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Article

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Research paper

A dual market structure design for the reform of an independent power grid system—The case of Taiwan

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ABSTRACT

In 1988, when the idea of economic liberalism was spreading across nations, the United Kingdom opened an electricity market. Soon, to increase the operational efficiency, other countries followed suit and gradually induced free competition to the electricity market. The reform aims to liberalize electric power industry, mainly features a vertical integration and deconstruction of the electric power enterprises.

This study researches the independent power grid system in Taiwan as an island, from the perspectives of the power industry and the general environment, including political and geographical factors. Difficulties faced in electricity industry reform are presented, followed by the proposition of a dual market structure and its execution plan. The dual market structure divides the whole power market into a household market and an industry and commerce market, with the hope of achieving better electricity pricing fairness and power utilization efficiency.

After studying the electricity market conditions in Taiwan from three aspects, safety, price, and environmental protection, it is concluded that both the household market and the industry and commerce market can reach a balance for supply and demand. The policies on distribution of electricity generation sources could provide the household market with a stable electricity price as well as good investment incentives for the industry and commerce market. For environmental protection, the dual structure could facilitate regulation, and reduce the disruption over the competition of the industry and commerce market. Thus, the proposed structure is suitable for the reform for an independent power grid system.

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1. Introduction

Electric power distribution is dependent on the market based on the supply and demand, due to the limitation of traditional ways of power distribution, as well as large amounts of capital that is needed for power conversion and transmission, the state-owned monopoly operation is often in place to make sure the entire society has an equal access to power. In 1988, when the idea of economic liberalism was spreading across nations, the United Kingdom opened an electricity market. Soon, to increase the operational efficiency, other countries followed suit and gradually induced free competition to the electricity market (Eikeland, 1998). However, due to the highly complex nature of the power industry, wherein a reform is possible if it involves industrial restructure, change of operation mode, etc., it is very likely to encounter unexpected setbacks in the electricity market reform

process. The setbacks could be spikes in electricity prices, electricity rationing, or even blackouts, as happened in the 2011 Southwest blackout in California, United States due to the removal of market restrictions (Portante et al., 2014). In recent years, Japan, Korea, and other Asian countries have made multiple amendments to their plans or have slowed down the reform process (Asano, 2006; Lee and Ahn, 2006). Meanwhile, changes in environment and advanced energy conversion technology have all contributed to the increasing variables in electricity market power.

As the supply and demand of power cannot be stopped, the reform must be in line with the electricity market's regular operation and the success or failure of a re-structural plan will have a massive impact. The reform methods adopted by many countries mainly aim to liberalize the electric industry and feature a vertical integration and deconstruction of electric enterprises. These methods usually would open up the supply end first, followed by liberalizing of the way of power consumption by users. However, most existing studies focus on market transaction and supervision, and pay less attention to the market characteristics or market structure applicable to different market environments.

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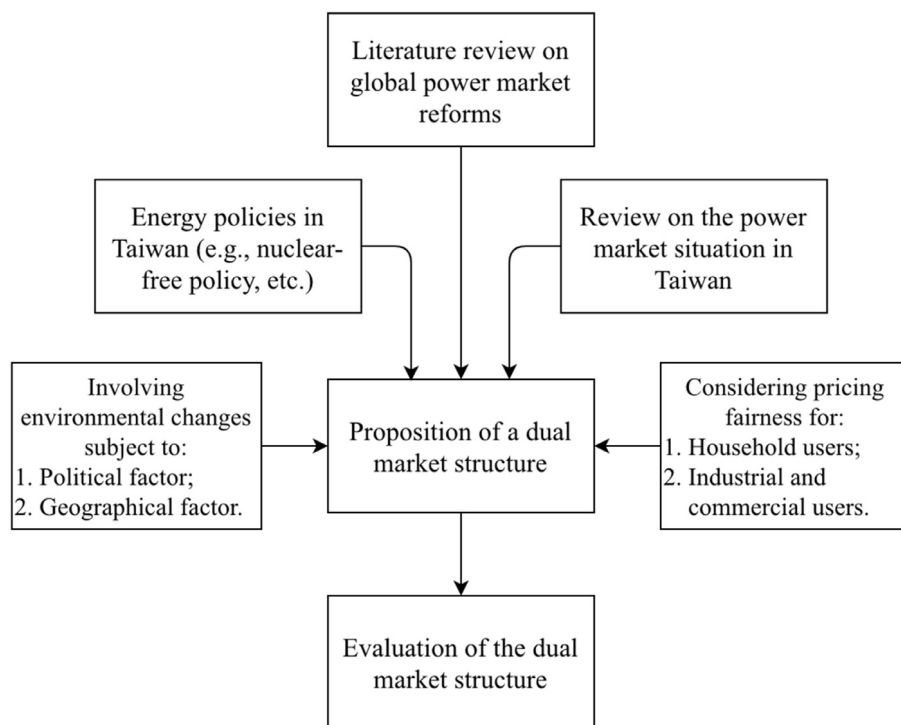


Fig. 1. Research methodology for this study.

Fig. 1 illustrates the research methodology for this study, from the perspective of market conditions of the power industry and influence of environmental changes, subject to the limitation of political and geographical factors, to the difficulties regarding reformation of its power industry, followed by putting forward a design concept for a dual exchange structure combining the household market and the industry and commerce market. The dual exchange structure combining the household market and the industry and commerce market is founded on fair distribution according to demand and redistributes different types of power supply to the household market and the industry and commerce market. It utilizes planning portfolio to identify consumers of different natures and restricts the two markets from cross-market exchange and development. Neutral units would be responsible for the construction of comprehensive power grid facilities, including public power grids that mutually regulate each other and maintain power stability. Rules regarding assistive services would be in place to carry out appropriate supervision over market operations and be responsible for the safety of the power grid. The government would adopt policy measures and price regulations through the household market, so as to safeguard the household demand. The industry and commerce markets would focus on constructing an environment of absolute fairness and freedom, in which the participants maximize their gains based on sufficient competition that is free from policy regulation without affecting the resource allocation needed for social welfare, intending to strike a good balance between competition and guarantee.

Since 1990, electricity market liberalization-oriented policies have been formulated in Taiwan, yet the legislation process has not been completed. In 2016, the new government came in office and with great effort, it has since promoted the legislation on the liberalization of the power industry; however, due to skepticism and other obstacles slowing the execution, the new government has only been able to open the market for renewable energy exchange. The plan is based on the current status quo of Taiwan's electric power industry. With the limitations of independent power grids and strong social subjective consciousness, a dual-market structure has been adopted to promote the

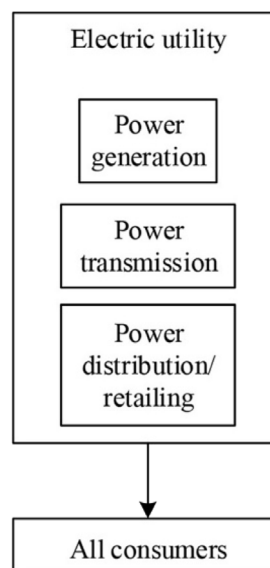


Fig. 2. Structure of the conventional electricity market.

transformation of Taiwan's electric power industry. With due consideration given to, and with due diligence exercised regarding, the assessment of safety, stability, and the environment, policies with which to plan for the allocation of energy type have been formulated. Under the premise of stable power supply, a fair and competitive market environment has been constructed to enable the society to feel the immediate benefits or expected benefits brought about by the market reform. Obvious market signals are essential to promoting and discussing the necessity of market reform. Energy and environmental protection policies and measures, without affecting the free market conditions, can quickly realize complete free competition in the market so that the market mechanism can be fully utilized.

