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How Much Would China Gain from Power Sector Reforms?

An Analysis Using TIMES and CGE Models

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Abstract

Many countries have undertaken market-oriented reforms of the power sector over the past four decades. However, the literature has not investigated whether the reforms have contributed to economic development. This study aims to assess the potential macroeconomic impacts of an element of the power sector reform process that China started in 2015. It uses an energy sector TIMES model and a computable general equilibrium model. The study finds that the price of electricity in China would be around 20 percent lower than the country is likely to experience in 2020, if the country follows the market principle to operate the power system. The reduction in the price of electricity would spill over throughout the economy, resulting in an increase in gross domestic product of more than 1 percent in 2020. It would also increase household income, economic welfare, and international trade.

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How Much Would China Gain from Power Sector Reforms? An Analysis Using TIMES and CGE Models[1]

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How Much Would China Gain from Power Sector Reforms? An Analysis Using TIMES and CGE Models

1. Introduction

Since the 1980s, many countries have undertaken market-oriented reforms or restructuring of the power sector, and it is continuing (Jamasb, Nepal and Timilsina, 2017). The primary objective of the reforms is to restructure the vertically integrated state-owned utilities to enhance efficiency in the electricity service industry by introducing market competition and thereby encouraging the participation of private and foreign investors (Joskow, 1998; Newbery, 1999). China started the first-round power sector reform program in 2002 by altering the role of the State Development and Planning Commission (SDPC) to manage the Chinese power sector (Yeh and Lewis, 2004). It created two power grid operators (the State Power Grid and China South Power Grid) and five electricity generation companies (China Guodian Corporation, China Huaneng Group, China Datang Corporation, China Huadian Corporation, and State Power Investment Corporation) (Xu and Chen 2006; Lei et al. 2018). It also established a State Power Regulatory Commission.

Despite the 2002 reform, the Chinese power sector continued to face several problems. For example, there was a seasonal mismatch between supply and demand, thereby causing a shortage of supply to meet the demand in some seasons, whereas there was surplus capacity in other seasons. The change in wholesale prices due to the fluctuation of coal prices did not pass through the consumers as the retail (end-use) prices were controlled by the National Development and Reform Commission (NDRC), which often kept the retail prices below the wholesale prices, thereby providing subsidies (Lei et al. 2018). In this context, China started the second-round of the electricity reform in 2015. The objectives of the 2015 power sector reform are to improve the power system reliability; to increase the use of market mechanisms for power supply; to protect residential and agricultural consumers; to facilitate energy savings, to reduce emissions of greenhouse gases (GHG) and local air pollutants; to increase deployment of renewable and distributed generation; and to improve power system governance and regulation (Dupuy et al. 2015; Lei et al. 2018). To accomplish these objectives, the reform aims to enhance competition, including in the transmission and distribution segment of the electricity industry, and also to reform the retail electricity pricing (e.g., reducing crosssubsidies between the provinces and between consumer categories) (Dupuy et al. 2015; Lei et al. 2018).

One critical question is whether or not the power sector reforms undertaken over the years in various countries have achieved their stated objectives. Through a review of several studies that analyze the impacts of power sector reforms, Jamasb, Nepal and Timilsina (2017) report that power sector reforms have helped to enhance operational and economic efficiency and sectoral productivity. However, its impacts to the overall economic development and growth are unknown as no study is available to measure the macroeconomic (economy-wide) impacts of power sector reforms.

China still exercises a balanced-revenue dispatching rule which assigns numbers of operating hours to a plant in a year so that it recuperates its investment and operational costs during its economic life (Ho et al. 2017[3]; Dupuy et al. 2015). But this is not the usual practice used in power plant dispatching in most of the power systems around the world no matter whether it is a fully deregulated electricity system or state-owned vertical monopoly. The usual practice used is economic dispatching or merit order dispatching, which dispatches electricity plants based on their operational costs, normally fuel costs. The problem with China's existing dispatching system is that it gives an equal signal to each type of power generation technology irrespective of its economics (i.e., power plants with higher levelized costs get higher numbers of hours for operation). Moreover, it also dismisses the prioritization of clean sources of power generation (e.g., hydro, solar, wind) which are crucial for climate change mitigation and reducing local air pollution (Dupuy et al. 2015). While the 2015 reform document stresses the importance of reforming the dispatching rule, how it would be implemented actually is not yet clear.

The objective of this paper is to illustrate with quantitative examples the importance of power system reforms or the implementation of the 2015 power sector reform in China.[4] While existing literature focusses on impacts of power system reforms in the context of the power sector only (e.g., impacts on generation mix, wholesale and retail pricing, emission reductions

[3] Describing the current practice of electricity load dispatching in China, Ho et al. (2017) highlight the challenges of implementing electricity market reforms without altering the existing load dispatching practices.

[4] While the scope of a power system reform could be very wide, our study focusses only on the upstream of the sector (generation). Downstream issues, such as direct subsidies on the distribution system or retail pricing, are beyond the scope of this study. Interested readers could refer to Timilsina et al (2018) for downstream reforms in Bangladesh.

from the power sector), our study aims to bring the bigger picture by assessing economy-wide impacts of power sector reforms.

We use two models for this study as analytical tools. The first model is an energy sector optimization model, TIMES, which determines an optimal mix of energy supply sources to meet projected demand for a planning horizon. The TIMES model determines the difference between the electricity price in a market-based energy system and the existing price in the absence of market reforms. The economy-wide impacts of the price difference are measured using a computable general equilibrium (CGE) model. The study reveals that if China allows its power system to operate based on market rules, the country could gain more than 1% of its economic output (GDP) in 2020.

