewable energy has not been fully developed in Taiwan due to market competitiveness issues (Lu, 2016, p. 400).

1. Sustainable Energy Development Policies in Taiwan

1.1. Renewable Energy Conversion Policies

To mitigate dependence on energy supply sources, reduce CO_2 emissions, and, ultimately, prevent global warming-related disasters while aiming for a low - carbon economy and promoting green industrial development, Taiwan has focused on adjusting policies to prioritize the development of renewable energy. The objective of this renewable energy development strategy is considered a necessary solution for sustainable development in the future. Developing renewable energy not only contributes to ensuring energy security but also brings many benefits for Taiwan's socio-economic development and environmental protection (Binh, P. T. T & Quang, V. N., 2023). The types of renewable energy include solar energy (including solar electricity and solar thermal energy), wind energy, hydropower, geothermal energy, marine energy (such as ocean thermal energy conversion, tidal energy, and wave energy, etc.), all of which are natural energy resources owned by the earth or the sun. Other renewable energy sources also include various types of bioenergy, such as energy from waste, bioelectricity, and biofuels, etc.

The current status of Taiwan's renewable energy development policies includes regulations and provisions from two agencies: A) the Environmental Protection Agency (EPA) and the Ministry of Economic Affairs (MOEA).

In response to climate change adaptation plans, Taiwan has taken decisive measures by passing the Greenhouse Gas Reduction and Management Act in 2015. This law emphasizes the goal of reducing greenhouse gas emissions by 50% by 2050 compared to 2005 levels. Additionally, according to the INDC report, Taiwan commits to reducing emissions by 50% by 2030 compared to the current development trend, meaning an additional 20% reduction compared to 2005 levels. Furthermore, The Taiwanese Government's Environmental Protection Agency announced the amendment of the Greenhouse Gas Reduction and Management Act to the Climate Change Response Act (2021) with specific adjustments such as imposing carbon taxes and controlling total emissions, aiming to achieve net-zero greenhouse gases by 2050 in order to further enhance response measures (British Office Taipei, 2022, p. 10).

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Additionally, With the aim of strengthening the government'ss statements on this issue so Taiwan's Ministry of Economic Affairs (MOEA) announced the "Taiwan Sustainable Energy Policy Framework" in 2008 which is setting commitments and measures to achieve energy efficiency goals and reduce CO2 emissions. The government pledged to reduce CO2 emissions by 20% from 2005 levels by 2015 and by 50% by 2025. Additionally, Taiwan aims to reduce CO2 emissions to 2008 levels from 2016 to 2020 and to 2000 levels by 2025. Commitments to increase the share of renewable energy from 8% to 16% by 2025 of the total installed capacity are part of Taiwan's sustainable energy strategy (Sun, 2010). MOEA also issues policies on energy technology development, amending electricity laws, and modifying regulations on Renewable Energy Development in order to increase the proportion of renewable energy capacity to 20%, changes in electricity prices, and distribution and transmission systems.

To achieve these goals, the government has implemented a series of new policies. The most notable policy is the Renewable Energy Development Act (REDA), passed in 2009, as Taiwan ranked third in Asia and 32nd globally on the Climate Change Performance Index (CCPI) regarding CO2 emissions, published by the Climate Action Network Europe (CAN-Europe) and Germanwatch (Shih, 2009). Essentially, the main objectives of this law are to i) exploit multiple renewable energy sources such as wind, solar, geothermal, and others, particularly increasing installation capacity. By the end of 2021, Taiwan's installed solar power capacity reached 7.7 GW. REDA requires an additional 6.5 gigawatts (GW) of renewable energy installation capacity, bringing the total to 10 GW within twenty years (Kuo, 2009); ii) REDA introduces credit and tax incentive policies, reducing taxes to encourage investment, transfers, or accelerated depreciation. Accordingly, the government supports up to 13% of infrastructure, tax deductions for all taxes from profits in business; low-interest loans for enterprises; iii) establish a Feed-in Tariff (FiT) pricing system for electricity generated from renewable energy and require electricity companies in Taiwan to purchase it; iv) encourage businesses to invest in the renewable energy market by establishing public construction projects involving corporate participation. Building photovoltaic urban areas, solar energy cities, and constructing solar energy roofs with a capacity of 1 MW.... The law also established a renewable energy development fund partly funded by fossil fuel and nuclear energy-using electricity companies. On the other hand, the government issued regulations on renewable energy, energy conservation, and CO2 emission reduction through architecture for businesses to refer to when constructing the aforementioned public projects (Phuong, T. & Tan, T., 2020). The government proposed to create two low-carbon model communities per city or county in the next two years, with 50% of the energy supplied from renewable sources. Taiwan aims to achieve six low-carbon counties or cities within five years.

These supportive policies have helped Taiwan become a pioneer in developing renewable energy products, including solar panels (ranking second globally after China with over 12% of production), LED lights, electric bicycles, and recycled fabrics. Additionally, Taiwan produces solar energy application products such as streetlights, pumps, and solar-powered LED lights. These products not only save electricity costs but also reduce emissions and can be recycled from 95% or more. In particular, microgrid systems combined with energy storage batteries have been deployed in many countries such as Indonesia, India, and Japan, providing stable green electricity to rural and remote island areas.