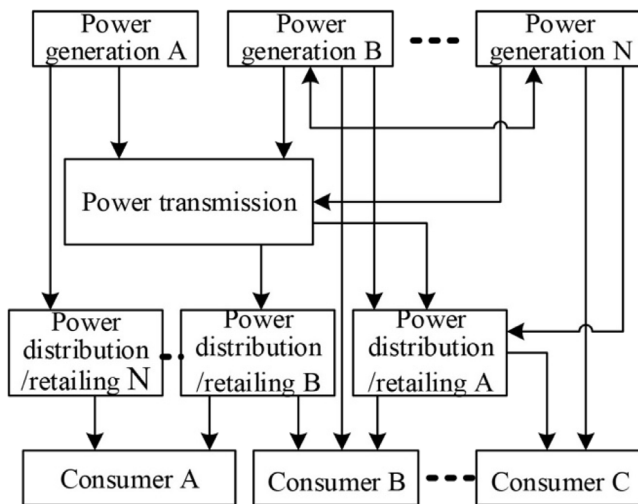


Fig. 3. Structure of the liberalized electricity market.

2. The design and development of electricity market

At the early stage of electricity market development, the main purpose was to satisfy the supply and the government played the leading role in terms of development and supply. The reform of the power industry, on the other hand, gradually took place at a later stage, when the vertically integrated market was often divided by a method that the opening of competition of power generator supply end came first, followed by opening the consumers' option right at the demand end by stages, the market structure gradually developed from conventional monopoly mode (Fig. 2) to open competition mode (Fig. 3). Due to the various opening extents of markets in different countries or regions, the results of the reform did not show instantly and neither were the operational efficiency nor the supply prices of electricity able to keep up with the market reform (Taiwan Power Company,

2017) (Fig. 4). This study reviewed the design and implementation of the electricity market reforms of the United Kingdom, which pioneered electricity liberalization; major regional electricity markets, such as those of the United States (Americas), Northern Europe (Europe), and China (Asia); and Asian countries with similar economic and social backgrounds to Taiwan, comprising Japan, Singapore, and South Korea.

2.1. Situations of different nations

The United Kingdom was one of the first countries to institute electricity market reform, and the results completely separated generation, transmission, distribution, and wholesaling activities in the market. The market is now managed and coordinated by the transmission companies, and retail wheeling is completely deregulated. However, because market reform since 1989 has primarily promoted a transactional mode of operation, basic concerns such as the desirability of capacity payments and the design of the wholesale and balancing markets, as indicated by Newbery, have remained unresolved (Newbery, 2005). Generally, the British Government's electricity market reforms have been confined to the introduction of new market and pricing mechanisms in an attempt to solve the problems of market capacity and reasonable pricing for renewable energies (Toke, 2011; Woo et al., 2003).

In the reform approach in the United States, the federal government enacts federal laws and regulations for all regions, and thereafter the regions report their experiences to the federal government so it can amend the laws accordingly. Generally, this approach allows independent transmission service providers and retailers to operate in the wholesale market, and liberalizes power-generation and distribution markets. Under this type of common framework set up by the federal government, states develop various market operation models, which lead to a range of results across the country (Joskow, 1997). The PJM market has been lauded as a success in electricity liberalization, whereas the California electricity market, which experienced a crisis, is considered a failure because of its flawed market mechanisms (Woo et al., 2003; Scott and William, 2011). Regarding Texas, although it has achieved free competition in the retail market, the state has

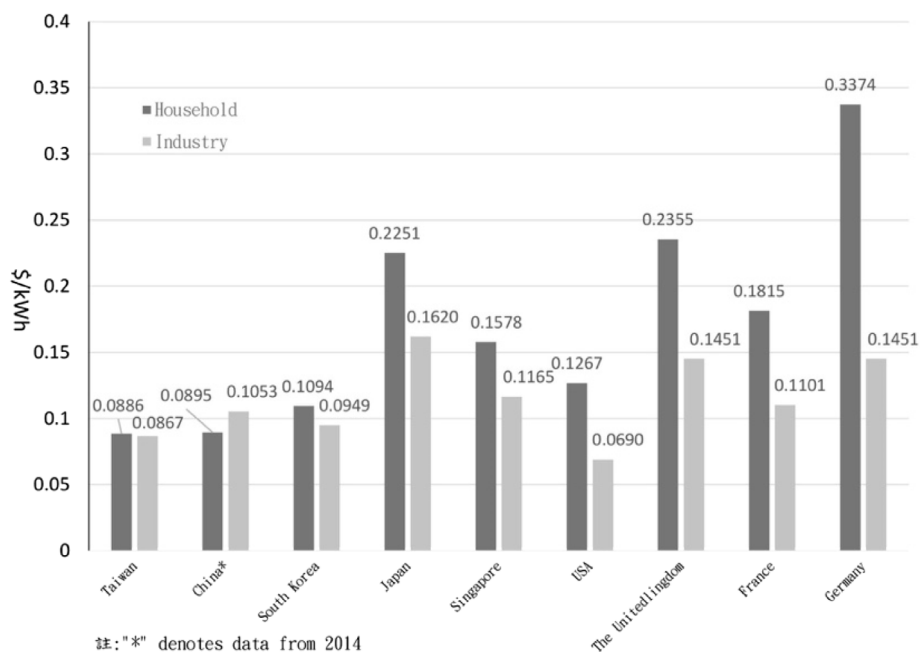


Fig. 4. Power rates of major countries in 2015.
Source: Taiwan Power Company.

failed to enhance market efficiency or lower power prices (Puller and West, 2013).

The electricity market in Northern Europe is characterized by joint trading and competition among countries with different transmission systems. The market operates smoothly because the participants have been granted full freedom of choice, which benefits product development and trade. For example, Sweden introduced green energy in 2004 for related futures trading, and in 2005 initiated carbon dioxide emissions trading in the Northern European market. However, because of the highly connected nature of the electricity pool, power line congestion considerably affects profit distribution among the operators in individual markets. Resultant disputes are resolved by countertrades and the establishment of regional power prices. Although allowing transmission system operators to benefit from power line congestions may be considered unreasonable, regulating power rates in accordance with power transmission and distribution costs can encourage investments in the electrical grid, thereby promoting the grid's healthy development. To encourage use of renewable energies such as the high-penetration wind power, the market for which involves challenges of insufficient system balance and expensive accessorial services, measures like distributed generation (for smaller generators < 10 MW) and consumer management strategies (for medium- and small-scale consumers) have been adopted. These measures regulate power prices based on consumer needs and have facilitated increases in regional market developments and operations (Bao et al., 2017).

