*Berkeley-Tsinghua Joint Research Center Working Paper 002*

# Electricity Demand and Economic Transition in China: A Regional Analysis

Authors:

**Jiang Lin**

**Lawrence Berkeley National Laboratory**

Energy Analysis and Environmental Impacts Division
China Energy Group

**University of California, Berkeley**

**Xu Liu**

**Lawrence Berkeley National Laboratory**

Energy Analysis and Environmental Impacts Division
China Energy Group

**Gang He**

**Stony Brook University**

Department of Technology and Society

**July 2018**

## Acknowledgements

This work was supported by the William and Flora Hewlett Foundation and the MJS Foundation, through the U.S. Department of Energy under Lawrence Berkeley National Laboratory Contract No. DE-AC02-05CH11231.

This is a working paper, therefore intended to facilitate discussion on research in progress. This paper represents the opinions of the authors, and not meant to represent the position or opinions of the authors' institutions. Any errors are the fault of the authors. Working papers published under this Series may subsequently be published elsewhere.

# Electricity Demand and Economic Transition in China: A Regional Analysis

Jiang Lin[ab], Xu Liu[a], and Gang He[c]

[a]Lawrence Berkeley National Lab, [b]University of California, Berkeley, [c]Stony Brook University

## Abstract

China's economy is going through a major transition, characterized by a slower growth rate, a structural shift to the tertiary (service) sector, and industrial deleveraging—a process to reduce overcapacity that has built up in key industrial sectors over the past decades. Given the uncertainties faced by China during its current economic transition and the overcapacity in coal power plants, it is important to understand the key trends driving future demand growth in order to inform system planning for China's power system. This analysis examined the relationship between electricity consumption, gross domestic product (GDP), economic structure, and overcapacity in heavy industries in China, using provincial-level data from 1995 through 2015. Our models showed that a structural shift to the tertiary sector and production reduction in heavy industries slows growth in electricity consumption, although GDP remains as the leading factor driving electricity demand. Our analysis projects an annual growth rate of 3.1 percent to 5.1 percent for electricity consumption in China by 2020, given that key features in China's economic transition are likely to continue in the foreseeable future. In addition, we found regional patterns in electricity demand growth, separating the more developed regions along the eastern coast and the less-developed inland regions, due to different economic and demographic trends. These results provide a more rigorous/reliable perspective on trends in future electricity demand at both the national and provincial level and suggest that China needs a more transparent, robust, and dynamic planning methodology and process for its power sector.

## Keywords

Electricity consumption, economic structure, overcapacity, China, panel analysis

# 1 Introduction

After 35 years of rapid growth, China's economy is going through a major transition, characterized by a slower growth rate, a structural shift from the industrial sector to the tertiary (service) sector, and industrial deleveraging—a process to reduce overcapacity that has built up in key industrial sectors over the past decades. China's gross domestic product (GDP) growth rate was 7.3 percent in 2014, 6.9 percent in 2015, and 6.7 percent in 2016 [1]. Contribution of the tertiary sector to total GDP has exceeded 50 percent since 2015 and grew to 51.6 percent in 2016 [1]. The growth of the six most energy-intensive industries (processing of petroleum, coking, and processing of nuclear fuel; manufacture of raw chemical materials and chemical products; manufacture of non-metallic mineral products; smelting and pressing of ferrous metals; smelting and pressing of non-ferrous metals; and production and supply of electric power and heat) decreased from 7.5 percent in 2014 to 6.3 percent in 2015, and to 5.2 percent in 2016 [1–3].

All of these factors have a profound impact on China's energy demand and electricity consumption. A result of rapid expansion over the past three decades, China has the largest electric power system in the world, with an installed capacity of 1,650 gigawatts (GW) and a total generation of 5,990 terawatt-hour (TWh) in 2016 [4]. Electricity consumption grew at an annual rate of more than 10 percent from 2010 to 2013. However, the rapid growth in China's electricity use has slowed significantly in recent years. Growth in electricity consumption slowed to 3 percent in 2014 [5] and 0.96 percent in 2015 [6]; however, it bounced back to 5 percent in 2016 [4].

At the same time, China's power sector is going through profound regulatory and technological changes, driven in part by China's commitment to clean energy targets under the Paris Agreement, i.e., aiming to obtain 20 percent of its energy from non-fossil energy sources by 2030. Although China leads the world in investing in renewable electricity sources, there is also a widespread overcapacity for coal-fired power plants and significant curtailment of wind, solar, and hydro power [7–9]. A careful integrated resource planning process and methodology is essential to avoid overinvestment in coal-fired power plants and renewable curtailment, and achieve the multiple objectives of economic efficiency, power system reliability, and environmental goals.

Understanding the trend in demand growth—to project future electricity consumption—is a fundamental part of this planning process. These projections must be based on an informed, realistic view of current trends in electricity usage and the economic factors that influence them, and rigorous economic models. Given China's current economic transition, it is important to examine whether the existing slowdown in electricity use represents a pivot in China's energy and economic dynamics or whether it's an anomaly, and future increases in electricity consumption will remain high. Our hypothesis is that the recent slowdown in China's electricity use is a result of a fundamental shift in China's evolving economic transition, characterized by the following:

(1) an economic slowdown from an average of 10 percent growth for the past three decades to a sub-7 percent growth rate in 2015

(2) the growth of the tertiary (services) sector, which is less energy-intensive, as China moves from an investment-based economy to a consumption- and services-based economy

(3) a decline in growth rates of heavy industrial products output, due to excess capacity and slowdown in demand for such products

Previous studies that forecast future electricity consumption in China primarily used either simulation models that estimate electricity consumption based on energy demand of end-use sectors [10–12], econometric models using national-level data [13], or econometric models using provincial-level data without considering all three key factors of economic transition in China [14]. The present study provides a perspective on future electricity consumption in 2020 that considers China's economic transition based on econometric models and highlights the importance of considering regional differences in electricity demand forecast and planning.