To further strengthen the policies outlined in REDA, the legislature has also passed a series of measures to enhance cooperation between local and central governments on energy conservation and emission reduction, establishing two pilot communities with 50% of the energy supplied from renewable sources in those areas, and the entire country will become a low-carbon area by 2020 (Shih, 2009).

Regarding the liberalization of the electricity market and the encouragement of renewable energy production by business companies, Taiwan amended the Electricity Business Act (TEA) in 2017 and continued to amend the Renewable Energy Development Act (REDA) in 2019 to incentivize more Taiwanese enterprises to actively invest in renewable energy. The TEA amendment separates the power generation business activities of Taiwan Power Company from transmission and distribution business activities by 2026 and allows direct sale of renewable energy to consumers. Alongside the goal of achieving 27 GW of renewable energy production by 2025, the registration process for renewable energy facilities with capacities below 2 MW has been streamlined, and renewable electricity sources smaller than 500 kW are exempted from electrical technical procedures. Power plants are allowed to choose to sell electricity through direct supply, wholesale, or retail to Taiwan Power Company (Nam, 2023).

The "Taiwan's Pathway to Net - Zero Emissions in 2050" plan which published in 2022, is a more specific and detailed action plan for Taiwan to achieve previously set goals, with a long-term vision until 2050. The goal of this strategy is to encourage progress in technology, research, and innovation in key areas. It also aims to guide the green transformation of industries, promote economic growth, and enhance financial sustainability. Additionally, this strategy focuses on increasing investments at critical milestones to ensure a smooth and equitable transition process. Taiwan's Net Zero 2050 pathway is built on two governance pillars (technology research and development and climate change legislation), along with four transformation strategies (energy transition, industrial transition, lifestyle transition, and social transition), supplemented by 12 action plans for identified key related areas such as: Wind/Solar Photovoltaic Power; Hydrogen Energy; Innovative Energy; Power System and Energy Storage; Energy Saving and Efficiency; Carbon Capture; Utilization and Storage (CCUS); Carbon-free and Electric Vehicles; Resource Recycling with Zero Waste; Carbon Sinks; Green Lifestyle; Green Finance; Just Transition (Climatetalks, 2022).
This implies that to achieve this commitment, the economy needs to enhance energy usage efficiency and maximize the proportion of renewable energy in the total energy mix. In recent years, Taiwan has been heavily investing in innovative energy technologies, especially in the field of renewable energy (offshore wind energy, solar power, hydrogen), aiming to reduce CO2 emissions and recycle limited waste resources. Taiwan's goal is to achieve a renewable energy utilization rate of 20% of the total energy consumption by 2025 and increase it from 60% to 70% by 2050 (Long, 2023) (figure 3)

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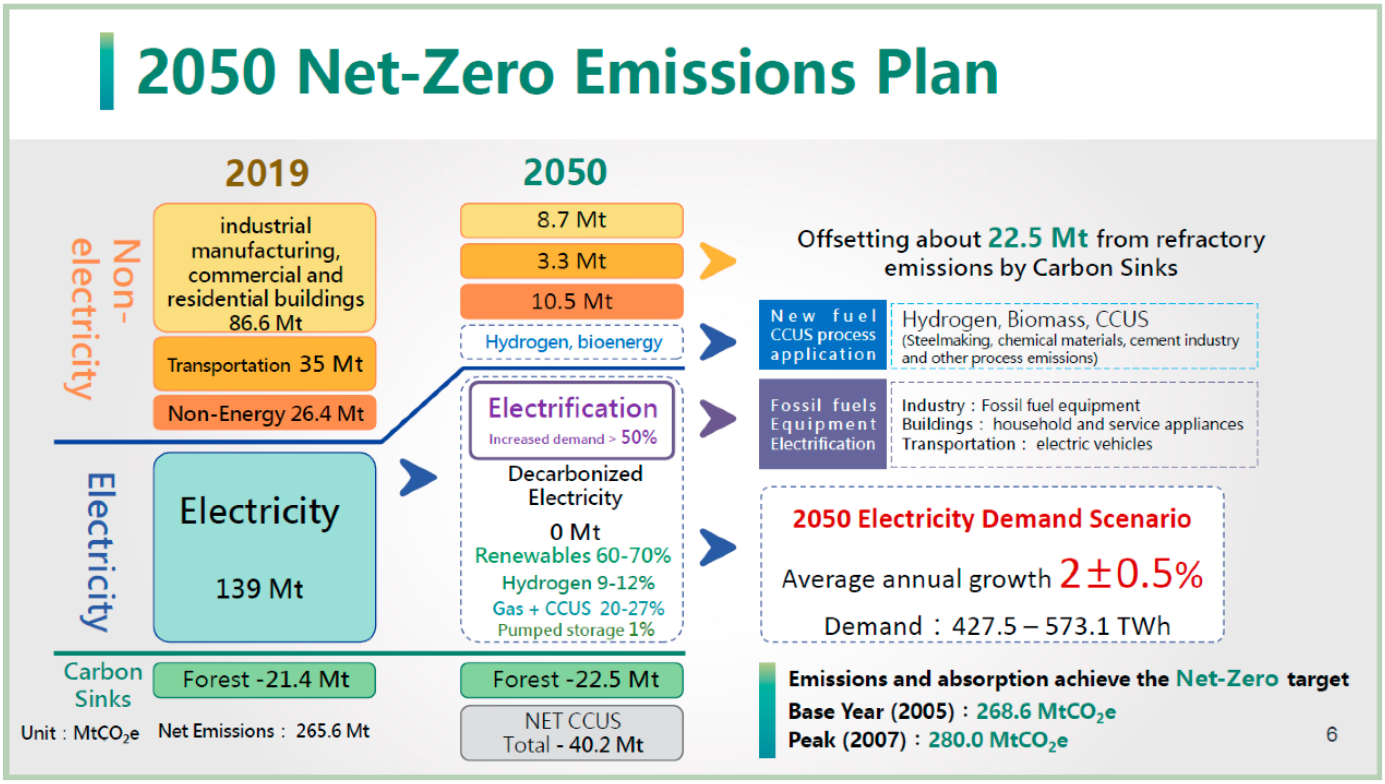
Figure 3: Taiwan's 2050 net-zero emissions plan



