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An assessment of Taiwan's energy policy using multi-dimensional energy security indicators

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ABSTRACT

Facing the challenges of global warming, energy scarcity and energy price fluctuations, many countries consider energy security to be a major part of their energy policy and have started to develop relevant strategies. This study applies multi-dimensional energy security indicators to review the performance of Taiwan's energy security related measures and to analyze the impacts of the current energy policy on Taiwan's energy security. The results show that Taiwan's current energy policy is effective in improving the security of the energy supply. Taiwan's dependence on imported energy is rather high, however, which makes Taiwan vulnerable to international energy price fluctuations and liable to suffer from increased energy costs.

Contents

1. Introduction

Energy security is a complex and global issue because of its multi-dimensional nature. Factors such as dependence on fossil fuels, energy market deregulation, financial market unrest, nuclear energy development, obstacles to energy technology development, increasing energy demands of developing countries, instability of international politics and large-scale natural disasters all have significant impacts on energy security [1–3].

Global energy competition and regional energy strategic management have recently been popular topics [4,5] because of energy resource inequality around the world. Many countries regard energy security as equivalent to national security because of its influence on national autonomy and development. Facing the challenges of energy price fluctuations, energy supply shortages, and energy resource scarcity, many countries not only

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work on maintaining adequate safety stocks, but they also practice various diplomatic energy strategies to safeguard the energy supply security [6,7]. Up until now, many developed and developing countries, along with international organizations such as the EU, WEF, OECD, NATO, APEC and G8, have incorporated energy security policies into their development policies [3]. The continuous growth of energy demands among Asian countries and the reliance on imports from specific countries has raised the issue of energy security and become the main focus of the government's decision-making process [8,9].

Moreover, in light of the close relationship between energy and the environment, international environmental conventions such as the United Nations Framework Convention on Climate Change and the Kyoto Protocol, their related implementing actions and domestic environmental regulations all have direct impacts on energy use and economic development [10,11]. Climate change strongly impacts global energy resources (especially for renewable energy such as hydro, wind and solar power), energy supply and energy consumption, and it has also influenced the direction of energy policy [12,13]. If one considers GHG emissions reduction together with the energy security problem, one may find that the GHG emissions reduction strategy has a different design [14–17]. To reduce carbon emissions, the energy structure will be adjusted accordingly so that carbon-free energy, such as renewable energy and nuclear energy, or low-carbon energy, such as natural gas, will be the primary sources of energy. Countries with different energy resource endowments will result in a variation of energy policies, while optimizing the energy structure to achieve carbon reduction goals. These energy security issues are still currently important for forming energy policy and carbon reduction practices [18].

Taiwan is especially vulnerable to international energy price fluctuations because it lacks energy resources. In addition, Taiwan's energy supply relies heavily on fossil fuels, which will face severe restrictions under global GHG emissions reduction regulations. In response to this situation, Taiwan's government has proposed energy security policy measures and various carbon reduction practices. However, to ensure the nation's energy security and effectively reduce carbon emissions while achieving carbon reduction goals, a quantitative assessment and analysis must be performed to ensure the effective implementation of energy policies. Following the introduction, the second part of this study will investigate the definition of energy security, and the third part will investigate energy supply and demand in Taiwan and the challenges Taiwan faces in energy security. The fourth part of this study will assess Taiwan's energy security policy using energy security indicators. Through a variety of energy security indicators, it will analyze the effectiveness of Taiwan's energy policy and further note the functional limits of energy security indicators.

2. Definition of energy security

The definition of energy security varies with the time, place and purpose for which it is defined [19]. During the period between the First World War and the Second World War, sufficient energy for military use was a core element of energy security strategies. The two oil crises in the 1970s changed the military-use orientation of energy security policy and broadened the issue to incorporate the impact of international politics and energy price trends on the economy [20]. Since the 1980s, developing bilateral or multilateral cooperation has become a major strategy to avoid possible political and military conflict. This platform has also become the new focus of energy security issues. The previously mentioned shift of energy security concerns does not mean that the latter issue fully replaces the former issue. Instead, new concerns are integrated into the scope of energy security considerations and broaden the strategy for achieving energy security.

In their new energy paradigm for the 21st Century, Flavin and Dunn [21] noted that energy, the economy and environmental issues have been linked more closely after the end of the Cold War. In an energy-economy respect, the balance between energy supply and demand is the premise for economic development and ensuring a modern society. In other words, energy is regarded as a basic precondition of economic security. Moreover, since the 1990s, the threat of global warming has been taken more seriously, and the increase in carbon dioxide emissions through energy usage has become an important subject for energy security. In the European Commission Green Paper, published in 2001, the focus has moved from conventional long-term energy supply security and emergency reserve issues to the environmental protection issue. In considering climate change, energy consumption patterns will be limited, especially for non-renewable energy sources such as fossil fuels. In this case, the integration of the environmental issue has brought a significant change into the context of energy security [22].

Although there is a wide spectrum of opinions on energy security, researchers generally agree that energy security and risks are related [23–26]. The first priority of energy security emphasizes the complete satisfaction and stability of the energy supply. This priority indicates that in the foreseeable future, there will be enough energy reserve and production capacity domestically or abroad to meet a country's energy needs. Moreover, the energy costs will not be high enough to threaten the country's survival or place the country at a competitive disadvantage [27]. The achievement of energy security is a state in which sufficient energy supplies could be acquired at affordable prices. Energy-importing countries especially need to reduce their dependence on imported energy to ensure that they have sufficient and stable sources of imported energy under the pressure of international competition for energy. Energy security could also be achieved through energy demand growth control to reduce the pressure on the energy supply [28,29].

The APERC [30] has indicated that energy security can be influenced by four factors, namely availability, accessibility, acceptability and affordability. It has defined energy security as the ability of an economy to guarantee the availability of the energy resource supply in a sustainable and timely manner, with energy prices at a level that will not adversely affect economic performance.

Moreover, environmental concerns have also been integrated into the context of energy security and have redefined energy security as ensuring the reliability of energy sources, maintaining a sufficient energy supply at an affordable price, and avoiding irreversible impacts on the environment [31,32]. Energy security is not a one-dimensional issue. It also addresses risk management, energy diversity, policy implementation and market differences [3].