The paper is organized as follows. Section 2 briefly presents descriptions of the analytical tools used (TIMES and CGE), followed by definitions of scenarios considered in the study in Section 3. Section 4 discusses the results of the model simulations. Finally, the key conclusions are drawn.

2. Methodology

This study uses a bottom-up engineering energy sector model, TIMES, and a macroeconomic model, CGE. The TIMES model produces an optimal mix of electricity generation technologies to meet the projected electricity demand as well as an optimal mix of energy sources to meet the projected total final energy demand (i.e., including demand for other energy commodities besides electricity). While doing so, it estimates the average price of supplying electricity as well as energy as a whole. The CGE model simulates scenarios reflecting the gaps between these average electricity costs, which serve as proxies of optimal electricity prices, and the actual electricity prices, and shows how much loss the economy is experiencing not following market-based rules for the electricity supply system. Below we briefly discuss the structures of the TIMES model and the CGE model.

2.1 Electricity sector modeling using TIMES

Since the focus of the study is the electricity sector, this section highlights how the electricity sector is modeled in TIMES. However, it would be appropriate to briefly introduce the overall framework for the TIMES model.[5] We will then describe how the electricity sector is modeled within the TIMES framework.

2.1.1. Overall Framework for the TIMES Model

The TIMES model is based on the reference energy system (RES). An RES refers to a system of meeting useful end-use energy demand (e.g., light, heat, electric traction, motive power etc.) in each economic sector (e.g., industrial, households) through various channels or networks that transport energy commodities (coal, oil, gas, electricity) from domestic primary energy sources or imported primary or final energy sources. Figure 1 illustrates the RES on which the TIMES model used for this study is based. Various energy consumption technologies that produce final energy to useful energy (e.g., a boiler converts natural gas to heat, a light bulb converts electricity to light, an electrical motor converts electrical energy to mechanical energy) in the demand side whereas energy production or transformation technologies (e.g., electricity power plants to produce electricity from fuels) in the supply side. Energy transportation facilities (e.g., pipelines for oil and gas, transmission lines for electricity) carry energy commodities from production locations to demand centers.

In the China TIMES model,[6] there are five demand sectors: agriculture, industry, commercial, residential and transportation. Energy-intensive industry sectors are further divided into sub-sectors based on technology or fuels. Altogether, the model considers 43 industrial sub-sectors and more than 400 technologies. The building sector is divided into urban residential, rural residential, and commercial categories, and energy demand is further divided into space heating, cooling, water heating and cooking, lighting and electric appliances. The transport sector is first divided into two categories: passenger and freight. The passenger transport is then divided into five types, and freight transport is divided into four types.

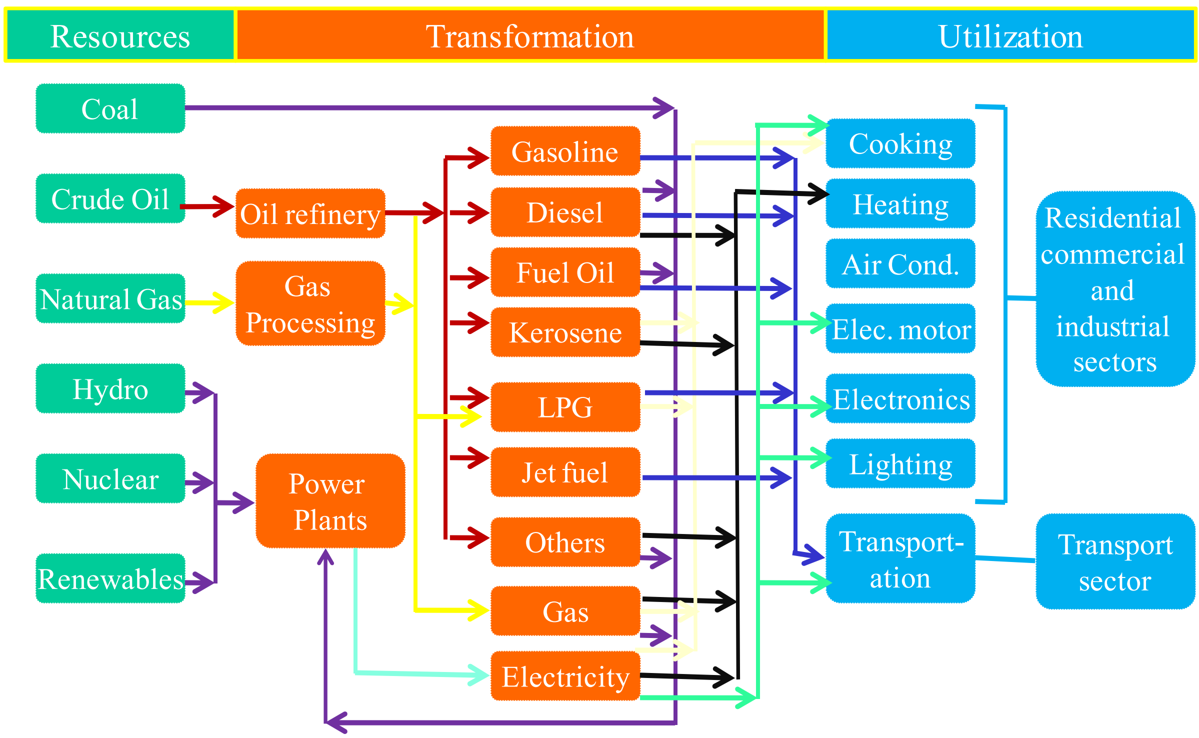
The TIMES model finds a mix of energy sources along with transformation/ transmission/transportation paths among the thousands of such possible mixes in such a way that the selected energy mix confirms that it is the least cost option to meet the given demand with available supply sources. While meeting projected end-use energy demand, the model satisfies all resource, technological, policy, and any other constraints specified. Thus, the model

[5] For more detailed description of the TIMES model, please refer to Timilsina et al. (2019).