Source: https://www.mdpi.com/2071-1050/15/6/5587#B13-sustainability-15-05587

1.2. Implementation Practices

Taiwan's renewable energy development policies mark the beginning of an economic restructuring process towards the energy sector, aiming to advance technology-oriented industries, enhance economic competitiveness, environmental sustainability, and contribute to global climate change initiatives, both within Taiwan and across the wider Asian region. Broadly, Taiwan's implementation policies focus on the following key areas: i) promoting the transition to green energy; ii) investing in new energy technologies.

1.2.1. Promoting the Transition to Green Energy

Taiwan is concentrating on developing sources such as solar energy, offshore wind energy, hydroelectric power, biomass, and geothermal energy...

The development of Taiwan's renewable energy will primarily rely on the utilization of wind and solar energy. In wind power development, the focus will be on deploying large-scale offshore wind turbine projects. It is projected that by 2030, the installed capacity of offshore wind power will reach 13.1 GW and increase to between 40 and 55 GW by 2050. As for solar energy, capacity expansion will be achieved through diverse land use types. By 2030, the installed capacity of solar energy is expected to reach 30 GW and increase to between 40 and 80 GW by 2050 (Climatetalks, 2022).

Taking into account the year 2015, renewable energy accounted for less than 9% of Taiwan's installed capacity, but had increased to 14% by 2019. There are two prominent facilities in the solar and wind energy sectors in Taiwan are the Hsinta plant in Kaohsiung and a plant in Taichung, both experiencing significant growth. Taiwan has achieved numerous accomplishments in developing renewable energy sources such as solar energy, wind energy, geothermal energy, and related fields (Binh, P. T. T & Quang, V. N., 2023).

Regarding offshore wind power development: Recently, the Taiwan government has formulated the "Two Plus Two" plan for innovative industries, shaping Taiwan's vision of sustainable development in the coming years and decades, with a focus on green and renewable areas. In the field of green and renewable energy, Taiwan continues to fulfill its commitment to green transition by establishing a national team for offshore wind power and collaborating with the Pacific Wind Power Production Chain (Department of Information Services, 2021). Offshore wind power development plays a crucial role in promoting green energy and helping the Taiwan government achieve its energy transition goals. Taiwan has significantly accelerated offshore wind power (WP) sources and aims to reach 5.7 GW by 2025, up from 2 turbines of 4 MW each in 2016 (PV, 2023). Taiwan ranks third in the list of largest offshore wind power markets in the Asia-Pacific region, after China and Vietnam (including nearshore wind power). With ambitious goals and clear plans, this market has attracted strong interest from technology providers and leading developers in offshore wind power. Currently, two pilot offshore wind power projects under the Encouraging Trial Program have been implemented: Formosa 1, with a total capacity of 128 MW, and the Changhua trial project, with a total capacity of 109 MW. Following these are larger projects including Greater Changhua 1 & 2a (900 MW), Formosa II (376 MW), Yunlin (640 MW), and Changfang Phase 1 (100 MW). The Greater Changhua 1 & 2a project started operation in April 2022. Formosa II and Yunlin are under construction and expected to make significant progress by 2023 (Phuong, N. X., Hung, L. V., Duong, T. T., & ect, 2023). The Changhua 1&2a project is one of the largest offshore wind projects, identified by Ørsted (Denmark) as the "largest offshore

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wind farm in Taiwan", installed off the west coast of Taiwan from 35 to 60 km offshore. This project having a capacity of around 900 megawatts and utilizing 111 wind turbines which provide enough electricity for approximately 1 million households in Taiwan (Quan, 2022). Currently, offshore wind power projects in Taiwan have completed construction with a total installed capacity of 2.25 GW, leading in the Asia-Pacific region with offshore wind power capacity exceeding 2 GW (Taiwan today, 2024). Additionally, Taiwan is also fully exploiting the potential of wind energy from coastal areas. In 2019, Taiwan inaugurated its first commercial offshore wind farm off the coast of Miaoli, capable of supplying electricity to 128,000 households (Chi, 2022).