Egenhofer et al. [33] regard energy security as a concept that continuously evolves along with the dynamic changes of the energy market, energy supplies and technology. As a result, we can observe that governments change their energy security policy in response to challenges, such as the energy market liberalization, regional market integration (such as the EU), increasing interdependence and competitive pressures between global economies, and global climate change, especially concerning traditional electric utilities. Governments' energy security policy design has transcended their traditional desire of ensuring a sufficient and stable energy supply. Increasingly, these policies have emphasized the market compatibility of relevant policies and focused on risk management strategies of both energy supply and demand.

The affordability of energy prices is an important factor in defining energy security, while energy markets play an important role in energy pricing. Limited by various constraints, perfectly competitive energy markets do not exist. Therefore, energy security policies aim to maintain the operation of the market mechanism through the intervention of government policy so that energy prices will be set at a point that can bring market equilibrium and optimal resource allocation [3,34]. It is usually assumed that this price reflects the cost of providing a reliable energy supply [35]. Previous studies have placed greater emphasis on the impact of energy price changes on energy security and have rarely mentioned that the energy price itself reflects the scarcity of energy and the cost of energy shortages [36].

3. The energy situation and security issue in Taiwan

3.1. The energy situation

Taiwan lacks indigenous energy resources. Imported energy accounted for 99.4% of the total energy supply in 2010. Furthermore, Taiwan's energy supply system is independent and does not have a foreign backup system. These factors render Taiwan's energy security system especially vulnerable. Moreover, Taiwan's energy supply sources rely heavily on specific countries. In Taiwan, 79.7% of imported crude oil came from Middle Eastern countries, making Taiwan easily influenced by the political and economic instability of Middle Eastern countries. As for coal, the majority of imported coal came from Australia and Indonesia, accounting for 82.8% of coal imports. Lastly, 67.3% of natural gas came from Malaysia, Qatar and Indonesia (Table 1) [37].

The fluctuation of international energy prices has not only worsened the problem of energy acquirement but has also increased the cost of energy imports for Taiwan, which is at the mercy of international energy prices and lacks bargaining power. The rising long-term energy price trend has become a great burden to industries and households. The value of energy imports to the GDP was 11.74% in 2010, while it was 3.80% in 1990. Moreover, the per capita energy imports were NTD 69,317 in 2010, compared to NTD 8323 in 1990.

Taiwan's energy supply structure mostly depends on fossil fuels. The total energy supply of Taiwan was 145.56 million kiloliters of oil equivalent in 2010, of which coal, oil and natural gas accounted for approximately 91.3%. As for the power supply, the total installed power generation capacity was 48,882 GW, of which fossil fuels accounted for 77.6%. At the same time, the total power generation was 247,045 GWh, and fossil fuels accounted for 77.6% of that amount.

Taiwan is the 17th largest economy in the world and ranked 22nd and 23rd in carbon dioxide emissions and energy consumption, respectively (Table 2). Under the pressure of global emission reduction, it has been challenging for Taiwan to determine how to reduce the country's dependence on fossil fuels and the carbon

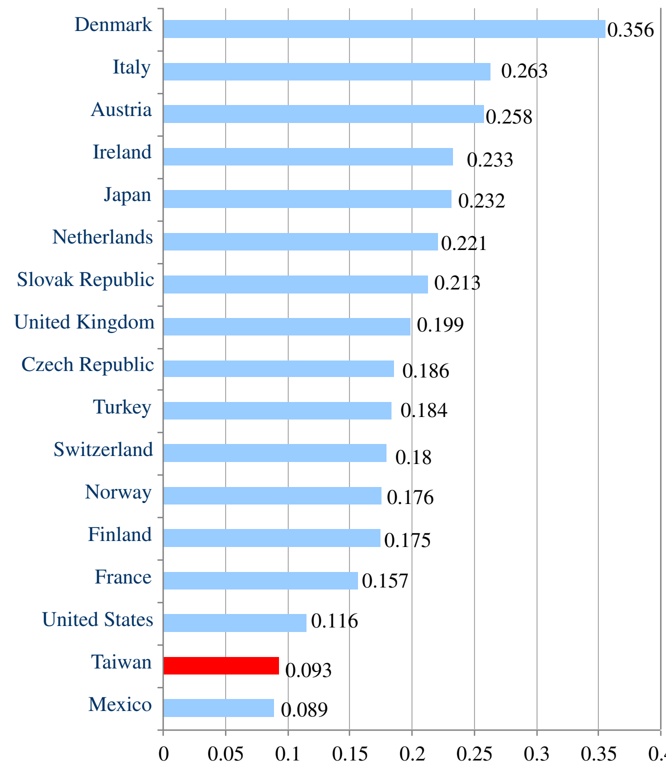

Fig. 1. Gasoline prices in Taiwan and worldwide.
Data source: IEA[39].

Table 1
Sources of energy imports for Taiwan (2010).
Data source: MOEABOE [37].

Energy Items	Unit	Amount	Import source
Coal	Million tons	63.16	Australia (45.4%), Indonesia (37.4%), China (6.2%)
Oil	Million barrels	316.68	Middle East (79.7%), West Africa (12.6%)
Natural gas	Million tons	10.95	Malaysia (25.6%), Qatar(23.8%), Indonesia (17.9%)

Table 2
Economic, energy, and CO_2 emission indicators (2009).
Data source: IEA [38].

Items	Taiwan			World	OECD
	Value	Rank	Ratio		
Total primary energy supply (Mtoe)	101.9	23	0.84	12,150	5238
CO_2 emission (Mt of CO_2)	250.1	23	0.86	28,999	12,045
GDP (billion 2000 US$)	630.4	18	0.98	64,244	32,114
Per capita energy supply (toe/capita)	4.4	23	–	1.8	4.3
Per Capita CO_2 Emissions (t CO_2/capita)	10.89	17	–	4.29	9.83
CO_2 emissions per unit of GDP (kg CO_2/GDP)	0.40	52	–	0.45	0.38
CO2 emission per unit of energy consumed (t CO_2/toe)	2.51	31	–	2.40	2.33

emission per unit of electricity consumption to lower the carbon footprint of industrial products and lessen the negative impact of a potential carbon tax in the future.