[6] There is also a separate TIMES model for China (e.g., Chen, 2005; Chen et al. 2014). Interested readers could refer to Timilsina and Jorgensen (2018).

produces an optimal mix of energy supply sources (e.g., coal, oil, gas, LNG, hydro, solar, wind, biomass) to meet the end-use energy demand (e.g., space heating, space cooling, lighting, electric motors, motive power) in various sectors (i.e., residential, commercial/service, industrial and transport). While determining the optimal energy supply- mix, the model simultaneously determines the cheapest path to transform/transmit/transport these energy commodities to energy end-uses.

Figure 1: The Framework for the TIMES Model



Source: Timilsina and Jorgensen (2018)

End-use energy demands in TIMES are projected using driving factors such as economic growth, population growth, expected structural change in the economy, energy efficiency improvement in different technologies. Government plans and policies, such as building energy efficiency standards, industrial process energy efficiency standards, vehicle mileage standards are taken into consideration while projecting the demand.

2.1.2. Modeling the electricity sector

The TIMES model is frequently used in the literature for long-term power as well as energy system planning (see, for example, Timilsina and Jorgensen, 2018; Chen, 2005). Here we highlight the electricity module of the TIMES because the focus of this study is the electricity sector. The electricity module of the TIMES model finds out the optimal mix of electricity generation technologies to meet the projected final demand for electricity in all sectors (i.e., buildings, industrial, transport, agriculture). There are 89 electricity generation technologies in the TIMES model, of which 51 are existing technologies and 38 new or emerging technologies, such as integrated gasified combined cycle (IGCC), coal-fired power plants with capture and sequestration facilities.

The total cost of electricity generation in a year y (TC_y) is the sum of the capital rent corresponding to an operating or future generation asset (CR_y), fixed O&M of that generating asset (FC_y) and variable O&M costs of producing electricity from the asset (VC_y). The total cost is given as:

$$TC_y = \sum_g [CR_{g,y} + FC_{g,y} + VC_{g,y}] \tag{1}$$

$$CR_{g,y} = \rho_g CC_{g,y}.\left(\frac{1}{cf_g x 24 x 365}\right) \tag{2}$$

where $$\rho_g = \frac{r(1+r_g)^{l_g}}{(1+r_g)^{l_g-1}} \tag{3}$$

$$FC_{g,y} = FOM_{g,y}.\left(\frac{1}{cf_g x 24 x 365}\right) \tag{4}$$

CC_g and FOM_g are respectively, capital cost and fixed O&M cost expressed in terms of rated capacity (e.g., Yuan per kW for capital cost and Yuan per kW for per year for fixed O&M cost). Pg and lg are capital recovery factor and economic life of a generation technology g. cf_g and r_g are the capacity utilization factor and discount rate of generation technology g. Note that CR, FC and VC are applicable for a power plant already operating or to be commissioned in future. The variable costs, which mainly include fuel costs, are calculated as follows:

$$VC_{g,y} = FP_{g,y}.HR_{g,y} \tag{5}$$

$FP_{g.y}$ refers to the price of fuel used in generation technology g in year y, such as yuan per ton of coal equivalent (tce). $HR_{g.y}$ is the heat rate (amount of fuel needed to produce one unit of output of electricity (e.g., tce/kWh) of technology g in year y. Heat rate decreases over time thereby increasing the variable costs of an old plant. The average cost of electricity generation in year y (AC_y) is the total electricity generation cost in that year divided by total electricity generation (G_y):

$$AC_y = \frac{TC_y}{G_y} \quad (6)$$

The average cost calculated in equation (6) is compared with the wholesale price of electricity, which is the average price of electricity sold by generators in China to state electricity grids. If the average cost is lower than the wholesale price, it could be interpreted that the system is operating inefficiently, thereby causing an economic loss. There could be many reasons behind this inefficiency; a power sector reform is expected to reduce this inefficiency. If the average cost is higher than the wholesale price, then the wholesale price is subsidized. It also introduces inefficiency. One could argue that average cost does not reflect the wholesale price. There are many other elements, such as production taxes, added to the average costs to determine electricity prices. However, in the competitive market, either long-run marginal or short-run marginal costs are equal to electricity prices. However, unlike the typical power system planning model, the TIMES model is not capable of determining the marginal cost. Therefore, we assumed that the electricity price should reflect at least the annual average electricity supply cost.

We developed two cases. The first case considers that electricity generating plants are dispatched following the current practice, and the second case considers dispatching the power plants based on merit or economic order. However, unlike the power sector planning models, the TIMES model does not precisely reflect economic dispatching of power plants. Instead, it portrays economic dispatching through the annual capacity utilization factor (CUF). We used a dispatching rule where a power plant with the smallest operational cost dispatched first. This is the standard or 'text-book' approach for power plant dispatching in the electricity economics literature. This approach favors green energy sources for power generation (e.g., solar, wind, hydro) as they have lower operational costs (i.e., zero fuel costs) and therefore is environmentally favorable as well; it helps reduce emissions from the power sector.[7] The

[7] One might ask why the levelized cost of electricity (LOOE) based approach is not used for power plant dispatching. LCOE is used as the basis for long-run marginal costs where both operational costs and new investments (or new fixed costs) are variables. Optimal electricity pricing reflects the long-run marginal costs. Moreover, using levelized costs as the basis for power plant dispatching would be unfavorable to clean and renewable energy resources which tend to have relatively higher levelized costs of electricity (LCOE) generation. In addition, the operational cost-based approach does not conflict with the objective of minimizing power system costs because it is used only for dispatching of power plants, the electricity pricing still accounts for long-run marginal costs that include both operational costs and investments.

operational cost-based approach does not conflict with the objective of minimizing power system costs because it is used only for dispatching of power plants.