Regarding Photovoltaic Energy: In Taiwan, despite the rapid increase in installed capacity from 410 MW in 2013 to 7720 MW by the end of 2021, a significant portion of suitable land remains unused, and solar energy supply only accounts for 0.59% of the total electricity supply. The largest solar power plant in Taiwan began operation in Kaohsiung City in October 2011. This plant had a construction cost of about 640 million New Taiwan Dollars (equivalent to 20.9 million USD) and utilized over 16 thousand solar panels. With an annual electricity production capacity of 5.92 MW (equivalent to the consumption of 1,600 households), this plant reduced carbon emissions by approximately 3,623 tons per year and is managed by the Taiwan Power Company (Binh, P. T. T & Quang, V. N., 2023). By 2021, electricity supply from coal-fired power plants had reached a historical high of 82.23%, while electricity supply from solar energy only accounted for 0.59%, thus keeping Taiwan's net carbon emissions at a high level and making it difficult to achieve the goal of becoming a carbon-neutral nation. In this context, the government has decided to further promote solar energy development by investing $40 billion annually to reduce fossil energy sources and improve environmental quality. According to the Renewable Energy Development Framework, about 3% of idle land will be reused to install solar panels to increase renewable energy supply and reduce dependence on fossil fuels (Shan, S. K., Hailing, L., and Chih, C. K., 2023, trang 2).

The Taiwanese government has established plans to use solar energy for public utilities and integrate green energy into daily life. Specifically, Taipei City has transformed over 3,000 solar panels on idle land into electricity sources, while areas in southern Taiwan have been equipped with over 5,000 solar panels generating 7 MW of electricity, about 3.2 times the amount of electricity produced by local hydroelectric power plants. Even the Penghu Islands have deployed solar panels, estimated to generate 83,000 kWh per year. The Kaohsiung Stadium in Taiwan is the world's first stadium to use solar energy for its roof, with a total of 8,844 solar panels capable of providing electricity for 33,300 light bulbs and 2 large television screens. It is expected that this solar panel system will produce about 1.14 million kWh of electricity per year and reduce CO2 emissions by up to 660 tons per year (Binh, P. T. T & Quang, V. N., 2023). Additionally, the joint development project of a 150MW solar and aquaculture energy project in Taiwan between Lightsource BP and Green Rock Energy, built in 2023, is one of the largest solar and aquaculture farms in Taiwan. When completed, the project is expected to produce 210,000 megawatt - hours of electricity per year, enough to supply electricity to about 43,000 households and reduce carbon dioxide emissions by up to 133,770 tons annually (Bang, 2022).

The government has achieved good results in promoting energy conversion, including 9,157 MW of solar power and 568 MW of offshore wind power integrated into the grid, with up to 80% of the population supporting the rapid development of solar power, indicating that this industry has many potential development opportunities in Taiwan's future (Taiwan today, 2024).

Regarding Geothermal Energy: Alongside wind and solar energy sources, geothermal energy is becoming a popular choice for electricity production, widely used in over 50 countries worldwide. Geothermal energy, originating from natural heat within the Earth, is considered a clean and sustainable energy source. Unlike other renewable energy sources such as wind and solar energy, geothermal energy is not affected by weather and climate factors, thus having a high efficiency coefficient. Taiwan, with its volcanic mountains formed on its territory, possesses abundant geothermal resources. In 2015, the Energy Bureau and the Industrial Technology Research Institute signed a contract with New Taipei City to promote a geothermal energy production project with a capacity of 10 MW. Meanwhile, researchers at Taitung University are conducting research on utilizing hot springs in the area to harness geothermal energy. Taiwan Power Company has initiated a geothermal power generation test plan on Green Island by drilling two test heat wells at the Jhaorih hot spring and setting up a 200 kWe power generator. It is expected that by 2025, the goal is to complete 11 heat wells at Yilan Lizuh and produce approximately 8 billion kWh of electricity annually.