Along with economic growth, Taiwan's energy consumption has been rapidly increasing at a rate of 4.4% per annum. In 2010, domestic energy consumption was 120.3 MTOE, which is 1.36 times more than the domestic energy consumption in 1990. If we analyze the domestic energy consumption by sector, we notice that the industrial sector was the greatest consumer, which accounted for 53.8% of total domestic energy consumption in 2010, and that the transportation sector ranked second. Moreover, within the industrial sector, energy intensive industries were the principal energy consumers, responsible for 65% of the energy consumption in the industrial sector. Energy efficiency in Taiwan, however, has improved since 2001. In 2010, energy intensity was 8.46 LOE/1000 NTD, which was 19.9% lower than that in 2001.

The average gasoline price in Taiwan was 0.95 USD per liter in 2009. It was lower than neighboring countries such as Japan, Korea, and most OECD countries but slightly higher than oil-producing countries such as the United States and Mexico (see Fig. 1). The main reason for this disparity was the lower energy related tax in Taiwan. The average electricity price for the residential and service sector was 1.0 USD per KWh in Taiwan, which was also lower than in OECD countries and neighboring Asian countries (Fig. 2).

3.2. Taiwan's energy security issue

Taiwan's energy security is relatively ineffective because of a lack of energy resources and high dependence on imported energy. Moreover, oil, coal and natural gas are the major sources of Taiwan's energy supply. These conventional, high-carbon energies are all imported from foreign countries. Thus, their supply could easily be influenced by the fluctuation of international demand, production, prices and regional politics. High-carbon fossil fuels are also a major source of greenhouse gas emissions such as CO_2. Global carbon regulations would also result in the uncertainty of high-carbon energy usage.

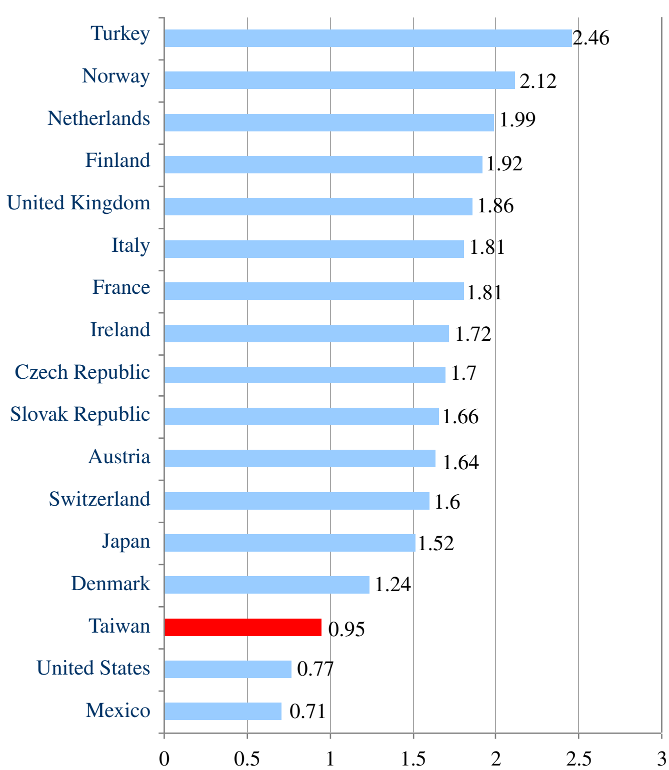

Fig. 2. Residential electricity prices in Taiwan and worldwide.
Data source: IEA[39].

From the perspective of electricity generation, a gas-fired unit enjoys the advantages of clean and environmentally friendly characteristics. The utilization of natural gas, however, is also limited by the import sources of natural gas, the capacity of the LNG terminal, loading capacity and inflexible contract terms. Moreover, its generation cost is significantly higher.

Although nuclear energy does not release carbon dioxide, the location of radioactive waste storage facilities and nuclear safety are important public concerns. Especially after the Fukushima nuclear disaster in March 2011, the issue of nuclear energy safety has been revisited and further analyzed. Taiwan's government then declared a policy to "steadily reduce nuclear dependency and gradually move towards a nuclear-free homeland" on November 3rd, 2011. Taiwan intends to rely less on nuclear energy in the future. Therefore, the proportion of nuclear energy will decrease along with the decommissioning of existing nuclear power plants [40].

Renewable energy is an indigenous energy source. It is also more environmentally friendly than conventional fossil energy. Except for wind power energy, the development of most renewable energy is restricted by its relatively higher costs, which makes it less competitive than traditional fossil energy. Given the present technology, the discontinuous characteristics of renewable energy cannot allow it to be the main energy source. On the other hand, the cost of renewable energy does not fluctuate with the price of global fossil fuels because of its non-import characteristic. As a result, increasing the proportion of electricity generation by renewable energy will reduce the costs and risks of electricity generation.

Although coal enjoys the advantages of low costs and energy source dispersion, it creates increased levels of SO_x, NO_x and CO_2 in comparison to other types of fossil energy. Therefore, the installation of coal-fired power generation facilities often faces opposition from residents and environmental organizations and cannot be completed. It needs a breakthrough in energy technology to overcome the present problem.

4. Taiwan's energy security policy

To cope with the insufficient indigenous energy supply and to satisfy the energy demands of industries and households, Taiwan's energy policy aims at securing the energy supply and improving energy efficiency. On June 5th, 2008, the government declared the "Framework of Sustainable Energy Policy" and announced the nation's sustainable energy policy objectives, which include securing stable energy supplies and plans to lower the dependency on fossil fuels and imported energy [41].