The CUFs under the existing dispatching and the merit-order dispatching are presented in Table 1.

Table 1: Capacity utilization factors used to model power plants dispatching in the TIMES model under the two cases considered

Fuel Type	Case 1: Existing load dispatching practice	Case 2: Merit order load dispatching
Coal	0.49 - 0.59	0.461
Oil	0.39	0.251
Gas	0.39 - 0.52	0.320
Hydro	0.19 - 0.45	0.457
Biomass	0.31- 0.58	0.350
Nuclear	0.80	0.800
Solar	0.16 - 0.29	0.263
Wind	0.22 - 0.34	0.263

Note: Under the Case 1, information is available for the detailed technologies, since it would be too cumbersome to list all technologies here, we presented the rage for a fuel type.

2.2 CGE model

The CGE model used in the study is a recursive dynamic model to analyze the economic effects of energy and environmental policies in China. It explicitly models the behavior of four economic agents: household, government, enterprise and the rest of the world (ROW). Productions sectors are classified into 16 sectors, of which five are energy supply sectors (coal mining, oil and gas extraction, petroleum refinery, gas processing, and electric power generation). Please see Table 2 for the definitions of the sectors.[8]

Table 2. Definition of sectors/commodities in the CGE model

Sector Name	Definition or coverage
AGRI	Agriculture, Forestry, Animal Husbandry and Fishery
COAL	Mining and washing of coal
OILNG	Extraction of petroleum and natural gas
MINE	Mining and processing of metal and nonmetal
FTPMF	Food, tobacco, textile, leather, fur, feather, timber, furniture, paper, printing
PETRO	Processing of petroleum, coking, processing of nuclear fuel

[8] Please refer to Timilsina et al. (2019) for detailed description of the CGE model.

CHEMI	Manufacture of chemical products
NMETA	Manufacture of non-metallic mineral products
METAL	Smelting and processing of metals
OTHMF	Other manufacture
ELECT	Production and distribution of electric power and heat power
GAS	Production and distribution of gas
WATER	Production and distribution of tap water
CONST	Construction
TRANS	Transport, storage and postal services
SERVI	Other services

As shown in Figure 2, the behavior of each production sector is represented by a six-tier nested constant elasticity of substitution (CES) combination function. This multi-tier CES representation provides flexibility to the model by allowing different substitution possibilities across the tiers. Like in most CGE model formulations, we assume that the market follows pure competition and the production process follows constant returns to scale. Domestic production and imports of a good/service are imperfect substitutes, popularly known as the Armington assumption. We use a CES function to combine them. A product is allocated to export and domestic markets following a constant elasticity of transformation (CET) function.

Enterprise income comes from capital returns and transfer payments from the government. Part of the after-tax enterprise income is transferred to the household, and the remainder is retained as profits from the enterprise. Households generate capital and labor incomes. Additionally, a household receives transfers from the government, the enterprise, and from abroad. Household savings are determined based on marginal propensity to save, and household expenditure is allocated to various goods and services through a Cobb-Douglas functional form. The government collects revenue through indirect taxes and import duties and goods/services, personal income tax on households and corporate income taxes on enterprises and transfer payments form other agents (households, enterprises, ROW). When a carbon tax is introduced, it is treated as an indirect tax on goods and services and carbon tax revenue goes to the government, which recycles to the economy in different ways. Total government expenditure is kept fixed and allocated to the purchase of various goods and services at the same portion as in the baseline. Government savings are the difference between total government revenue and total government expenditure.

Like in a standard CGE model, total labor supply is equal to total labor demand at the national level where labor mobility is allowed across the sectors. The same is true for the capital account – total capital demand is equal to total capital demand and capital mobility is fixed across the sectors. Wage rates and capital prices (or user costs of capital) are different across the sectors. Similarly, the total supply of a good/service (imports plus domestic production) is equal to the total demand for that good/service (domestic consumption plus exports) – Walrasian condition. The total investment is equal to total savings, which is the sum of household, government, firms and foreign savings (macroeconomic balance).

The model is made dynamic through the population growth rate (i.e., labor supply growth rate) and investment. Total savings of the previous period (or year) is the investment of the current period (year). Demand for the total capital of the current period is determined by the previous period's capital stock plus depreciation and interest payment and new-added investment (which is the previous period's total savings). The total investment is allocated across sectors in proportion to each sector's share in the aggregate capital account, and these proportions are adjusted by the ratio of each sector's profit rate to the average profit rate for the whole economy. In addition, Autonomous Energy Efficiency Improvement (AEEI) in the CGE model is considered in this study, and is assumed to be 1% per year following the common assumptions in the CGE model. Since the available social accounting matrix (SAM) is for 2012, our base year is 2012. If the model has to adopt the projected growth rate of GDP (e.g., projected by the government), it is done through adjustments in total factor productivities (TFPs).

3. Scenario simulated

We considered the following three scenarios:

BAU Scenario: The BAU scenario assumes that the increasing trend of the wholesale price continues in the near future.

Case 1: The second scenario assumes that China follows market-based rules to allocate energy resources to produce electricity (e.g., priority building of power plants based on their lower levelized costs). However, it still keeps its existing practice of balanced revenue–based load dispatching.

Case 2: In the third scenario, the dispatching constraint of the second scenario is relaxed by following the economic or merit-order load dispatching instead of the existing practice of load dispatching.