Regarding Hydrogen Development: Hydrogen[3] is considered a clean energy source with great potential, with important applications such as production, storage, transportation, and utilization in various fields such as power generation, heating, and synthetic fuels. The development of the hydrogen industry requires comprehensive expansion of national infrastructure. Currently, Taiwan primarily supplies hydrogen from three major domestic gas suppliers (Linde Lienhwa Industrial Gases Co., Air Products San Fu, and Air Liquide Far Eastern), with a total supply of approximately 10,296 tons per year, but additional sources are needed to meet increasing demand in the future. To achieve the net - zero carbon emissions goal by 2050, careful assessment and analysis of the hydrogen supply - demand situation and trends in hydrogen energy development in Taiwan are necessary (British Office Taipei, 2022, p. 24). The current supply in Taiwan is limited because CCUS technology and carbon storage locations have not been addressed. CCUS technology has developed rapidly worldwide. However, carbon storage is only suitable for countries with large areas, sparse populations, and solid land. In Taiwan, rock formations or deep salt layers in the west are the most suitable areas for carbon storage. In 2023, the Taiwan Central Research

[3] Global hydrogen production is classified into gray hydrogen, blue hydrogen and green hydrogen. Gray hydrogen, produced from rock or natural gas, emits large amounts of hydrogen. Green hydrogen is created by electrolysis of water with renewable energy, including solar power, wind power, hydraulic power, etc. Blue hydropower is hydropower generated through carbon capture, utilization and storage (CCUS) in a hydroelectric system during the production process. Blue hydrogen is considered a transition product from gray hydrogen to green hydrogen in the process of developing hydroelectric energy. The hydrogen mentioned in the study is green hydrogen and green hydropower in Taiwan according to the goal of net zero carbon emission energy by 2050.

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Institute developed power generation technology through "Carbon Reduction by Hydrogen Combustion Technology" integrated into the hydro and thermal power plants of Taiwan Power Company, capable of unlocking natural gas to remove carbon and burning only hydrogen to produce clean electricity, with plans to scale up production, aiming to reduce carbon emissions by over 7,000 tons per year (Kim, 2023).

1.2.2. Investing in efficient energy technologies

Taiwan, with rapid development in the technology and electronics manufacturing sectors, has been dubbed the "Silicon Valley of Asia". This nickname reflects Taiwan's advancement and reputation in the high - tech industry, particularly in semiconductor chip manufacturing and other advanced electronic products. Having the presence of numerous leading global technology conglomerates and a dense network of businesses and research centers, Taiwan has become a significant hub for research, development, and production of high-tech products. The development of the technology industry in Taiwan not only generates strong economic growth but also contributes to the sustainable development and progress of the Asian region. In the context of Taiwan aiming to achieve net - zero emissions by 2050, Taiwan has developed and researched various renewable energy technology applications to save energy and reduce carbon emissions in multiple fields, including production design, energy management, and production efficiency enhancement.

Speedtech Energy Co. Ltd is a typical example, not only producing solar energy application products such as street lights, pumps, and LED lights but also focusing on developing products capable of providing natural light, reducing energy costs, while reducing carbon emissions and being recyclable from 95% or more. The company has effectively applied micro-grid system products combined with storage batteries in countries such as Indonesia, India, and Japan (Phuong, T. & Tan, T., 2020).

Electric and Machinery Manufacturing Corp (CHEM) develops primarily fuel cells mainly powered by natural gas LNG and hydrogen gas. The company also develops micro - grid system products combined with storage batteries. This micro-grid system combines solar energy, wind energy integrated with fuel cells or conventional storage battery products. CHEM's micro-grid system operates independently, providing stable green electricity to remote rural and offshore areas where grid coverage is difficult or electricity supply is unstable.

Ecolohas Energy Technology successfully integrates a range of energy storage systems, providing ultra-small grid systems that can be used in both industrial and small-scale settings such as households, both in grid-connected and off-grid areas. Specifically, convenient electricity assembly of solar energy systems and energy storage systems in areas where the national grid does not reach, allowing people to use electricity. Especially, Ecolohas Energy Technology's batteries are recycled from used motorcycle batteries, making them cheaper than other brands. Additionally, to power outdoor electronic signs (advertising signs, traffic signs, signs in shopping malls, entertainment areas, and even in hospitals) which require electricity to operate, Sable Corporation has come up with the idea of producing electronic signs combined with solar power systems, saving energy compared to conventional LCD electronic signs (consumption level equal to 1% using LCD electronic signs) and independent of the grid.

Ta Ya Electric Wire & Cable Co., Ltd is one of the pioneering companies in combining environmental protection with modern material production. The company currently provides a range of low-halogen electrical cables, heat-resistant electrical cables, non - toxic and smoke-free optical cables, and solar energy cables. This company has around 40 years of experience in wire and cable development, flat wires, and TILW, it provides products widely used in industrial, consumer, automotive, electromechanical, and electronic fields. The company's eco - friendly electrical cable products contain no halogen and have high flame resistance, while their solar energy cables are also UV - resistant and withstand humid and high-temperature environmental conditions. In particular, Ta Ya also supports many enterprises and organizations in Taiwan in building solar power plants using the PV - ESCO model, helping them rent rooftops to install solar panels (Huong, 2020).

1.2.3. Government Subsidy Plans

In addition to focusing on research and development (R&D), Taiwan also develops plans and provides subsidies to promote energy development projects, setting goals for installation capacity and requiring domestic ratio targets (60%).