In 2009, in response to the impact of global energy trends and climate change, Taiwan also held the "National Energy Conference" to seek public consensus on energy development strategies. This conference also included a discussion on energy security and reached the following conclusion: "Energy is not only the basis for social and economic activities but also an important element in our national security strategy. Thus, many countries regard energy security as equivalent to national security, and integrate energy concerns into their diplomatic policy. To cope with the present and future energy situation, Taiwan's energy planning should equally address energy security, economic development and environmental protection concerns [42]". Therefore, at the present stage, Taiwan's energy policy is pursuing sustainable

Table 3
Taiwan's energy policy direction and objectives.
Data source: MOEABOE [41].

Dimension	Policy direction	Policy objective
Energy	• Energy security equals national security, and energy development should reflect energy security's position as a top priority	• Fully consider the natural endowment, supply risk, and costs of all energies and design a stable and affordable primary energy supply and electricity supply structure
	• Give equal consideration to economic development and environmental protection, and establish a secure and affordable energy supply and demand system	• Reduce the dependence on imported energy and the concentration of the energy supply
Economics	• Efficiently use and manage the limited energy resources • Urge the adjustment of the industrial structure towards high added value and low energy consumption	• Improve energy utilization and production efficiency so that the energy efficiency improves by at least 2% per year, i.e., the energy intensity decreases by 2% per year
Environment	• Develop environmentally friendly clean energy	• Increase the share of low-carbon energy in the electricity supply to 50% in 2020
	• Pursue a low-carbon and low-pollution energy supply	• Reduce the national CO_2 emissions so that the total emission could be reduced to the 2005 level in 2020 and to the 2000 level in 2025

Table 4
Safety stock requirements in Taiwan.
Data source: MOEABOE [43].

Energy items	Regulations	Safety stock requirement
Coal	Energy Management Law	If the enterprise engaged in energy supply meets the required level of performance set up by the central competent authority, the said enterprise shall establish energy storage facilities and maintain a safety stock If the enterprise engaged in power supply has installed a capacity larger than 500 MW, its coal-fired power plant needs to maintain 30 days of safety stock
Petroleum	Petroleum Administration Act	• Oil refinery operators and importers are required to maintain an oil security stockpile of no less than sixty days of supply. The supply amount will be based on the average domestic sales and private consumption during the past twelve months. • The security stockpile of the LPG must amount to no less than twenty-five days of the supply. The supply amount will be based on the average domestic sales and private consumption during the past 12 months. • The government should make use of the Petroleum Fund to finance the storage of oil. The amount stored shall be calculated according to thirty days of the average domestic sales and consumption of the previous year.

energy development and balances the objectives of energy security, economic development and environment protection (Table 3).

4.1. Strategies for stabilizing the energy supply

To ensure a sufficient energy supply, Taiwan has set safety requirements for coal and petroleum products (Table 4). To diversify the source of imports, Taiwan has increased the proportion of long-term purchase contracts and set the upper limit for the energy procurement from a single country or region. Taiwan also promotes international energy cooperation and subsidies the exploration for and development of oil and natural gas reserves in the Middle East, West Africa and Latin America with the Petroleum Fund according to the "Petroleum Administration Act." As for international energy cooperation, Taiwan is unable to participate in regional and international energy organizations because it is confined to the limitations of the international political situation. Therefore, integrating energy cooperation issues with a multilateral consultation platform such as the WTO and APEC, strengthening the bilateral energy cooperation mechanism, and applying energy diplomacy strategies are the major energy security policy measures used to enhance Taiwan's energy security.

4.2. Strategies for diversifying the energy supply

In diversifying the energy supply, Taiwan aims to develop a clean, secure, independent and sustainable low-carbon energy system. Its strategies include the following measures:

(1) Accelerating the development of renewable energy sources by expanding the renewable energy development targets. The installed capacity of renewable power generation units is expected to reach 9952 MW in 2025 and 12,502 MW in 2030.
(2) Increasing the usage of low-carbon natural gas to bring its share to at least 25% of the electricity system in 2025 through the construction of combined cycle gas turbine units, increasing the capacity of gas-fired power generation units, and expanding the capacity of the LNG terminal and storage system.
(3) Reducing the dependence on oil in the energy supply system in response to the scarcity of global crude oil resources and international energy trends.
(4) Accelerating the retirement of less efficient power plants, establishing power plant efficiency enhancement plans and requiring new power plants to apply the best available commercial technology. Another strategy is to reduce the capacity factor of old, coal-fired power generation units and treat them as stand-by units.
(5) Bringing in clean coal technology and developing carbon capture and storage through international R&D collaboration to reduce carbon emissions of the electricity system.
(6) Promoting the "Advanced Meter Infrastructure Project" to combine the use of smart meters with the information and communication system and creating an electricity user management system.

4.3. Strategies for improving energy efficiency

Improving energy efficiency is a major strategy designed to reduce greenhouse gas emissions. It can reduce the energy costs of industrial production and strengthen industrial competitiveness. In the "Framework of Sustainable Energy Policy," Taiwan set the policy objective to increase energy efficiency by at least 2% a year during the next eight years so that energy intensity in 2015 will fall by at least 20% when compared to the 2005 level; through technological breakthroughs and support measures, Taiwan will reduce the energy intensity by at least 50% in 2025.

For the industrial sector, which accounted for 52.4% of total electricity consumption, Taiwan has carried out various energy efficiency improvement projects, such as the expansion of energy auditing, the set-up of the energy consumption reduction target for per unit production in intensive industries, the establishment of internal energy service groups and energy conservation agreements within group enterprises, and the introduction of ESCOs. The energy efficiency improvement measures for industry, transportation, buildings, government and public sectors are shown in Table 5.

To effectively reduce the peak load of electricity and the pressure on the power supply system, Taiwan adopted many load management measures, such as interruptible power, time tariffs, seasonal tariffs, remote load shedding for ice storage air-conditioning systems and central air conditioning systems. Moreover, Taiwan set energy efficiency standards for energy consumption equipments, raised the energy efficiency standards for electric appliances, and developed energy-saving technical regulations for air conditioning and lighting devices so that the growing trend of peak load is reduced.