From power undersupply prior to 1985 to oversupply after 1998, China has been able to quickly resolve related problems using incentive policies and to continue its reforms to establish a competitive market. However, because the market still retains features of planned production and the power price rates are still controlled by the government, local governments determine electrical output to balance enterprise interests and do not prioritize market efficiency. This phenomenon, along with the lack of related laws, has limited the effectiveness of official supervision (Shi, 2014; Andrews-Speed and Dow, 2000). The 2015 reforms addressed the development of the electrical grid, comprehensive supplementary measures for market transactions and power pricing, the development of green energy, and maintenance of a stable power supply for civil use. The completion of independent dispatching mechanisms has facilitated capital investment from the society, including from power-generation companies, for development of the electrical grid. However, consumers have been discouraged from sourcing their power directly from power-generation companies to prevent the operators shirking their social responsibilities (Liu, 2016).

As described, Singapore was the first country in Asia to liberalize its electricity market. Through corporatization, it unbundled electric utilities and gradually advanced from wholesale to bilateral contracts. Supervision mechanisms have prevented monopolization of the market. Overall, the reforms exhibit traces of British influence. The government approached reforms with a firm hand; measures such as maintenance of steady power supply were implemented through careful planning; and fuel supply was shifted from oil to more ecofriendly and efficient gas.

In South Korea, electricity was formerly provided by the Korea Electric Power Corporation (KEPCO), a state-owned vertically integrated electric utility. In 1994, a performance assessment of the corporation confirmed the necessity of privatization, which prompted the government to begin preparations for electricity liberalization. At the end of 2000, amendments to the Act on the Promotion of Restructuring of the Electricity Industry and the Electricity Business Act dictated the forced privatization of KEPCO and the splitting of its power generation, transmission, distribution, and retailing businesses to create a two-way bidding pool (Choe, 2002). However, due to lack of support for

further changes among stock shareholders, the companies have remained under the management of KEPCO. This has substantially deterred progress toward a fully competitive market. Moreover, the privatization policy was met with vehement opposition from KEPCO's labor union, the members of which claimed that privatization would lead to undesirable results, such as an unstable power supply, rising power price rates, and transfer of national assets overseas. This opposition forced the government to replace the division of the power-generation business with subsidiaries or business entities affiliated with KEPCO, and to postpone commitment to the two-way bidding pool (Wang et al., 2008).

The Japanese electricity market began to undergo reform during 1995–2011 with the progressive unbundling of the vertically integrated market structure. This process opened the independent power producer market and allowed mid-to-high-voltage consumers, who consumed nearly 60% of the country's electrical power, access to competitive retail supply. However, these measures were ineffective. The power shortage in the aftermath of the 2011 Tohoku earthquake resulted in a shift in reform direction toward the coordination of cross-regional power transmission to improve mutual regional support. The subsequent report prompted the House of Councilors to pass the Policy on Electricity System Reform on November 13, 2013. This policy aims to reform the electricity system in the common structure of power generation, power transmission, and power distribution and retailing through a three-step approach: (1) establishing an organization to supervise the wide-area synchronous grid and thereby reinforce cross-regional coordination among transmission operators, (2) allowing full retail competition to achieve reasonable power rates, and (3) legally unbundling the transmission and distribution sectors to promote equality in grid use. The ultimate purpose of the policy is to secure a stable supply of electricity for all regions through the wide-area synchronous grid and alternative power-generation methods, effectively suppress rising power rates by controlling fuel costs through market competition, and achieve electricity liberalization by expanding choices for consumers and reinforcing the competitiveness of the retail market (Expert Committee on Electricity System Reform, 2013; Agency for recourses and energy, 2013).

2.2. Case countries and regions

The aforementioned countries all enacted electricity market reforms toward liberalization and free competition, emphasizing the unbundling of power generation, transmission, and distribution, as well as the establishment of a public grid (Table 1). To reform their electricity industries, China, Singapore, and the United Kingdom directly broke up their integrated utilities and divided ownership of their electrical grids; Japan and South Korea started from the gradual legal unbundling of their integrated utilities by forming holding companies and subsidiaries; and Northern Europe and the United States enacted reforms based on regional autonomy and did not require division of electrical grid, although they did adopt supervisory measures to ensure impartial transmission and distribution. Operators in both Japan and the United States remain private companies, whereas their counterparts in China and Northern Europe are state-owned, and those in South Korea, Singapore, and the United Kingdom have been gradually privatized. By and large, the electrical grids of all the discussed markets remain public, and each administration has worked to develop a super grid that is stable and widely connected to expand the electricity market and promote competition. China, Japan, Northern Europe, and the United Kingdom all allow their transmission operators to maintain ownership and operative rights of their electrical grids, whereas Singapore,

Table 1

Electricity markets of selected country or region.

Country	Restrictions on the market	Restrictions on transmission operators	Operator attributes	Major wholesale transaction models	Power dispatching and transaction agency	Supervisory agency
United Kingdom	Compulsory division of power generation, transmission, distribution, and transaction	Allow simultaneous ownership and holding of operative rights	Moving toward privatization	Bilateral contracts, balanced market, spot market	Nation Grid Company	Office of Gas and Electricity Markets
United States	No compulsory separation or division	No simultaneous ownership and holding of operative rights	Privatized	Long-term contracts, capacity market, spot market	Independent System Operator of the State	Federal Energy Regulatory Commission
Northern Europe	No compulsory separation or division	Allow simultaneous ownership and holding of operative rights	State owned	Voluntary pool	Transmission System Operator ^a	Electricity regulatory agencies of member states
China	Compulsory division of power generation, transmission, distribution, and transaction	Allow simultaneous holding of ownership and operative rights	State owned	Centralized bidding and bilateral contracts	State Grid Corporation/State Grid Dispatching Digital Network	State Electricity Regulatory Commission
Singapore	Compulsory division of power generation, transmission, distribution, and transaction	No simultaneous holding of ownership and operative rights	Moving toward privatization	Voluntary pool	Energy Market Company	Energy market Authority
Japan	Compulsory separation of power generation, transmission, distribution, and transaction	Allow simultaneous ownership and holding of operative rights	Privatized	Bilateral market and spot market	Organization for Cross-regional Coordination of Transmission Operators	Ministry of Economy, Trade and Industry
South Korea	Compulsory separation of power generation, transmission, distribution, and transaction	No simultaneous ownership and holding of operative rights	Moving toward privatization, but power transmission remains state owned	Compulsory pool	Korean Power Exchange	Korean Electricity Commission

Note:

^aStatnett SF Company, Svenska Kraftnat Company, Fingrid Company, Energinet.dk Company, etc.

South Korea, and the United States impose restrictions on the simultaneous holding of such rights. All the countries appear to have established supervisory agencies over their electricity industries. Related monitoring measures allow reasonable control of transmission and distribution prices and guarantee healthy competition in the wholesale and retail markets, which are essential conditions for the maintenance of power supply stability and market order.