Tax Incentive Policies

Tax incentive policies for installation subsidies and tax incentives play a crucial role in promoting the development of the renewable energy industry in Taiwan. Challenges such as prolonged payback periods, complex application processes, and low electricity transmission efficiency have been addressed by this policy. The government has allocated budgets and subsidies for various renewable energy system models, motivating organizations and agencies to participate in the deployment of these systems. Legal amendments, such as the 2017 Electricity Business Act Amendment and the 2019 Renewable Energy Development Act, have helped liberalize the electricity market and promote renewable energy production. These measures not only simplify registration procedures and enhance options for renewable energy producers but also create favorable conditions for achieving Taiwan's renewable energy goals in the future.

Moreover, credit policies and tax incentives also play a crucial role in promoting the development of the renewable energy industry in Taiwan. These measures include tax reductions to encourage investment, transfer, or accelerate depreciation, and tax exemptions for imported equipment not produced domestically. Specifically, in the "Promotion Regulation for Upgrading Industries", the government provides support of up to 13% for infrastructure, tax deductions from business profits, and tax credits ranging from 10 to 20% of investment costs in the industry's stock market. These measures not only promote the development of the renewable energy industry but also play an important role in achieving Taiwan's renewable energy goals.

Government Electricity Subsidies

Taiwan has opted to use a fixed subsidy level instead of the method of adding support to reduce the risk from fluctuations in electricity prices for investors in the renewable energy sector. In 2023, the Taiwan Ministry of Economic Affairs adjusted the Feed-in Tariff (FIT) prices to align with the domestic renewable energy development situation and to encourage the development of other types of renewable energy. Specifically, the FIT prices for solar

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power systems will remain stable without significant changes, maintaining the current tax incentives as a measure to encourage investment in new solar energy production. For other types of renewable energy such as onshore wind power from 30kW and above, offshore wind power, biogas energy with digestion equipment, geothermal power under 2MW, agroforestry, small hydropower under 500kW, and over 500kW but under 2MW, there will be a slight increase to incentivize producers to complete construction as early as possible. Finally, the Ministry of Economic Affairs commits to conducting the FIT price evaluation process for 2023 in a fair, transparent, and rigorous manner, considering factors such as domestic development environment, promotion objectives, as well as renewable energy technology development trends, to ensure the sustainable development of the renewable energy industry in Taiwan (MOEA, 2023).

2. Prospects for Taiwan - European Union Cooperation

2.1. The Necessity of Taiwan - European Union Cooperation in the Energy Sector

The relationship between Taiwan and the EU plays a crucial role for both parties, encompassing political issues, as well as science and technology, particularly semiconductor chips and energy technology.

The EU and Taiwan have a close economic and trade partnership. In 2020, Taiwan became the EU's 14th largest trading partner worldwide, with total merchandise trade between the two reaching a record 84.2 billion euros in 2022 (European Commission, 2023). For the EU, Taiwan is seen as a reliable and valuable partner in the Asian region (European Economic and Trade Office in Taiwan, 2021), both share many common goals, including dealing with climate change challenges, transitioning to renewable energy economies, and developing new energy technologies for sustainable growth. By 2021, approximately 22% of energy in the EU was derived from renewable sources, but there were significant variations among countries. While Sweden led with a renewable energy share of 65%, countries like Luxembourg, Malta, the Netherlands, and Ireland only had around 13% renewable energy in their total energy usage (TTXVN, 2023).

Furthermore, both the EU and Taiwan are economically developed regions with high levels of science and technology, but they are constrained by reliance on external fossil fuel energy supplies, affecting energy policies. Consequently, both have identified carbon emission reduction strategies as crucial for long-term development to achieve carbon neutrality by 2050. The European Green Deal: a roadmap for Europe to become the first climate-neutral continent by 2050, along with the RePowerUp plan (2022) proposed by the European Commission, aims to reduce carbon emissions by 45% by 2050.

Moreover, sharing core values such as democracy, freedom, human rights, and the rule of law, Taiwan and the European Union (EU) are like-minded partners, creating favorable conditions for enhanced cooperation in many areas. In 2021, the European Commission and the European External Action Service (EEAS) jointly published the "EU Strategy for Cooperation in the Indo-Pacific," which includes enhancing cooperation with Taiwan in semiconductor technology development, strategic sectors such as the semiconductor industry, information and communication technology, green energy, etc (Ministry of Foreign Affairs, 2021).

The EU considers Taiwan as one of its potential partners in various sectors such as automobiles, mobile devices, healthcare, biotechnology, information and communication technology. Statistics show that the EU is the largest source of foreign investment in Taiwan in recent years, accounting for about 25% of total foreign direct investment, but Taiwan's investment projects in the EU are still low, accounting for only 1.7% of Taiwan's investment projects.