4.4. Strategies for maintaining affordable energy prices

In September 2006, the Taiwanese government introduced the floating oil price adjustment mechanism for gasoline and diesel to cope with soaring international energy prices. In light of price stability and household livelihood, however, this mechanism was eventually discontinued on November 2, 1996. It was not reestablished until May 28, 1997. Currently, the domestic gasoline and diesel prices are adjusted weekly, while fuel oil, natural gas and LPG prices are adjusted monthly by the Taiwan CPC Corporation. In response to rising fuel costs since 2007, the Taipower Company made a two-staged adjustment to the electricity tariff on July 1 and October 1, 2008.

In summary, the characteristics of recent energy price adjustment practices in Taiwan include the following: making regular price adjustments, reflecting changes in international energy prices, determining the magnitude of price adjustments according to the market or policies, considering consumer prices and manufacturing costs, and having state-owned petroleum and power companies share part of the fuel costs.

Taiwan's energy price policy is to rationalize the energy prices. In the short-term, it aims to reflect current fuel costs and considers household livelihood and industrial competitiveness; in the long-run, it aims to gradually reflect external costs (including the cost of environmental externalities) and to internalize external costs to enhance energy conservation and environmental protection. The implementation of the energy price policy applies a low-cost policy to benefit households and industries and does not appropriately reflect energy costs. This policy may be regarded as a short-term energy price stability strategy [44].

5. Multi-dimensional energy security indicators

The quantitative assessment of energy security has already begun in this decade [45–48]. Various indicators were developed to assess the diversity of energy sources, the dependence on imported energy, political stability [30,49,50] and the vulnerability of the oil market [51]. Kendell [52] classified the energy security indicators into three categories: dependence, vulnerability and reliability. The reliability indicators are especially suitable for the power sector, while the dependence and vulnerability indicators may be further divided into the physical indicators and economic indicators. The former shows the relative level of imports and the possibility of supply shortages, while the latter shows the impact of rising import costs or price change.

Kruyt et al. [53] summarized relevant studies on energy security indicators in recent years and classified both the simple and complex energy indicators into four categories, i.e., the availability, accessibility, affordability and acceptability. They used these indicators to assess the effectiveness of energy policies in the areas of energy security, and global energy geopolitical, economic and environmental dimensions.

This study refers to all energy security indicators summarized in the study performed by Kendell [52] and Kruyt et al. [53], and

Table 5
Sectoral energy conservation measures in Taiwan.

Sector	Policy measures
Industry	• Urge the adjustment of the industrial structure towards high added value and low energy consumption to bring the carbon emission intensity per unit of GDP down by more than 26% in 2020. New major investment projects will favor the green energy industry and non-energy intensive industries • Promote eco-industrial development through the construction of energy and resource recycling chains among industries and the establishment of a resource recycling system • Encourage the industry to apply the best available production technology internationally. Promote clean production, reduction of waste and carbon emissions, and development and investment of the green industry
Transport	• Construct a convenient mass transit network to slow down the use and growth of cars and motorcycles • Build an "intelligent transport system" to provide real-time traffic information and strengthen the functions of traffic management • Create a people-oriented urban transport environment filled with green modes of transport • Increase the efficiency level of new cars by 25% in 2015
Buildings	• Enhance urban planning and promote forestation in urban areas to create a low-carbon city • Promote low-carbon and energy conserving green architecture through energy conserving designs of building facades and air-conditioning systems as well as the utilization of green materials and the installation of renewable facilities • Promote energy performance labeling systems for buildings. • Enhance the energy efficiencies of electrical appliances by 10–70% in 2011 and further raise the standards in 2015
Government	• Promote negative growth in electricity and oil consumption in the next years among government agencies and schools and set the accumulated saving target of 7% • Incorporate the "carbon neutral" concept in policy planning and carry out carbon management by the principles of prevention, warning and screening
Public	• Conduct an energy conservation and carbon reduction campaign to call on the public to cooperate in the goal of "reducing 1 kg carbon footprint per person per day" • Mobilize all organizations, from central and local governments to township and village offices, from agencies and schools to businesses and private organizations, to push for carbon-free consumption habits to create a low-carbon and recycling-oriented society

Table 6
Structure of the multi-dimensional energy security indicators.

Dimension	Content	Indicators
Dependence	Dependence on energy source and type	• Dependence on imported energy
Vulnerability	Impact on the instability of the energy and power system	• Concentration of energy supply • Energy intensity
Affordability	Impact of energy costs on industry and household.	• Value of energy imports/GDP • Per capita energy imports
Acceptability	Impact of energy use on the environment	• CO_2 emission per unit of energy consumed

we construct the energy security indicators (Table 6) while considering the characteristics of Taiwan's energy supply and demand, and energy security issues. The indicators are divided into four dimensions: dependence, vulnerability, affordability and acceptability. By studying the trends of the various indicators, this paper analyzes the effectiveness of the energy security policy in every dimension of energy security.

- Dependence: Dependence on imported energy
  Definition: (indigenous energy supply+energy imports from long-term contracts+nuclear power supply+energy imports from controlled foreign energy mines)/total energy supply.
  This indicator is meant to review the self-sufficiency of the energy supply. It is defined as the share of indigenous energy and non-short-term energy imports over the total energy supply. The indigenous energy includes the production of coal, crude oil, natural gas, renewable energy and nuclear energy (according to the EIA, nuclear power supply is classified as production). The non-short-term energy imports include the energy imports from long-term contracts and controlled foreign energy mines.
- Vulnerability

(1) Concentration of the energy supply
Definition: This indicator uses the Shannon–Weiner index (SW index) to analyze the concentration of the energy supply, and it is calculated as follows:

$$\sum_{i=1}^{I} -p_i \ \ln(p_i)$$

where p_i is the share of energy i in the total energy supply.
This indicator is meant to measure the concentration of the energy supply. It applies the share of various energies in the total energy supply. The Shannon–Weiner index (SW index) is commonly used to analyze the diversification of market power in a single market. The U.S. Department of Justice and Federal Trade Commission adopted this indicator to measure whether a case of merging will lead to either an oligopoly or monopoly market [54]. Von Hirschhausen and Neumann [55] applied the SW indicator to measure the diversification of gas imports of specific OECD countries.
The British Department of Trade and Industry published the "UK Energy Sector Indicators 2011", which calculated the SW index of the diversity of primary fuel supplies in OECD regions in 2010 to measure the relative level of the UK energy supply stability [56]. If the proportions of all energies are relatively equal, then the index reflects the fact that the energy supply does not rely on any particular type of energy.