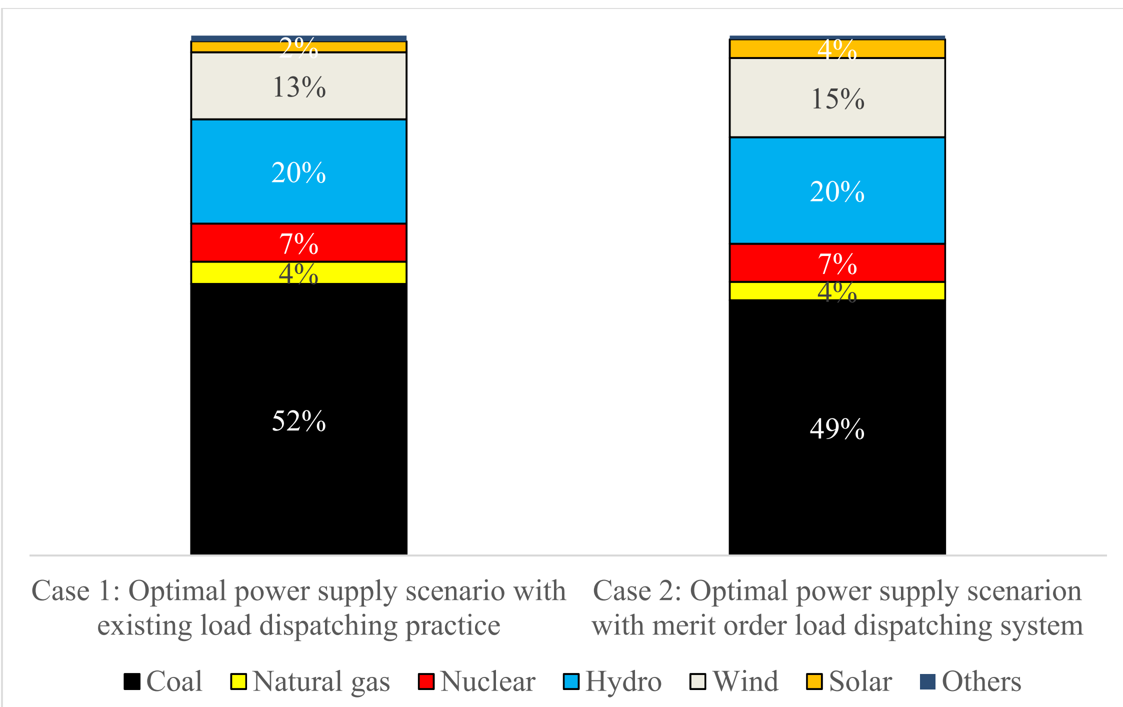
4. Results from model simulations

In this section, we first discuss results from the TIMES model followed by the discussions of results.

4.1 Results from the TIMES model

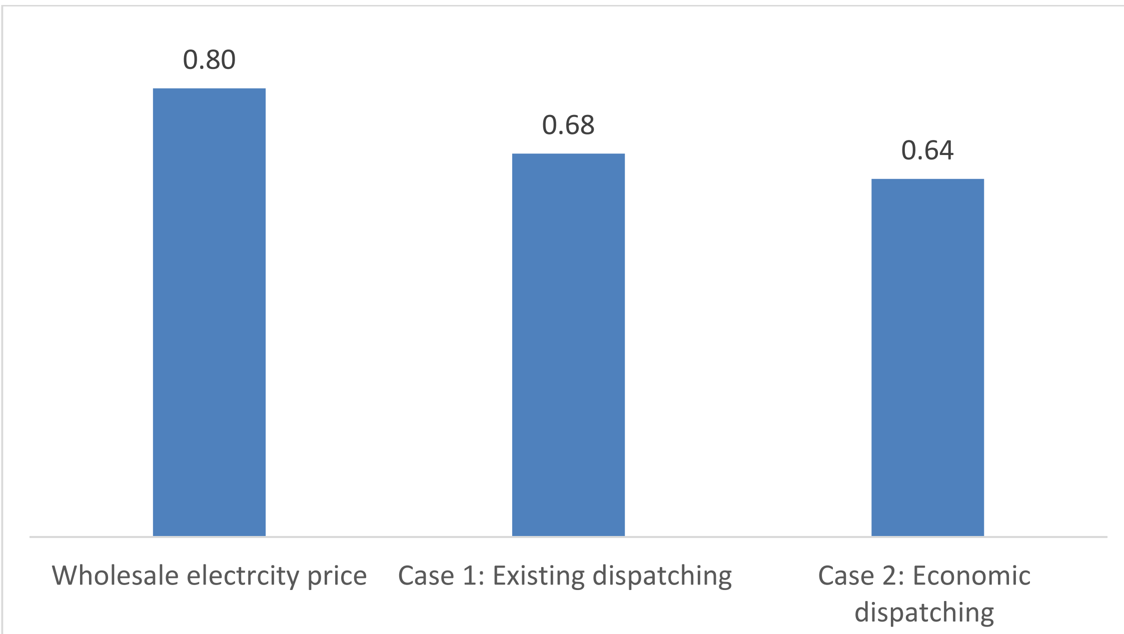
Figure 3 presents the electricity generation mix in year 2020 in two cases: Case 1 that refers to an optimal power supply scenario with existing load dispatching practice, and Case 2 that refers to optimal power supply scenario with economic (merit order) load dispatching system. The figure shows that if optimal power system planning is exercised including merit order load dispatching, electricity generation from solar power plants would double; the share of wind increases by 2 percentage points. Wind and solar basically displace coal, whose share decreases by three percentage points.