The EU requires Taiwan's support in the European Chips Act and the €43 billion investment package in the supply chain and semiconductor industry, an initiative to enhance the EU's technological competitiveness with the US and Asia in controlling key technologies of modern electronic products and devices, and to double the EU's global market share in semiconductors to 20% by 2030. In the context of Taiwan Semiconductor Manufacturing Company (TSMC) considering investing in building its first chip production plant in Europe (Saxony, Germany), Taiwan has the potential to expand its global operations, which has not been fully utilized in the European market. The EU is a large market, having signed 41 trade agreements with 170 countries. Therefore, urging Taiwan to invest in the EU could help Taiwan access not only the entire EU market but also the rest of the world more easily (Diep, 2020)

2.2. Challenges in cooperation between Taiwan and the EU

The future prospects of energy development cooperation between Taiwan and the EU entail significant strides. The EU recognizes Taiwan's importance economically, commercially, and technologically (Dang, 2023). However, there are still numerous obstacles related to political factors and China's influence in the EU's foreign policy and its relations with Taiwan.

Firstly, enhancing political ties with Taiwan to support EU economic interests: China's standpoint has shown strong concern and opposition to any EU measures to enhance relations with Taiwan. China regards Taiwan as "an inseparable part of its territory", and the EU should "seriously respect China's sovereignty", and changing EU relations with Taiwan is "not a trade issue but a serious political matter related to the political foundation of China - EU relations" (An, 2022).

In 2021, the European Parliament passed a comprehensive plan to strengthen ties with Taiwan, proposing to "enhance comprehensive partnership relations". The resolution also supported renaming the European Economic and Trade Office in Taiwan to the European Union Office in Taiwan "to reflect the large scale of the relationship between the European Union and Taiwan" when Beijing "basically threatens the status quo through new policies towards Taiwan, then 'European countries must also change their policies towards Taiwan to help maintain stability" (Thorsten, 2021). Therefore, strengthening political relations is a move to support economic goals, especially in the semiconductor technology sector.

Secondly, ensuring global supply chain for semiconductor devices and global trade operations: China's military exercises around the Taiwan Strait since 1996 and a potential conflict in this area not

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only threaten the continuity of trade activities with the East Asian region but also have the potential to disrupt the global supply chain in general and with the EU in particular, altering the security structure in Asia and causing significant consequences for the European Union's economy. For example, 40% of the EU's external trade volume and no less than 100,000 commercial vessels pass through the Taiwan Strait annually. Meanwhile, about 30,000 European citizens are living in Taiwan, indicating a potential humanitarian crisis that could occur for EU member states if a conflict erupts in this region (Philippe, 2024).

Thirdly, Taiwan is a democratic model and a responsible global citizen, contributing to global democracy, human rights, health, and many values shared by the EU. Therefore, the EU should cooperate with Taiwan because Taiwan's economic and social policies are predictable, and the political situation is stable, crucial for international cooperation and investment (Yi, 2022). Advanced technologies and experiences in the mentioned industries can lead to mutually beneficial cooperation, thereby enhancing trade relations and technological innovation. Furthermore, China's economic influence in the EU can translate into political leverage. The European Union should cooperate with Taiwan to understand how to balance China's trade and infiltration, and ensure that democracy and national security are not sacrificed to support economic deals. Moreover, the EU needs to provide alternative options for Chinese investments in European countries, and they can do this by cooperating with Taiwan (Marzia, 2019, p. 3).

2.3. Potential areas and specific cooperation plans between Taiwan and the European Union

The prospect of cooperation between Taiwan and the European Union opens up many opportunities in the field of renewable energy that both countries benefit from. Taiwan has made many significant achievements and has a strong development plan. more in the future. Cooperation with the European Union can help Taiwan improve new energy technology, while creating large cooperation projects that help Taiwan gain access to the larger European market and promote cooperation for many other fields.

Wind energy development cooperation

The Taiwanese government has efficiently utilized cooperation mechanisms by establishing partnerships with both experienced foreign companies and domestic enterprises to transfer technology. Another significant strategy of the government is to encourage and establish offshore wind power industrial parks and simultaneously support attracting international manufacturers during the initial phase of deployment (Phuong, N. X., Hung, L. V., Duong, T. T., & ect, 2023).

The EU stands as Taiwan's fifth most important economic-trade partner, with trade turnover reaching $46.2 billion from January to November 2020. In terms of investment, the EU represents the most significant source of foreign investment in Taiwan, particularly from offshore wind power companies in Europe, which have recently experienced rapid growth. By the end of October this year, EU investment in Taiwan is estimated to have reached around $48.5 billion (Ministry of Economic Affairs, 2020).

The Associated British Ports (ABP) of the United Kingdom and the Taiwan International Ports Corporation (TIPC) have signed a memorandum of understanding (MoU) to cooperate in developing port infrastructure related to offshore wind power and exploring future business cooperation opportunities. ABP is one of the leading and largest port operators in the UK, managing a network of 21 ports nationwide and handling a significant portion of the UK's cargo, valued at £157 billion (approximately $193 billion) in 2022. The company provides crucial support services for various sectors, including the energy industry, yacht tourism, container transportation, agriculture and forestry production, automotive, and steel. Many ABP ports are located near large offshore wind farms in the UK and provide services to meet the needs of this industry (Bojan, 2023).