(2) Energy intensity
Definition: domestic energy consumption/GDP
This indicator is meant to review the decoupling of energy consumption and economic growth. It is defined as a ratio of the energy consumption over the domestic real GDP. The greater the energy intensity, the more closely economic growth is related to energy consumption. Conversely, smaller energy intensity levels show that the economic growth and energy consumption are decoupled. That is to say, the country's economic development is more efficient, which is a positive development for energy security.

- Affordability

(1) Value of energy imports/GDP
Definition: Value of energy imports/GDP
This indicator is meant to review the share of energy import costs in real GDP, i.e., the proportion of GDP used in the purchase of imported energy. The higher this proportion, the heavier the energy import expenditure. Energy is an important factor in economic growth. The higher the energy import expenditure is to the GDP, the more an economy must pay to access the necessary energy. If the proportion of energy imports to GDP is too high, it is unfavorable to energy security.

(2) Per capita energy imports
Definition: Value of energy imports/population
This indicator is used to measure the extent of per capita energy imports expenditure. It is defined as the amount each person pays for energy imports. The greater this amount, the heavier the energy import burden for each person. A higher per capita energy import displays not only the rapid increase of energy import expenditure but also indicates that a hidden energy efficiency issue must be resolved. A higher per capita energy import is not beneficial to a household's livelihood and national energy security.

- Acceptability: CO_2 emission per unit energy consumed
  Definition: CO_2 emissions from fuel combustion/total primary energy supply

This indicator is used to reflect the intensity of high-carbon fossil fuels in the energy mix. It is defined as CO_2 emissions per unit of energy consumed. The greater this indicator, the greater the proportion of high-carbon-content coal and oil in the energy mix. The high-carbon fossil fuels, such as coal and oil, are the principal sources of greenhouse gas emissions. Therefore, if the share of high-carbon fossil fuels in the energy mix is too high, then it will have a negative impact on energy security and environmental quality. That is to say, the share of high-carbon fossil fuels has an inverse relationship with energy security [57].

6. Results and analysis

Based on the multi-dimensional energy security indicators mentioned in the previous section, this study analyzes the effectiveness of Taiwan's energy policy on ensuring the security of future energy supplies. This study uses the energy statistic data published by the Bureau of Energy, Ministry of Economic Affairs of Taiwan, to calculate the energy security indicators, and observes the historical trend of these indicators from 1990 to 2010. These indicators reveal the following characteristics in Taiwan's energy supply security:

(1) Because of the decrease in indigenous natural gas production and the damage of conventional hydraulic power plants in the

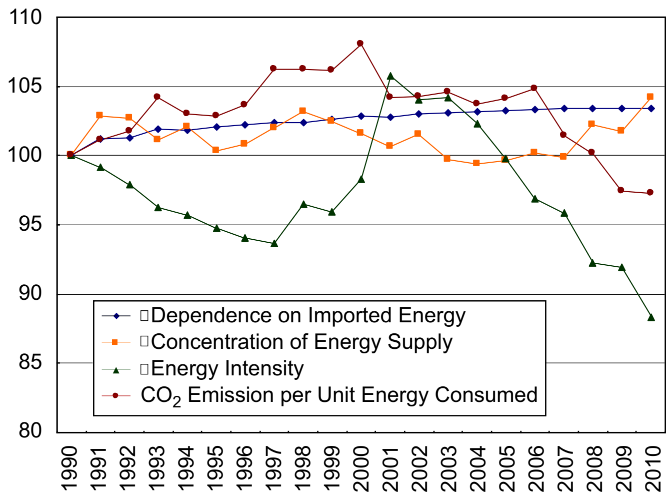

Fig. 3. Multi-dimensional energy security indicators (in dependence, vulnerability and acceptability dimensions).

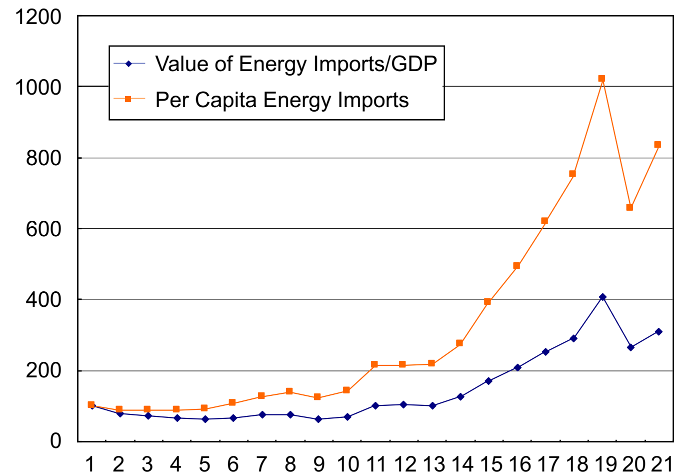

Fig. 4. Multi-dimensional energy security indicators (in the affordability dimension).

921 Earthquake in 1999, the dependence on imported energy has increased steadily. It was 99.3% in 2010 and reached a record high percentage (Fig. 3).

(2) Taiwan's energy supply mostly came from oil and coal, which accounted for more than 80% of the total supply, whereas nuclear power accounted for approximately 10%. Recently, the shares of both natural gas and renewable energy have been rapidly increasing. As a result, the concentration of the energy supply has gradually improved. Oil and coal still account for approximately 80% (Fig. 3).

(3) Along with economic growth, Taiwan's energy consumption has also been growing rapidly at a rate of 4.8% per annum, where the industry sector was the major energy-consuming sector, accounting for 52.6% of Taiwan's energy consumption, while the energy-intensive industries accounted for 65.03% of the energy consumption of the industry sector in 2010. This finding explains why Taiwan's overall energy efficiency was worse than that of other developed countries. The government has introduced a number of energy efficiency improvement measures in recent years, however, and the energy intensity has gradually decreased in the past 10 years. In the past three years, energy consumption and economic growth have showed a decoupling trend (Fig. 3).