Figure 2. Electrcity generation mix in 2020



The TIMES model estimates that the average cost of electricity supply in 2020 would be ¥0.68/kWh under Case 1 and ¥0.64/kWh under Case 2. The historical wholesale electricity prices (the average prices at which generation companies sell electricity to the state electricity grids) in China is reported to be ¥0.48/kWh in 2005, ¥0.57/kWh in 2010 and ¥0.68/kWh in 2014 (LBNL, 2016). If we assume that the historical trend will continue, the wholesale electricity price will reach ¥0.80/kWh in 2020. Since this simple linear projection is highly uncertain, we limit the analysis in 2020, assuming that this sort of projection would hold in the short-run if not in the medium or long-run. The comparison of the wholesale price with optimal prices generated by the model shows that the actual electricity prices are higher as compared to those in a situation if China follows optimal electricity system planning where electricity generation mixes are decided based on the least cost principle. Even in the base case, the optimal electricity prices would be about 15% lower from the projected wholesale price in 2020. Under the market reform case, the optimal electricity prices would be 20% lower from the projected wholesale price in 2020.

Figure 3. Actual electricity price vs. optimal prices (¥/kWh)



4.2 Results from the CGE model

The macroeconomic and welfare impacts of allocating electricity generation resources with the existing load dispatching practice and merit order or economic dispatching system are illustrated in Figure 4. As can be seen from the figure, if China follows optimal electricity planning based on the market principle, the economy and the households will gain. The reduction of the electricity price from the current trend of the wholesale price due to optimal electricity system expansion would increase GDP, household income, household consumption, overall outputs from the industries and international trade. While the GDP impact appears small in percentage terms due to a large base, it is significant in absolute terms. Optimal planning of the power system would increase China's GDP in 2020 by ¥727 billion. Note that there might be several distortions, including the one caused by not following economic load dispatching. If China follows the market-based electricity dispatching system, the total increase in GDP would be ¥964 billion in 2020. The reduction of electricity pricing from the existing trend of wholesale price stemmed from the optimal electricity pricing with economic load dispatching would increase household consumption, gross output and exports around 1% each in 2020.

Figure 4. Impacts on aggregate macroeconomic variables in 2020 (%)

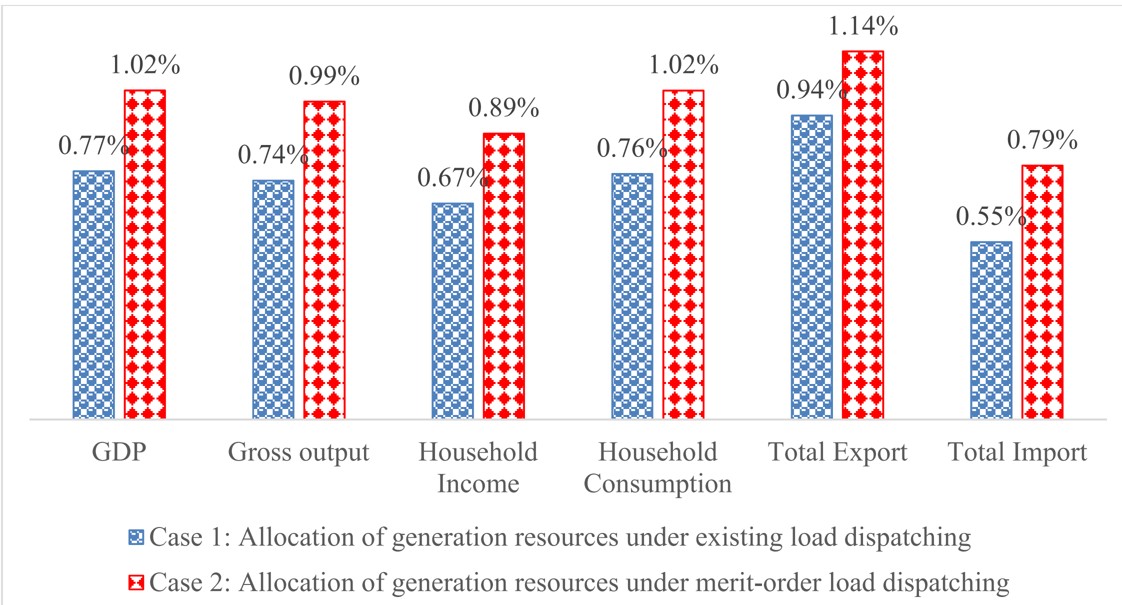
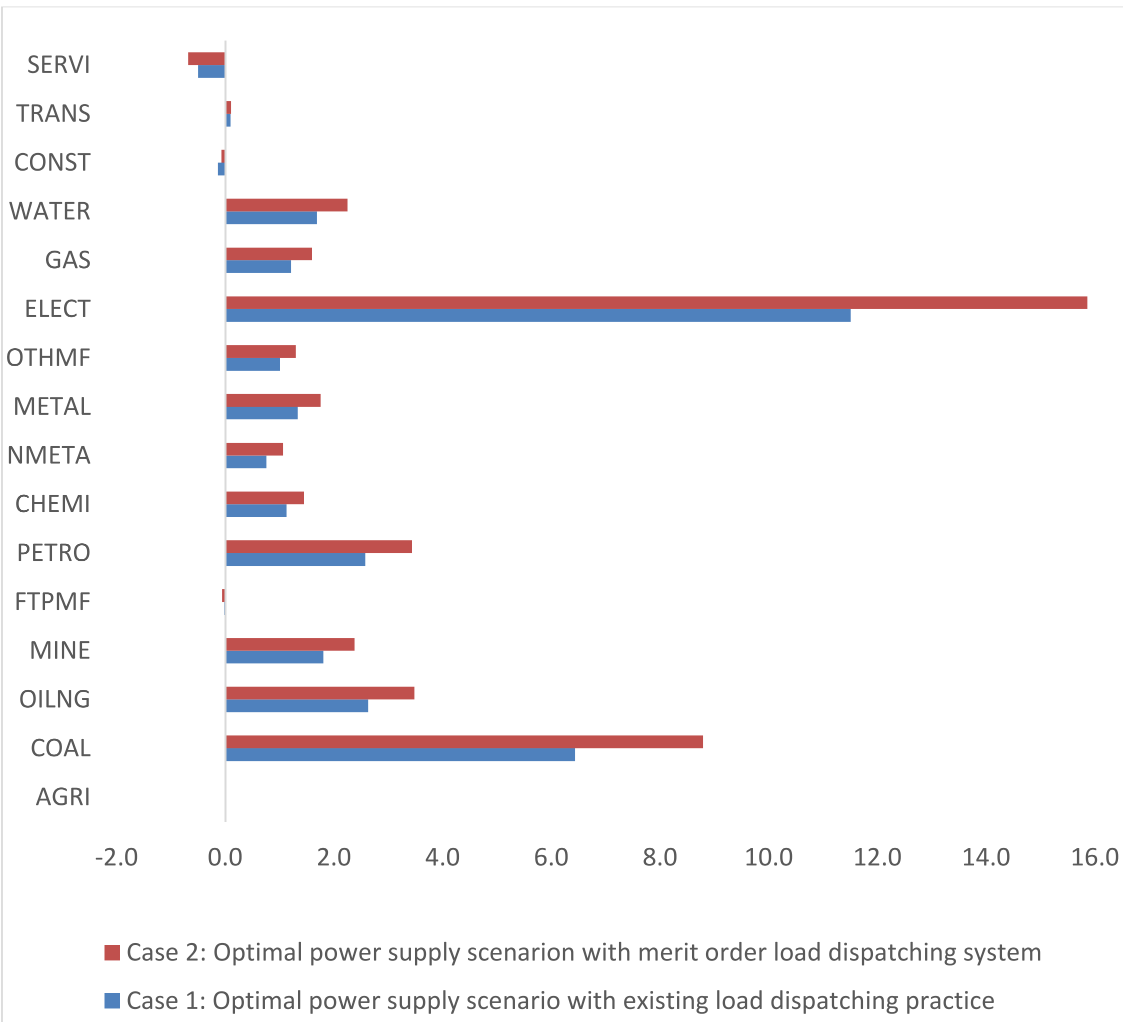