Under the restriction of limited energy resources, the optimal process for electricity market reform involves the coordination of power supply and allocation based on market mechanisms. These operations should be divided into generation, transmission, distribution, and transaction sectors, which should progress from monopoly, deregulated supply, and wholesale competition, to retail competition under the supervision and support of monitoring agencies and supplementary legislation (Wang and Kuo, 2015). The literature reveals the strengths and weaknesses of electricity markets worldwide and the reasons behind reforms of original market structures (Department of Energy and Climate Change, 2012). Numerous researchers have determined that a healthy electricity market requires the following: (1) the avoidance of large quantities of on-the-spot or short-notice transactions; (2) the avoidance of short-sighted practices that disturb long-term plans for installed capacity; (3) accurate reflection of regional supply and demand in prices to encourage investment in supply; and (4) greater transmission margins and generation reserve margins to undergird the market by strengthening market

power, which may increase prices. The most influential factor in achieving reform is market power. A free market can only function efficiently when supply is abundant, the number of participants is sufficient, and relevant information is accessible, because these factors prevent market competition from lowering market efficiency and compelling independent retailers to create monopolies (Moutinho et al., 2014; Karthikeyan et al., 2013; Wu, 2014; Joskow and Tirole, 2006). In recent times, several countries have proactively developed smart grids to strengthen the regulations of distributed renewable energy resources and coordinate with regional loading dispatching, together with energy storage applications. It is estimated that the high environmental costs associated with the use of fossil fuels for energy generation, and the improved efficiency of renewable energy facilities/technologies and their corresponding decreased costs would eventually lead to certain incentives that would attract owners to use distributed renewable energy sources. Politics and social consensus often play prominent roles in electricity market reform. After the Chinese government proclaimed its plans, all related measures and pilot programs were adopted immediately, and results were achieved in a short span of time. Singapore, whose electricity market is small, also exhibits a relatively stable political environment. Singapore smoothly enacted policies following the steady reform paradigm of the United Kingdom and was the first country in Asia to achieve electricity market reform. By contrast, electricity market reform in South Korea has been hampered by social discord and union interference. Despite unrelenting governmental efforts,

Table 2
Power sources in Taiwan in 2016.

Source	Number of suppliers	Installed capacity (MW)	Annual output (GWh)	Power generation share
Conventional hydroelectric	46	2089.4	6555.49	2.48%
Pumped-storage hydroelectric	2	2602	3293.67	1.25%
Thermal coal	5	10700	88011.71	33.33%
Thermal gas	11	15245.1	82866.36	31.38%
Thermal petroleum	5	3323.1	10667.74	4.04%
Nuclear	3	5144	31661.36	11.99%
Wind	29	682.1	1445.28	0.55%
Solar	41	1210.2	1132.23	0.43%
Cogeneration	–	8108.5	38456.23	14.56%
Total	142	49104.4	264090.07	100.00%

these opposition forces are still preventing achievement of the reform objectives.

Joskow, 2008 reviewed the electricity liberalization worldwide since its initiated in Great Britain 25 years ago and offered the following suggestions for the development of a competitive electricity market: (1) Horizontal unbundling of power generation should be compulsory to ensure fair competition in the power-generation wholesale market and reduce the influence of market powers. (2) Consumer participation can facilitate efficient allocation of power resources; therefore, users should be allowed free choice in the electricity market to promote the diversification of business models. (3) Mechanisms that allow seamless transition to a competitive market should be carefully planned to prevent conflict between existing and new systems. This is particularly worthy of attention.

3. Challenges in the reform of Taiwan's power industry

Taiwan, which is an island, is under environmental and political restrictions. Its power generation system has a long-time dependence on energy import and is unable to formulate a power grid connecting different countries or regions; thus, an excess or lack of power generation cannot be balanced with outbound regulation, making its power grid system an independent one. Aiming to build a nuclear-free home, the government attempted to reform the power industry and the entire market structure through the 2016 revision of the Electricity Act, which is shown in Fig. 5. The main purpose of this revision is to build a nuclear-free home, combining the introduction of green energy in power generation and retailing, testing the open competition mechanism with power industry reform, which promotes more usage of renewable energy while preserving the state-owned power enterprise at the early stage to maintain stable supply. However, the government has scheduled to separate the accounting system from the power enterprise within two years and complete the separation of corporates within six to nine years, dividing the enterprise into a holding company, a power generation company, and a power transmission and distribution company, which would lay the foundation for subsequent reform. The government adopted proactive methods in opening the electricity market, such as developing renewable energy and increasing the ratio of green energy during power generation. Due to the need for a large investment in offshore wind and solar power generation that still awaits the government to offer high feed-in tariff, as well as the intermittent nature of supply and higher uncertainties, it is highly challenging for regulators to maintain the system stability and current low prices during the reform process.

Table 3
Consumption of electricity in Taiwan in 2016.

Sector	Annual consumption (GWh)	Consumption ratio
Industrial	135474.01	51.30%
Transportation	1361.42	0.52%
Agriculture	2918.57	1.11%
Services	49146.25	18.61%
Household	47332.37	17.92%
Power plants	19045.15	7.21%
Line loss	8684.58	3.29%
Statistical difference	127.72	0.05%
Total	264090.07	100.00%

3.1. The environment of electricity market in Taiwan

In 2016, the total installed capacity of Taiwan electricity market was 49104.4 MW and the annual output was 264090.07 GWh, mainly contributed by thermal power such as thermal coal, accounting for 33.33% of the annual output, and thermal gas, accounting for 31.38% (Table 2). The system average load and peak load were 27883.6 MW and 32060.4 MW in 2006. In 2016, the two figures increased to 31397.7 MW and 35863.6 MW and the percent reserve margin increased from 16.1% in 2006 to a 28.1% peak in 2009 and declined to 10.4% in 2016 (Fig. 6), which indicated a shortage of the supply end. In addition, in 2016, deducting the energy department such as power plants' own consumption of 19045.15 GWh (accounts for 7.21% of the total consumption) and line loss of 8684.58 GWh (accounts for 3.29% of the total consumption), the industrial sector consumed the highest share of the demand end—135474.01 GWh (51.30% of the total consumption). The service sector consumed 49146.25 GWh and the household market consumed 47332.37 GWh, and adding the industrial consumption, the three sectors were accountable for more than 85% of power consumption (Table 3) (Taiwan Power Company, 0000).

3.2. The issues concerning reform of power industry in Taiwan

In Taiwan, electric power has long been supplied by a vertically integrated state-owned electric utility. According to statistics reported in 2017 by the International Energy Agency, in 2016 Taiwan's household power price rate was the second lowest in the world, and its industrial power price rate was the world's seventh lowest. However, despite its ability to maintain low power rates, which have benefitted its competitiveness in the global market, Taiwan has been plagued by inefficient operation of public utilities and information asymmetry.

The state-owned company needs to continue its investment in power generation and grid facilities so as to maintain the

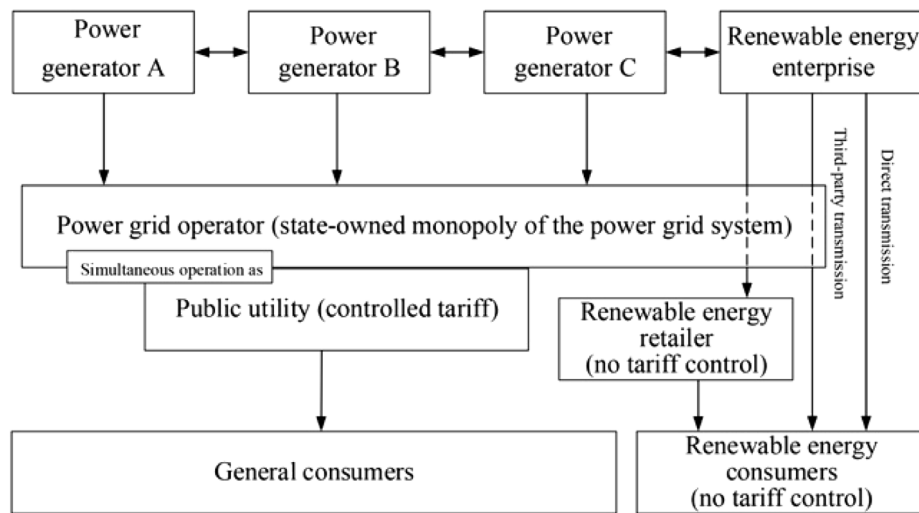


Fig. 5. Market structure envisioned by the most recent Electricity Act in Taiwan.