(4) Taiwan's total CO_2 emissions were 250.11 million tons in 2009, which accounted for 0.91% of the total global emissions and ranked 23rd in the world. In the same year, Taiwan's per capita CO_2 emissions were 10.89 t, ranking 17th in the world, and were higher than the OECD average of 10.61 t of CO_2. As the world's 18th largest economy, carbon emissions have become an important subject for Taiwan's participation in the international community. Taiwan's energy mix still relies on high-carbon energy. Although Taiwan has increased the utilization of natural gas and renewable energy in recent years and has gradually reduced the CO_2 emission intensity in terms of energy consumption, Taiwan's electricity emission factor is still much higher than its trade competitors, such as South Korea, and will have a negative impact on the carbon footprint of its products. Therefore, the main objective of Taiwan's energy policy is to reduce carbon emissions so that its export-oriented economic system is not harmed by the export barriers or increases in production costs caused by future global carbon regulations (Fig. 3).

(5) Taiwan's energy supply structure relies heavily on oil, which accounts for more than 50% of the total energy supply and is almost entirely dependent on imports. As international crude oil prices were soaring, Taiwan's over-reliance on oil resulted in the increase of energy import costs to society. This trend could be witnessed by observing the value of energy imports in comparison to the GDP (15.43%) and per capita energy imports (NTD 85,013) in 2008, when both indicators reached historic highs (Fig. 4).

This study further uses the MARKAL engineering model to simulate Taiwan's energy supply and demand in 2025 under the energy security policy settings, including the following: the renewable energy development targets, the expansion of natural gas utilization, the nuclear energy development plan, the development of clean coal and carbon capture and storage technology, the improvement of power generation efficiency, the development of cogeneration, and the improvement of energy efficiency. According to the simulation, this study calculates the previously mentioned energy security indicators (Table 7) and analyzes the effectiveness of Taiwan's energy security policy through observing the changes in the trends of these indicators. The main observations are as follows:

(1) Due to the acceleration of renewable energy development and the expansion of the target for installed capacity, the dependence on imported energy will decrease but will continue to be over 98%. Compared to other countries, Taiwan's energy security is fragile in terms of dependence.

(2) Along with the decommission of existing nuclear power plants, the share of nuclear power in the energy supply will decrease and the share of coal and natural gas will increase for coal-fired and gas-fired units; therefore, natural gas will be used to substitute nuclear power. This substitute will result in the fluctuation of the concentration of the energy supply indicator. The energy policy, however, helps to diversify the energy supply in general.

(3) One goal of the energy policy is to create improvements in energy intensity. Therefore, the result of the simulation also shows the trend of the policy objectives. The existing energy-saving and energy efficiency improving measures lack a quantitative link to the policy objectives. It is uncertain whether these measures are sufficient for achieving Taiwan's energy efficiency goals.

(4) The effect of improved energy efficiency benefits the performance of the energy imports/GDP indicator values. As mentioned above, energy efficiency improvement's effectiveness is uncertain. The per capita energy imports are projected to

Table 7
Results of Taiwan's energy security indicators.

Dimension	Indicator	2010	2015	2020	2025	2030
Dependence	Dependence on imported energy	99.30	99.33	99.10	98.70	98.37
Vulnerability	Concentration of energy supply	1.180	1.228	1.243	1.200	1.259
	Energy intensity	8.47	7.61	6.88	6.21	5.60
Affordability	Value of energy imports/GDP	11.74	9.28	9.06	8.66	7.88
	Per capita energy imports	69,317	71,146	84,756	93,747	96,477
Acceptability	CO_2 emission per unit of energy consumed	2.11	2.06	2.07	2.12	2.03

grow 1.5 times in the next 20 years due to the forecasted increases in energy prices, the increasing number of imports of fossil energy used to substitute nuclear power, and the stagnant population growth.

(5) The CO_2 emissions per unit of energy consumed do not significantly change under the effects of the decrease of nuclear power, the increase of fossil fuels, and the expansion of renewable energy. Until the year 2025, when the CO_2 emissions per unit of energy consumed will increase due to a substantial decline in nuclear power, this indicator is projected to decline in the coming years. This prediction shows the effectiveness of Taiwan's policy in promoting low-carbon energy.

7. Recommendations for Taiwan's energy policy and energy security indicators

7.1. Reflecting energy security costs through energy prices

The energy price policy is a key factor in constructing a sustainable, efficient and clean energy supply and demand system. Through the operation of market mechanisms, energy prices can provide market signals for the allocation of energy resources. Because of the nature of energy resources, different types of energy are able to substitute or complement others. While the absolute energy price is important for the competitiveness of different countries and industries, the relative energy price is even more important in terms of causing structural changes in the energy supply, which is the focus of the energy policy.

Under the rational energy pricing mechanism, not only are the economics and environment beneficial, but the consumers' decisions regarding their preferred energy sources and industrial structures are also respected. It is also a common choice of the whole nation under the guidance of social consensus and economic incentives. This choice implies that society shares the internal and external benefits of this energy structure and is willing to bear the possible risks of energy security. In a democratic society, price mechanisms are the most cost-effective way of reaching public consensus on energy development when considering the complex energy issue and its correlation with international and domestic politics, social equity, environmental protection and economic development. Therefore, it is essential to design an appropriate energy price structure in the country's energy policy. In addition to reflecting internal costs, such as fuel costs, it also needs to reflect the non-market external benefits in the promotion of renewable energy and carbon reduction, along with the costs to the environment and society. By considering these factors, the energy prices could reasonably, adequately and effectively reflect all costs, operate fairly, and become an effective policy tool for energy conservation.

The conflicts between the goals of economic development, environmental protection and energy security often leads to the energy policy losing its position. Energy pricing tools are often used to serve other developmental goals. In this case, the energy price indicator is no more economically efficient and cannot ensure the optimal allocation of national resources. When the absolute energy price does not fully reflect the internal costs, it cannot ensure the effective operation of the energy industry, nor can it explore the energy-saving potential from a consumer behavior standpoint.