Figure 5 presents the sectoral impacts caused by the lower electricity price, which results from optimal electricity planning based on market principle. The lower electricity price increases its demand in the production sector and also in the final demand sectors. This would result in an increase in the electricity sector output by almost 12% under Case 1. It would increase by another 4% under Case 2, meaning that electricity pricing facilitated by optimal allocation of generation resources and economic dispatching of electricity generation plants would increase the output of the electricity sector by 16% from the status quo situation. Outputs from various sectors increase as their electricity input, and other electricity intensive inputs become cheaper relative to that in the baseline. Relatively low electricity intensive production sectors, such as AGRI (agriculture, forestry, livestock and fishery), FTPMF (food and tobacco, textile, leather, fur, feather, timber and furniture, paper, printing), construction, transportation, do not experience noticeable impacts. The figure shows that coal sector output also increases. However, this happened due to the limitation of the CGE model. Our CGE model has one aggregated electricity sector. If electricity output increases, it cannot identify from which type of generation sources; thereby it assumes that electricity generation from all types of sources increases proportionally. This phenomenon highlights the need for disaggregating the aggregated electricity sector of the CGE model into the different types of generation technologies even if the CGE model gets input from the bottom-up (here TIMES) model where different types of electricity generation technologies are explicitly represented.

Figure 5. Impacts on sectoral outputs in 2020 (%)



Impacts on individual commodities are presented in Table 3. The impacts on commodities are consistent with that on sectoral outputs. As electricity price goes down by 17% under Case 1 and by 22% under Case 2, the demand for electricity increases by 21% and 29% under Case 1 and Case 2, respectively. Reduced electricity prices are reflected in reduced prices of commodities produced from electricity-intensive industries. The lower prices of commodities would result in increased exports. Although increase in electricity export is high; the amount is relatively small compared to the total production volume.

Table 3. Impacts on commodities in 2020 (%)

Commodity	Case 1: Optimal power supply scenario with existing load dispatching practice				Case 2: Optimal power supply scenarion with merit order load dispatching system			
	Household consumption	Consumer prices	exports	Imports	Household consumption	Consumer prices	exports	Imports
AGRI	0.3	0.4	-1.4	0.9	0.4	0.5	-1.4	1.1
COAL	0.7	0.0	9.0	6.3	0.9	0.0	9.0	8.7
OILNG	n.a.	-0.1	4.1	2.3	n.a.	-0.1	4.1	3.1
MINE	n.a.	-0.6	6.3	0.1	n.a.	-0.7	6.3	0.2
FTPMF	0.4	0.2	-1.6	0.9	0.5	0.3	-1.6	1.2
PETRO	0.8	-0.1	4.1	2.2	1.1	-0.2	4.1	3.0
CHEMI	1.1	-0.5	3.6	-0.8	1.5	-0.6	3.6	-1.0
NMETA	1.4	-0.7	5.0	-2.9	1.8	-0.9	5.0	-3.7
METAL	n.a.	-0.6	5.7	-1.0	n.a.	-0.8	5.7	-1.2
OTHMF	0.8	-0.2	2.1	0.2	1.1	-0.2	2.1	0.4
ELECT	20.8	-16.7	67.2	-34.4	29.0	-21.8	67.2	-43.3
GAS	0.7	0.0	n.a.	n.a.	0.9	0.0	n.a.	n.a.
WATER	2.3	-1.6	n.a.	n.a.	3.0	-2.1	n.a.	n.a.
CONST	n.a.	-0.1	0.5	-0.4	n.a.	-0.1	0.5	-0.3
TRANS	0.3	0.4	-1.4	1.1	0.3	0.6	-1.4	1.5
SERVI	0.1	0.6	-2.9	0.7	0.1	0.8	-2.9	1.0