Hydrogen energy enhace cooperation

Both Taiwan and the EU recognize the role of Hydro in green energy development strategies to achieve the goals set for 2050. Taiwan's target for the ultimate use of hydro is to reach 9-12% of the energy mix. Renewable energy is expected to account for 60-70% of the mix by 2050, while Carbon Capture, Utilization, and Storage (CCUS) are planned to handle 20-27% of the emissions that are difficult to remove by transitioning from fossil fuels to renewable energy. Meanwhile, the EU also sees the future production of renewable hydro as a top priority, with sixteen EU member states having developed hydro strategies and set targets for renewable hydro production and usage. Hydro is also a resource used for large vehicles and energy storage to balance the grid from intermittent renewable sources, particularly as a resource in industries that are difficult to electrify using renewable energy, such as steel production.

Taiwan has plans for renewable hydro production but faces challenges in terms of funding for infrastructure establishment, building appropriate storage and distribution systems, and importantly, Taiwan currently does not have enough renewable energy sources for both electricity generation and providing energy for hydrogen production plants. Therefore, Taiwan greatly needs cooperative support in sharing the experiences of foreign companies, providing appropriate technology, and financial support. On the other hand, the EU is a suitable partner due to the development strategy of the region's hydro. The EU provides institutional funding for the Clean Hydrogen Partnership, supports the development of renewable hydrogen systems and production, and the Clean Hydrogen Alliance supports both renewable and low-carbon hydrogen. The Clean Hydrogen Alliance has about 1,700 members and a network of 850 projects aimed at generating 67GW of capacity by 2030 across Europe, with 70% of projects planned to be operational by 2025. herefore, cooperation between the two sides in this area is meaningful to Taiwan, because it will help Taiwan have more advantages in achieving its set goals, creating a premise for cooperation in other fields develop together (ECCT, 2023).

Green technology development

In many forward-looking industries such as semiconductor manufacturing or wind energy production, rare metals and noble gases are considered irreplaceable components or necessary in the production process. This is particularly true in the semiconductor manufacturing industry. With about 95% of the industrial processing of rare metals controlled by Chinese companies, we can observe the significant dependence of the economies of Taiwan and the European Union on China for the supply of rare metals and noble gases. Additionally, the process of extracting rare metals is often associated with the release of hazardous chemicals into the environment, including radioactive residues. Given the expected increase in demand for rare metals and with some countries -

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including the United States, Brazil, Mongolia, and India - announcing plans to exploit rare metal elements, developing environmentally friendly technologies becomes extremely important. Collaborating with Taiwan within the framework of a Science and Technology Cooperation Agreement will provide a means to enhance the European Union's value interests in this industry (Jörn, C. G.; Steffi. W. & Markus, T., 2022, p. 32)

The Taiwanese government actively supports foreign companies investing in Taiwan and contributes to the implementation of its renewable energy policies. In the first half of 2022, the Taiwanese government approved investment projects from Denmark (Orsted Wind Power TW Holding A/S; CI II Changfang K/S) and the Netherlands (NP Hai Long Holdings BV) in local offshore wind power projects (Taipei Document, August 25, 2022). Japanese companies acquired a 25% stake in the offshore wind power production field of the "Formosa I" wind farm in March 2022 - where German EnBW also owns a portion. Germany's Linde participated in Taiwan's first hydrogen refueling station built as a pilot station in Tainan, Taiwan. A Taiwan Fuel Cell Partner (TFCP) was established in 2011, combining companies and research centers. However, while Taiwanese companies export their technology, the domestic market for fuel cells has not yet developed strongly. The Taiwanese government sponsors the Industrial Technology Research Institute (ITRI) specifically in developing hydrogen storage cylinders and other technologies. However, Taiwan faces difficulties in achieving its ambitious goals (Jörn, C. G.; Steffi. W. & Markus, T., 2022, p. 37).

Conclusion

In conclusion, Taiwan's sustainable energy development initiatives demonstrate a proactive approach towards reducing carbon emissions and transitioning towards green energy sources. The collaboration between Taiwan and the EU presents promising prospects for advancing these efforts further. Taiwan's emphasis on offshore wind power and hydrogen production aligns with the EU's focus on renewable energy technologies, making them natural partners for cooperation. Despite facing challenges such as funding constraints and the need for adequate infrastructure, Taiwan's commitment to renewable energy remains strong. The EU's support in sharing expertise, technology, and financial resources can significantly contribute to Taiwan's sustainable energy goals. Moreover, the EU's initiatives in renewable hydrogen production complement Taiwan's objectives, fostering synergy between the two entities. As Taiwan strives to diversify its energy mix and achieve greater energy independence, collaboration with the EU can play a crucial role in overcoming obstacles and accelerating progress. By leveraging each other's strengths and resources, Taiwan and the EU can foster a mutually beneficial partnership that drives innovation, promotes sustainability, and addresses global energy challenges. Ultimately, this collaboration holds the potential to not only enhance energy security and environmental sustainability but also strengthen diplomatic ties and promote economic growth for both Taiwan and the EU on the international stage.

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