When the relative energy price is too low and does not reflect the external benefits and costs, it cannot provide a sufficient incentive for the development of alternative energy sources and equipment replacement. In this case, it will fail to lead the energy supply and demand toward a low-carbon and more efficient structure. Moreover, if the energy price information is not open and transparent, it may result in false expectations and interpretations of the public and industries and thus lead to the malfunction of long-term energy market mechanisms and the irrational allocation of resources and risks.

Taiwan's energy prices are relatively low, and the recovery period for the investment on energy conservation improvement is too long, which leads to manufacturers and energy users lacking any incentives to produce energy-saving equipment and to invest in energy conservation. Moreover, the timing and magnitude of energy price adjustment is often manipulated by non-energy policy considerations. This adjustment does not meet the user-pays principle and loses policy fairness by making the general public share the losses of state-owned Oil and Power Companies. Moreover, energy prices do not fully reflect the costs of energy security. This shortcoming prevents energy users from taking energy security issues into consideration through the adjustment of energy prices in the energy market; therefore, Taiwan's energy security fully relies on the efforts of government policy.

7.2. Improvement of energy security indicators

The operational definition of energy supply security has fundamentally changed in recent years as a result of the development of the international energy market and technological progress, as have the concepts for energy system planning. They have moved from emphasizing the "quantity," i.e., a sufficient and stable supply, in the traditional energy policy to the risk management of the "price" changes. For the government, a stable energy supply is a basic requirement. During times of volatile energy price changes, the maintenance of the energy supply security not only relies on a stable energy supply but also the risk management of energy prices so that energy costs may be reduced. Present energy planning concepts still follow the least-cost planning approach. This approach will inevitably choose commercial energy, which is becoming scarce these days. Their price fluctuations will become more volatile, along with an increase in its scarcity, and will consequently result in high price risks. In contrast, the supply of renewable energy is passive and capital-intensive (high fixed cost). Although the energy price risk of renewable energy is low (or even zero), its real value can be easily underestimated under the least-cost planning approach.

Renewable energy has the following characteristics, which are helpful to the security of the energy supply, energy prices, and system dispatching:

(1) Renewable energy is indigenous.
(2) The renewable energy supply is independent from international markets and political situations.
(3) The production cost of renewable energy is generally a fixed cost. In the short-term, given the fixed production technology, the price fluctuation is rather modest and does not vary with international energy prices.

Based on the above-mentioned characteristics, renewable energy could be considered as a hedging tool against fuel price changes during times of fuel price fluctuations due to the relatively stable renewable energy prices. Renewable energy is indigenous and clean, and its production cost is not usually correlated with global fossil fuel prices. Increasing the share of renewable energy in the energy mix is helpful for reducing the risk of price changes in imported energy. In this regard, ignoring the contribution of renewable energy to national energy security would underestimate its benefit. Theoretically, the above-mentioned risk premium of renewable energy and fossil fuels could be reflected appropriately in energy prices. When certain risks are related to external conditions, however, the specific external costs (such as the environmental cost) or external benefits (such as reducing dependence on imported energy) cannot be reflected by the price mechanism in the case of market failure. This problem will result in the distortion of the energy supply structure and create market barriers for specific energy types.

Furthermore, according to present energy security indicators, different types of energy are treated as independent without taking into consideration their complex complementary and substitution relationships observed in the real energy market.

For example, according to historical fossil energy price data, we observe that the prices of crude oil, natural gas and coal are highly correlated. If the energy security policy selects these fossil fuels as substitutes for one another, then this policy will surely not be able to effectively reduce energy costs and risks. That is to say, even though the energy supply structure is diversified under the energy policy guidance, it still cannot ensure that the policy can effectively reduce energy security risks if the selected energy types are correlated in price and have common energy supply and demand patterns.

In energy security policy planning, although we can distinguish the risks from different energy sources and technology categories, not all risks can be reasonably quantified. Therefore, in energy planning and energy security analysis, the appropriate means to determine risk factors and their correlations, to minimize risk in the energy mix, and to understand the effectiveness of the related energy security policies with respect to risk are all factors that may be improved upon.

8. Conclusion

Taiwan is surrounded by the sea and lacks indigenous energy sources; therefore, it is highly dependent on imported energy. The energy supply situation is more severe than that of many other countries. According to the multi-dimensional energy security indicators developed in this study, Taiwan's energy security policy can effectively reduce the nation's dependence on imported energy and improve the diversification of the energy supply. In 2011, Taiwan's energy policy clearly announced that Taiwan will gradually reduce its dependence on nuclear energy. The major challenge to Taiwan's energy supply security and energy development is how to design the supporting measures to replace the 17% of electricity supplied by nuclear power. Considering that energy resources are scarce to Taiwan, the nation should no longer regard energy sources as intermediate inputs used to fully satisfy the need of social development and economic growth. Instead, economic development should be limited by energy supply constraints. A comprehensive energy security policy should also aim at establishing an efficient economic and social system and reducing the dependence on energy. This goal is also key to effectively reducing carbon emissions and the burden of energy costs in Taiwan. The foundation of an efficient economic and social system is built on the efficiency of its energy system, energy technology and industrial structure. It also requires corresponding production and consumption patterns, energy efficiency improving incentives and policy measures, along with the legal system and market mechanisms. This requirement is not only limited in technical aspects but also includes the adjustment of economic growth and consumption behaviors. The core of this policy is reasonable energy prices. Taiwan's current energy prices are low compared to other countries. Under the social atmosphere of populist leadership, government policies are relatively weak with respect to consumer challenges and energy prices inevitably become a political issue, thus preventing market mechanisms and policy measures from functioning.

Therefore, future energy price mechanisms must have flexible, immediate and transparent characteristics to provide decision-making information for energy trading and resource allocation so that the energy resource allocation can satisfy the requirements of economic efficiency, energy efficiency, greenhouse gas emissions reduction, and social equity.

Within the present energy security indicators, different types of energy are treated as independent without reflecting their complementary and substitutionary relationships. They do not properly reflect the characteristics and roles of specific energy types within the whole energy system. For this reason, energy security indicators often fail to reveal the reality of energy security. Energy security indicators can be further improved in the above-mentioned ways.

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