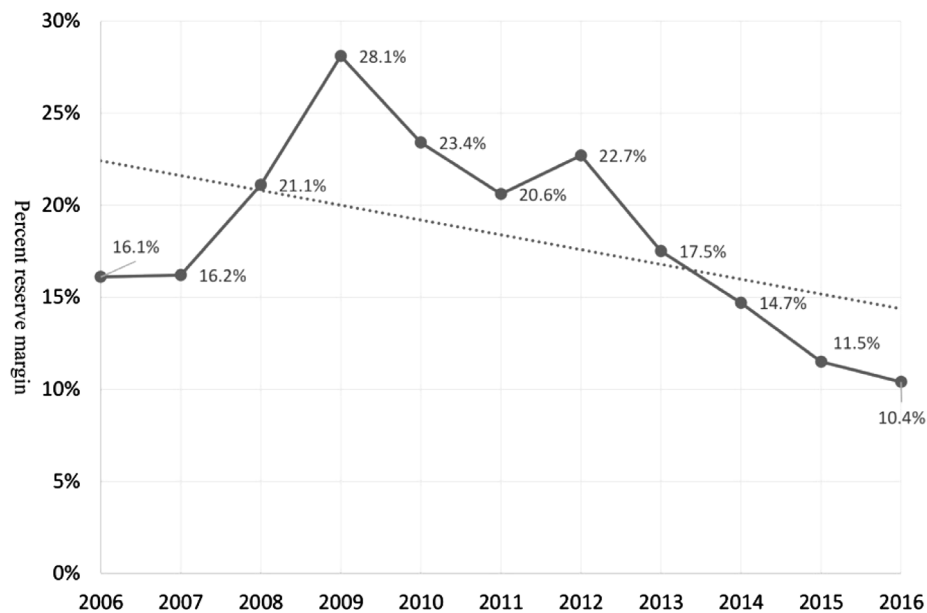


Fig. 6. Changes in percent reserve margin from 2006 to 2016.
Source: Taiwan Power Company.

stable supply; however, low electricity prices have left the people unaware of the operational difficulties in the electricity industry. Despite the popular support for environmental protection and renewable energy, several polls show the population's resistance to a price rise. For example, from 2012 to 2013, higher fuel prices compelled the government to adjust electricity prices, which was met with strong opposition from the society and a slump in support rate for the governing party, making it unable to lower consumption with higher prices. It can be concluded that it is difficult for the government to engage free competition mechanism so as to promote the reform of power industry and remove the government's burden as a leading role in the power industry. Although the government has a monopoly market place and the electricity price is easily controlled through vertical integration to share equally the costs of generation, when open competition is introduced, the opening of power generation and sales by stages fails to create a fully competitive market immediately. The controlled electricity prices fail to easily cause the happening of investment, and adding the shortage of supply and the support

from a grand power grid, it is inevitable for the power plants to be selective; thus, the shortage of supply effects the stability of power supply. Opening the market would increase the exchange costs, combining with the government's feed-in tariff and system cost to promote renewable energy, the electricity price is bound to go up.

The establishment of a nuclear-free home target encouraged environmentalists and their activities aiming to reduce thermal coal power generation. To mitigate the public grievance over air pollution, regional governments adopted administrative measures, requesting local power plants' cooperation with air pollution monitoring and load reduction. Environmental protection has affected the power system's daily operation.

The electricity market reform in Taiwan is based on considerations of the experiences of countries worldwide. The reforms follow the global trend of developing renewable energies, and use of renewable-energy-based pilot programs for liberalized competition to gradually deregulate the electricity market addresses Taiwan's energy security and environmental protection needs.

However, the plan as a whole is subject to restrictions imposed by the existing electric utility, and the design and supervision for the supporting market mechanisms are tenuous at best. So far, little information regarding the coordination of power sources and plans for and progress of new power supply infrastructure has been disclosed. Without such information, market mechanisms cannot function, and market players and stakeholders cannot adjust or formulate plans. Moreover, power supply has already exhibited signs of failure, and the forceful promotion of green energies without adequate integration of the grids and systems will only increase related security risks. Because power rates are still regulated by the government and the electricity market as a whole does not support fair competition, little social consensus for the ongoing reform is foreseeable. Ultimately, the reforms may be further inhibited by the effects of liberalization processes on the credibility of the government.

It can be concluded that on the premise of stable power supply, a market environment of fair competition is the necessary condition for the reform of power industry in Taiwan as well as for the society to feel the timely benefit or in a predictable period. Hence, the reform should be carried out on the four premises listed as follows:

- a. Stable power supply and low electricity prices must be maintained during market reform.
- b. There should be clear market signaling for public awareness of the necessity and reasons of market reform.
- c. Energy and environmental protection policies should not affect free competition in the market.
- d. The market should achieve complete free competition as soon as possible so as to give full play to the market mechanism.

4. A dual market exchange structure combining the household market and the industry and commerce market

For independent markets where there are no raw materials for self-produced energy, there is no easy access to other power grids or mutual support among them. Such markets need to feature a high degree of social consensus during the power industry reform because of their demand for energy in variable proportions. This paper, based on the fair distribution of demand, puts forth a dual market structure design for the promotion of reform of power industry, combining the household market and the industry and commerce market under one power grid, fulfilling their respective demands with different suppliers, making sure the household demands are met with stable supply and cheap regulated prices while the industrial and commercial demands are met in a fair and free environment in which sufficient competition maximizes profit.

4.1. The design concept of the market structure

The characteristics and prices for the generation of electricity vary because of diverse kinds of energy sources. The dual market structure design redistributes different types of power supply into the household market and the industry and commerce market. A planning portfolio is used to identify household consumers and industrial and commercial consumers of different attributes. Suppose that in a region with an energy mix for power generation that consists of nuclear, thermal coal, thermal gas, thermal petroleum, solar energy, wind energy, and hydroelectric, the policy makers could allocate to the household consumer a combination of power generated by nuclear that is controlled by the government, thermal coal that is maintained at a cheap price, and solar energy that is applicable to a wide range of facilities;

the industrial and commercial consumers would be allocated a combination of power generated by thermal gas and thermal petroleum, which are expensive but capable of timely regulation, and wind energy that requires relatively large investments. The two combinations are strictly allocated to the two markets that are restricted from cross-market exchange and development (as shown in Fig. 7). Neutral units should be responsible for the construction of a sound power grid – the public power grid performs as a coordinator to keep stable power supply – and a set of assistive service rules must be established so as to perform proper supervision over market operations and be responsible for the safety of the power grid. For future participants, both large-scale fossil fuel facilities and small-scale renewable energy facilities shall be supervised alike through a comprehensive mechanism by an impartial market supervisor. Power distribution is led by a neutral agency, which utilizes such infrastructures as a smart grid together with a comprehensive pricing mechanism for power transmission, so as to carry out regulations to ensure stable efficiency in using power. Moreover, it provides greater transparency of information compared with conventional practices, so that market players can evaluate the best solution for energy dispatch based on the information. The policy-making procedures are shown in Fig. 8.