5. Conclusions

Over the past four decades, many countries have undertaken market-oriented reforms or restructuring of the power sector for multiple reasons, including attracting investment, particularly from the private sector, introducing market competition, and improving electricity service delivery. However, one critical question –- whether the power sector reforms achieved the stated objectives – has not been satisfactorily answered yet. Existing literature has shed some light on the impacts of power sector reforms from the micro perspective (e.g., impacts on generation mix, wholesale and retail pricing, emission reductions from the power sector). No literature exists to assess the macroeconomic impacts of power sector reforms. This study aims to contribute to filling this gap in the literature by assessing the potential macroeconomic impacts of an element of the power sector reform process started in China in 2015. It focusses on estimating how an effort of optimal allocation of power generation resources in terms of investment in power generation technologies and their economic operation or dispatching would bring down power supply system costs and eventually price, and how that drop in electricity price would stimulate the overall economy. The study uses an engineering bottom-up TIMES model and a top-down macroeconomic CGE model.

The study reveals that the average price of electricity in China would be around 20% lower than what the country is likely to experience in the short-run (2020) if the country follows the market principle to operate the power system including economic or merit-order dispatching of power plants instead of the current practice of dispatching administered by the government. The reduction in electricity price spills over to the economy through drops in production costs of goods and services and increased household income and welfare. The GDP increase due to this reform in 2020 amounts to 1% of GDP in that year (almost one billion yuan). It would have positive impacts on all economic indicators, such as household income, consumption and international trade.

This paper focusses only on the upstream (i.e., generation) business of the power industry. This is only a part of the power system reforms the government launched in 2015.

The economy could benefit from other parts of the reforms, such as reflecting the power supply costs in the retail pricing of electricity. This could be a natural extension of the study in future.

References

Chen, Wenying. 2005. "The costs of mitigating carbon emissions in China: findings from China MARKAL-MACRO modeling" Energy Policy, 33:885-896.

China Electricity Council (CEC). Electricity industry statistics 2010-2015.

Dupuy, M., and F. Weston and A. Hove (2015). Stronger Markets, Cleaner Air and Power Sector: Deepening Reform to Reduce Emissions, Improve Air Quality and Promote Economic Growth. The Paulson Institute. Chicago.

Ho, M.S, Z. Wang, and Z. Yu (2017). China's Power Generation Dispatch. Discussion Paper, Resource for the Future (RFF), Washington, DC.

Jamasb, T. R. Nepal and G.R. Timilsina (2017). A Quarter Century Effort Yet to Come of Age: A Survey of Electricity Sector Reform in Developing Countries. The Energy Journal, Vol. 38 (3), pp. 195-234.

Joskow, P.L. (1998). "Electricity Sectors in Transition." The Energy Journal, Vo. 19, No. 2, pp. 25–52.

Lei, N., L. Chen, C. Sun and Y. Tao (2018). Electricity Market Creation in China: Policy Options from Political Economics Perspective. Sustainability, Vol. 10, pp. 1481.

Max Dupuy, M., F. Weston and A. Hove (2015). Power Sector: Deepening Reform to Reduce Emissions, Improve Air Quality and Promote Economic Growth. Paulson Dialogue Paper. The Paulson Institute, Chicago.

Newbery, D.M. (1999). Privatization, Restructuring and Regulation of Network Utilities, MIT Press.

Teng, F., F. Jotzo, X. Wang, 2017. "Interactions between Market Reform and a Carbon Price in China's Power Sector." Economics of Energy & Environmental Policy, 2017, 6(2): 39-53.

Timilsina, G.R., S. Pargal, M. Tsigas and S. Sahin (2018). How Much would Bangladesh Gain from the Removal of Subsidies on Electricity and Natural Gas. World Bank Policy Research Working Paper. No. 8677, World Bank, Washington, DC.

Timilsina, Govinda R. and Erika Jorgensen (2018). The Economics of Greening Romania's Energy Supply System. Mitigation and Adaptation Strategies for Global Change, Vol. 23, pp.123-144.

Timilsina, Govinda R., J. Pang and X. Yang (2019). Linking Top-Down and Bottom-UP models for Climate Policy Analysis: The Case of China, World Bank Policy Research Working Paper. Forthcoming.

Xu, S. and W. Chen. 2006. The reform of electric power sector in the PR of China. Energy Policy, Vol. 34, pp. 2455–2465.

Yeh, T.E. and J.I. Lewis (2004). State Power and Logic of Reform in China's Electricity Sector. Pacific Affairs, Vol. 77, No. 3, pp. 437-465.

Yuan, J., X. Guo, W. Zhang, S. Chen, Y. Ai, and C. Zhao, "Deregulation of power generation planning and elimination of coal power subsidy in China," Util. Policy, vol. 57, pp. 1–15, Apr. 2019.

Zou, P., Q. Chen, Q. Xia, C. Kang, G. He, X. Chen. Modeling and algorithm to find the economic equilibrium for pool-based electricity market with the changing generation mix. 2015 IEEE Power & Energy Society General Meeting. DOI: 10.1109/PESGM.2015.7285840.

Geng, Z., Q. Chen, X. Chen, Q. Xia, J. Li, Y. Wang, Y. Chen. Environmental economic dispatch towards multiple emissions control coordination considering a variety of clean generation technologies. 2015 IEEE Power & Energy Society General Meeting. DOI: 10.1109/PESGM.2015.7286311.