The design concept of two independent markets operating under a neutral and comprehensive power grid could steadily promote the reform of the power industry within the current framework. During the reform process, the household market offers cheap power to satisfy the demands of household consumers, while the industry and commerce markets operate at full speed and strive for an environment of complete and free competition. The two markets are independent, and the policy-related subsidies and controlled electricity prices for the household market would not exert any impact on the free competition in the industry and commerce markets. As for the emissions and pollution produced by power generation, regulators must make it clear which market should bear responsibilities, efforts should be made to achieve purposes concerning three dimensions, which are safety, price, and environmental protection, the government should shoulder the safeguarding role and guarantee the household consumers' right of power consumption, and the industrial and commercial operators would attain their right of power consumption through free market competition as illustrated in Fig. 9. After the benefits of market reform and public support are delivered, adjustments to the range and ratio of power supplied to the two markets are still needed in order to cope with the changes of market environment.

4.2. Discussion of feasibility of dual market

In view of the concept of dual-market structure, which serves as the market operation mechanism for the transformation process of the electricity industry, the dual-market structure is mainly designed to reach social consensus with low electricity prices maintained under stable electricity supply, with the transformation of the existing electricity market, and to construct a perfect competition market in real time. Thus, the assessment of feasibility should be based on whether the electricity in two independent markets can supply immediate demand after the existing electricity market is transformed into dual-market and whether the industrial and commercial markets boast developable competitiveness. However, it is worth noting that with the dual market operation, in the event of an emergency, the same grid can still support both, with each market supporting the other, revealing that the risk of actually affecting the stability of power supply is expected to be quite slight.

For the foregoing discussion regarding electricity supply, reserve margin rate (shown as formula 1), commonly used by

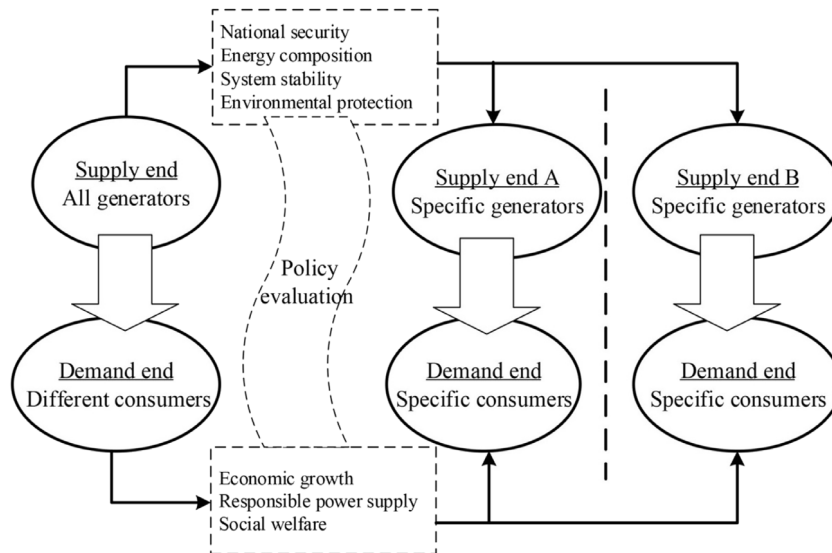


Fig. 7. Concept of the dual market structure.

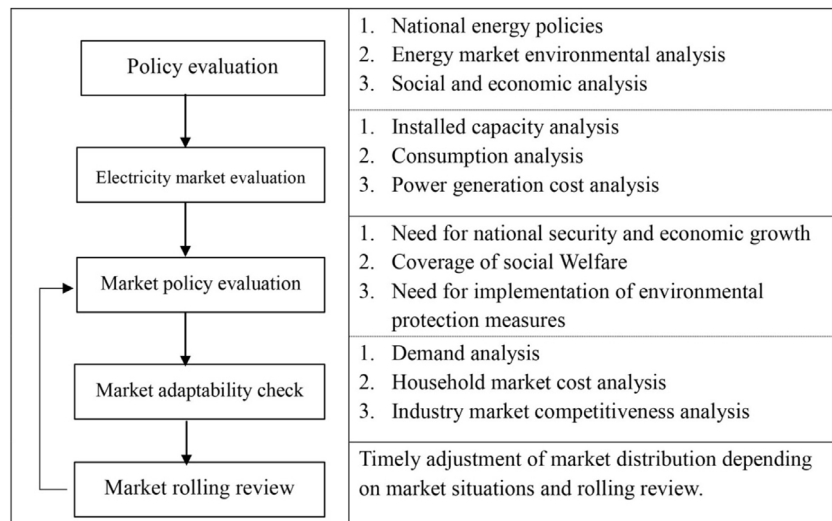


Fig. 8. Market construction process.

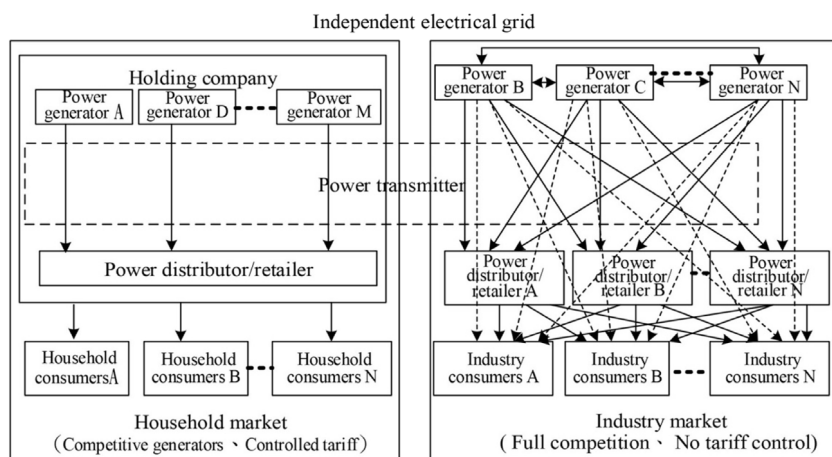


Fig. 9. Design of the dual market structure.

Table 4
Current power supply situation in Taiwan.

Source	Coal	Gas	Nuclear	Petroleum	Wind	Sun
Generator availability factor ^a	>90%	>85%	>90%	>90%	28 ~ 38%	14%
Generation costs in 2016 (NTD/kWh)	Public 1.09 Private 1.89	Public 2.12 Private 2.64	2.34 ^b	3.61	Land-based 2.79 Offshore 5.749	6.48–5.21 ^c
CO ₂ emissions in 2015 (g/kWh)	Approx. 880	Approx. 406	Approx. 742	0	0	0
Safety stock	Approx. 30 days	7–14 days	Approx. 1.5 years	Approx. 60 days	–	–

Note:

^aThe time (h) per year a generator is available for grid connection divided by 8760.

^bIncluding generators that are to be decommissioned and have their adjusted assets recognized for amortization.

^cFeed-in tariffs published in 2016.

the power sector as an indicator to measure the reliability of power supply of the power generation system, is adopted for evaluation. With the exception of Japan, the definition for reserve margin in the various globalized nations is generally the same, with the definition being the difference between the maximum generating capacity provided by the system when each generator set functions normally (i.e., the net peak capacity planned by the system), and the maximum hourly power consumption per year (i.e., the peak load). The higher the reserve margin, the more reliable the power supply system, the higher the investment, and the higher the power supply cost.

$$\text{Reserve margin rate} = \frac{\text{Reserve margin}}{\text{peak load}} \quad (1)$$

Reserve margin = the difference between the net peak capacity planned by the system and the peak load of system

Net peak capacity planned by the system = The reliable capacity at the peak of electricity consumption based on the characteristics and constraints of each device capacity.

Peak load of system = The maximum hourly power consumption per year

In order to create a market environment with complete and free competition for the industry and commerce market, the market power is used to evaluate whether the structure of industry and commerce market satisfies the conditions for fair competition (Moutinho et al., 2014; Karthikeyan et al., 2013), indexes used here include Herfindahl–Hirschman Index (HHI), a measure of market concentration, as in Formula 2, which is generally used by many countries for evaluation, and Residual Supply Index (RSI), a static concentration measure, as in Formula 3, complying with the standards of US and EU that require an HHI smaller than 2000 as well as less than 20% of market share, RSI should be greater than 1.

$$\text{HHI} = \sum_{i=1}^N \left(\frac{X_i}{X} \right)^2 = \sum_{i=1}^N S_i^2 \quad (2)$$

where N = Numbers of power plants, $\frac{X_i}{X}$ = Market share of installed capacities, S_i = Market share

$$\text{RSI} = \frac{(Q_{all} - Q_n)}{D_{all}} \quad (3)$$

where Q_{all} = Total installed capacities, Q_n = Installed capacities of power plants, D_{all} = Total demand load

4.3. Discussions on the application of dual market structure in Taiwan

With the dual-market structure put into trial use in Taiwan, a comparison between the current power supply situation

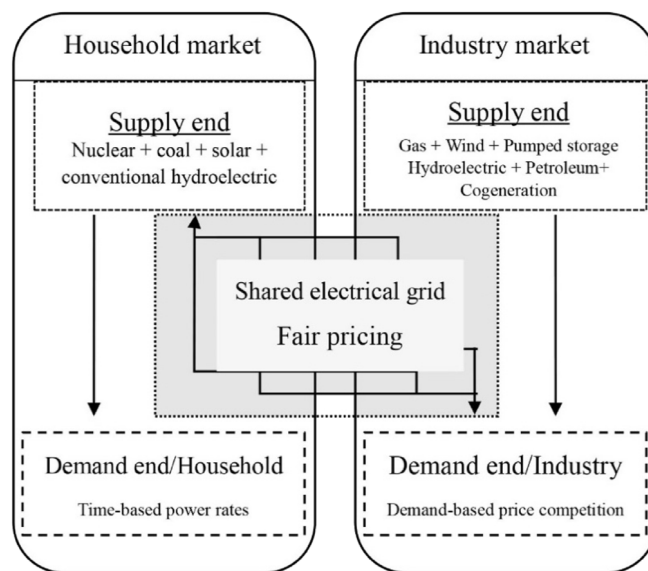


Fig. 10. Dual market system.

(Table 4) and the power consumption situation of different demand is carried out. Assuming that the policy evaluations regarding national security, energy composition, economic growth, and other factors have been conducted, the construction of the dual market structure combining household market and the industry and commerce market would continue in the following steps, at the supply end, those sources for power generation that are relatively cheap, requiring fuel control and relatively high policy-related subsidies or subject to environmental management, meaning conventional hydroelectric, thermal coal, nuclear, solar energy, and their installed capacities, should be allocated to the household market for the benefit of national security, price regulation, and environmental protection. Other sources of power generation, which are suitable for active investment, that is, pumped-storage hydroelectric, thermal gas, thermal petroleum, wind, cogeneration, and their installed capacities, should be allocated to the industry and commerce market (Table 5). At the demand end, the service, household, agriculture, and transportation sectors should be categorized into the household market and accept power supply with regulated prices, and the industry and commerce market mainly comprises industrial sectors that are accountable for high ratios of power consumption and in need of competition. The distinction between the two markets is as shown in Fig. 10.

Assuming that the public power grid is able to conduct mutual coordination and maintain stable power, comprehensive assistive service rules have been established, market operation is under appropriate supervision and the power grid is neutral, the market

Table 5
Installed capacities and net peaking capabilities in the dual markets.

Household market			Industry market		
Source	Installed capacity (MW)	New peaking capability (MW)	Source	Installed capacity (MW)	Net peaking capability (MW)
Conventional hydroelectric	2 089	1 792	Pumped-storage hydroelectric	2 602	2 392
Thermal coal	10 700	10 116	Thermal gas	15 245	14 737
Nuclear	5 144	5 054	Thermal petroleum	3 323	3 262
Solar	1 210	170	Wind	682	40
–	–	–	Cogeneration	8 109	2 042
Total	19 144	17 132	Total	29 961	22 473

Table 6
Simulated percent reserve margin of the dual market system.

Date	2016/02/25			2016/07/28		
Type	Single market	Household market	Industry market	Single market	Household market	Industry market
Peak load (MW)	26 742.82	10 781.12	15 961.70	35 863.00	17 001.30	18 862.36
Percent reserve margin	48.10%	58.91%	40.79%	10.43%	0.77%	19.14%

conditions concerning three dimensions, which are safety, price and environmental protection, are discussed as follows:

1. **Safety Dimension:** Simulated results of the reserve margin (Table 6) to determine whether the power supply market is sufficient demonstrate that, in 2016, the single market's peak load reaches its highest in February and lowest in July, the two figures are 48.10% and 10.43%. The simulated results under dual market structure show that, in the household market, the two figures are 58.91% and 0.77%; and in the industry and commerce market, the figures are 40.79% and 19.14%. The two markets achieve supply and demand balance, only in July 2016. The household market shows low reserve margin, meaning that it needs supportive services of public power grid to guarantee sound power supply. The results demonstrate that the dual market structure is more precise in terms of revealing the signaling in steady power supply. That is to say, when the single market meets its peak load, the reserve margin is 10.43% and in an emergency situation, which is often caused by a steep rise of household power consumption for air conditioning use during days of high temperature, the government would not adopt appropriate measures to address the household consumption that could cause popular grievances since the household consumers are not aware of the shortage in the power supply. In contrast, the dual market structure could distinguish between the reserve margins of the two markets. When the reserve margin of household market drops to 0.77%, it is indicative of the shortage of supply and conducive for the government to carry out related policy responses and notifications, such as attracting more investment into solar photovoltaics or improving management measures regarding demand so as to guide the consumers to change their habit of power consumption; furthermore, the measures applied in household market would not affect the operations of the industry and commerce market.
2. **Price Dimension:** In 2016, the estimated results based on the power generation costs in Taiwan (Table 7) state that the average power generation cost of the single market is 1.942 New Taiwan Dollar (NTD)/kWh; if we calculate the cost based on the dual market structure, the average power generation cost of the household market is 1.592 NTD/kWh and is 2.268 NTD/kWh for the industry and commerce market (Table 8), demonstrating that the policy-related distribution of the dual market structure is appropriate.

Table 7
Power generation costs in Taiwan in 2016.

Participants	Source	Rate (NTD/kWh)
Taiwan power company	Conventional hydroelectric	1.12
	Pumped-storage hydroelectric	2.89
	Wind	2.25
	Solar	9.49
	Coal	1.09
	Petroleum	3.61
	Gas	2.12
	Nuclear	2.34
Privately owned	Conventional hydroelectric	1.57
	Solar	6.12
	Wind	2.27
	Coal	1.89
	Gas	2.64
	Cogeneration	1.90

Table 8
Simulation of average power generation costs in the dual market system.

Single market (NTD)	Household market (NTD)	Industry market (NTD)
1.942	1.592	2.268

The average power generation cost of household market is lower than that of single market, such distinction is conducive for electricity price regulation, adjustment and energy policies, and the average power generation cost of industry and commerce market is higher than that of single market, which can attract investment.

3. **Environmental Protection Dimension:** Both the household market and the industry and commerce market are within the coverage of same environmental protection laws and regulations. The thermal coal as the biggest source of impact among all power sources is allocated to the household market, making it easier for the government to control the greenhouse gas emissions and reach the national goal it has committed. Whereas, the industry and commerce market is allocated with a large amount of thermal gases for power generation, which emit less pollution and hence mitigate the pressure from environmental protection activities.

The market power is used to evaluate whether the structure of industry and commerce market satisfies the conditions for fair competition, indexes used here include Herfindahl–Hirschman Index (HHI), as in Formula 1, and Residual Supply Index (RSI), as

Table 9

The HHI and RSI values in the industry market.

Supply end	Market share	Square of market share	RSI
Talin	7.94%	63.016	1.1067
Hsieh-ho	8.82%	77.797	1.0961
Nanpu	4.93%	24.302	1.1429
Tunghsiao	8.19%	67.070	1.1037
Hsinta	9.82%	96.373	1.0841
Tatan	19.33%	373.840	0.9697
Star Energy Power Corporation	3.97%	15.754	1.1544
Hsin Tao Power Corporation	2.65%	7.002	1.1703
Kuokuang	2.12%	4.481	1.1767
Chiahui	2.95%	8.731	1.1666
Hsingneng	2.16%	4.670	1.1762
Sun Ba	4.32%	18.679	1.1502
Star Buck Power Corporation	2.16%	4.670	1.1762
Takuan	4.41%	19.449	1.1491
Mingtai	7.06%	49.790	1.1173
Others	9.17%	84.146	1.0919
HHI:919.77			

in Formula 2, the computation results show that 90% of power plants in the industry and commerce market are accountable for less than 10% of market share, with an HHI of 919.77, complying with the standards of US and EU that require an HHI smaller than 2000 as well as less than 20% of market share, as for the RSI results, except Tatan Power Plant, which indicates 0.9697, all the other power plants have their RSIs between 1–1.2 (Table 9), that is to say that none of the power plants have market power and the market showcases competitive features (Wang and Kuo, 2015).

5. Conclusions

The purposes of open competition in reform of the power industry are to improve the operational efficiency, cope with changes of energy and environment through market mechanism, reduce environmental harm, and maintain stable power supply at a cheap price. At the current stage, countries generally promote the liberalization in a way of breaking the vertically integrated structure, separating power generation, transmission, distribution, retailing, and opening the market by stage. However, they fail to guarantee their consumers with benefits of reform or predictable profits. As a result, consumers seldom support reform, which is the biggest obstacle during reform process.

Confined by the independent power grid, Taiwan has a long-established history of state-owned power company backed by the government and its monopoly position funds the cheap electricity price. Since 1990, the electricity liberalization followed the reform examples and structures of other countries, failing to raise the public consensus to realize liberalization. The latest revision of the Electricity Act in 2016 only focused on opening the market of renewable energy, making it hard to form a free market in the short term and with inability to obtain support from other regional markets, leaving many other challenges unresolved. This paper, based on fair distribution, puts forth a dual market structure combining household market and industry and commerce market, a system that safeguards the stable power supply at a relatively cheap price for the household market while maintaining the fair and free competition for industry and commerce market, to maximize gains.

The power generation category with relatively low power generation costs that require policy control or subsidy is provided to the people's livelihood market, such as the service industry,

housing, agriculture, transportation, etc., and price control is implemented. The other power generation category is suited to ample competitive investment by industrial users with demand for high volume electricity and competition. For this category, free competition in the industrial and commercial market is allowed, and price control is not implemented, which can be carried at the beginning of the transformation, that is, after social consensus is reached and a competition environment is created. From the discussions of the market conditions in Taiwan regarding three dimensions – safety, price, and environmental protection – it can be concluded that the household market and the industry and commerce market both have the conditions for supply and demand balance. The reserve margin rates for the household market and the industrial and commercial markets were 0.77% and 19.14%, respectively, at their peak in July 2016. Such data shows the differences more clearly than a single market with reserve margin of 10.43%. The policies on distribution of power generation sources could provide the household market with stable electricity price as well as good investment incentives for the industry and commerce market, as for environmental protection, the dual structure could facilitate regulation and reduce its disruption over the competition of industry and commerce market. The market power test run on the industry and commerce market, the computation results show that 90% of power plants in the industry and commerce market are accountable for less than 10% of market share, with an HHI of 919.77, complying with the standards of US and EU that require an HHI smaller than 2000 as well as less than 20% of market share, as for the RSI results, except Tatan Power Plant, which indicates 0.9697, all the other power plants have their RSIs between 1–1.2, that is to say that none of the power plants have market power and the market showcases competitive features.

The structure is suitable for the reform of the power industry confined by independent power grid, the advantages of this structure are listed as follows:

- The supply and demand of the market showcases clear signaling, good revealing capability, and transparency, which are conducive to market operation and management.
- Regulations conducted while opening competition are guaranteed, preventing policies and market operations from interfering with each other and affecting market fairness.
- In the household market, price regulation could be used to guide the population to change their power consumption habits or to encourage decentralized sources allocation.
- In the industry and commerce market, enterprises could gain power sources through sufficient competition, making the related supply chains reflect the actual cost of sources.

In the course of implementing power industry reforms, countries would have faced problems like increasing transactional costs. The market framework proposed in this paper is no exception. The primary focus of this paper is to address the lack of consensus and its caused difficulties to independent grids in the course of power industry reform. On the basis of maintaining the existing operation of the power system, this paper aims to develop a flexible market framework that adapts to changes in the environment. It is hoped that the proposed framework could gradually help achieve a consensus in society and facilitate power industry reforms. The proposed dual market structure, if applied under a comprehensive public power grid with sound assistive services and reasonable coordination, could be anticipated to facilitate the liberalization and reform of the power industry. The structure could, with its flexible advantages, cope with dynamic adjustment of policies based on changes of environment, redistribute the sources to supply end and demand end, and achieve

complete and free competition step-by-step. These are the goal of the reform of a power industry, and could provide reference for the government in terms of decision making for promoting electricity liberalization reform. The framework's potential benefits to the power system are open for subsequent studies. If a power industry reform can reference this framework and be rolled out successfully, there would be more cases of fully liberalized power markets in the future, which would eventually give rise to a mechanism that would significantly benefit the operations of a power system.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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