We used econometric models to examine the correlation between economic development and electricity consumption, considering structural change and the reduction of heavy industry overcapacity, to examine the impact of economic transition on electricity consumption. Assuming that these trends in economic transition will continue in the foreseeable future, we tested the impacts of these trends to understand if they would increase or decrease the growth rate of electricity use in the future. Our research can be used to help policy-makers make informed, scientifically based decisions on power system planning and investment in China.

In addition, we tested whether there existed regional patterns for electricity growth, considering that provinces are under different stages of economic development. We used provincial-level time series data to capture provincial differences and examined whether subnational-level planning is necessary for electricity planning.

Assuming that the existing economic transition continues in China, our model projects an annual growth rate of 3.1 percent to 5.1 percent in electricity consumption, reaching 6623 to 7290 TWh in 2020, similar to the results of IEA and Lin et al. (2016) and the *13$^{th}$ Five-Year Plan* [10,14,15]. Our results also show regional patterns of electricity growth, indicating that different models are needed to fit different stages of economic development in different provinces of China.

This paper is organized as follows: Section 2 reviews previous studies on forces driving electricity consumption and electricity demand forecasting. Section 3 describes the econometric models used in this study to examine the impact factors of electricity consumption in China since 1995 and includes the data set. Section 4 presents results and an electricity demand forecast for China in 2020 using the models discussed in Section 3. The final section provides our conclusions.

# 2 Literature Review

Current literature on electricity consumption and economic growth focuses primarily on two categories: (1) the causal relationship between electricity consumption and economic growth as measured by GDP, and (2) the influence of specific economic variables and/or demographic variables (impact factors) on electricity consumption, and electricity forecasting. Although our analysis focuses on the second—impacts factors on electricity consumption—our literature review encompasses both categories to present a whole picture of the current academic literature on this topic.

## 2.1 Causal relationship between electricity consumption and economic growth

International studies have found mixed results on the causal relationship between electricity consumption and economic growth (see Table 1). Acaravci and Ozturk (2010) examined the long-term relationship and causality between electricity consumption and economic growth in 15 European transition countries using the Pedroni panel co-integration technique for the years 1990 through 2006 [16]. They found no causal relationship between electricity consumption and economic growth in any of these 15 countries. Wolde-Rufael (2014) re-examined the causal relationship in these countries using a bootstrap panel causality approach using data over the period of 1975 through 2010. They found that some countries had unidirectional causality, some had bidirectional causality, and some did not show causality in any direction [17]. Ciarreta and Zarraga (2010) examined the long-run and causal relationship between electricity consumption and GDP for 12 European countries using national-level data from 1970 to 2007 and found a unidirectional causal relationship from energy consumption to GDP [18]. Osman et al. (2016) investigated the relationship between electricity consumption and economic growth in the Gulf Corporation Council countries using panel data analysis with annual data from 1975 to 2012 and found bidirectional causality between economic growth and electricity consumption [19].

International studies that included analysis of China include Cowan et al. (2014), Chen et al. (2007), and Karanfil and Li (2015) [20–22]. China-specific analyses include Shiu and Lam (2004), Yuan et al. (2007), and Cheng et al. (2013) [23–25]. Two of these studies found no causal relationship between electricity consumption and GDP in China [20,21], one found short-run or little unidirectional causality from GDP to electricity [22], and three found unidirectional causality from electricity consumption to GDP [23–25].

Zhang et al.'s (2017) [26] review of studies on causality studies between electricity consumption and economic growth concluded that, for China, the causal relationship between electricity consumption and economic growth varies across the provinces and that the reduction in the growth of electricity consumption in China is the result of economic structural shift to tertiary sector. They called for more quantitative empirical research on the relationship between electricity consumption and economic growth. Our study provides one perspective to answer their call.

In summary, various studies draw diverse conclusions on causality between economic growth and electricity consumption in China. Our study assumes that economic growth is correlated with electricity consumption in China, and examines the correlation instead of the direction of the causality between these two.

**Table 1. Summary of literature results from causality tests between electricity consumption and GDP**

| Authors | Countries | Methodology | Causal Relationship |
|---|---|---|---|
| **Studies not including China** | | | |
| Acaravci and Ozturk (2010) [16] | 15 European transition countries | Pedroni panel cointegration | No long-term equilibrium relationship between electricity consumption per capita and real GDP per capita |
| Ciarreta and Zarraga (2010) [18] | 12 European countries | Panel unit root tests and panel cointegration tests, fully modified OLS, panel system GMM | Unidirectional and negative short-run and strong causal relationship from energy consumption to GDP |

| Authors | Countries | Methodology | Causal Relationship |
|---|---|---|---|
| Osman et al. (2016) [19] | Gulf Corporation Council countries | Dynamic panel data analysis: PMGE, demeaned PMG, AMG, MGE, and DFE | Bidirectional causality between economic growth and electricity consumption |
| Wolde-Rufael (2014) [17] | 15 European transition countries | The Konya (2006) bootstrap panel Granger causality approach | Unidirectional Granger causality from electricity consumption to economic growth in two countries and the other way around in four countries; bidirectional causality in one country; no Granger causality in any direction in the rest of the countries |
| | | **Studies including China** | |
| Cowan et al (2014) [20] | BRICS countries | The Konya (2006) bootstrap panel Granger causality approach | Neither electricity consumption nor economic growth is sensitive to the other in Brazil, India, and China. |
| Chen et al. (2007) [21] | 10 Asian developing countries | Error-correction model for a single country and panel Granger causality test | No causality relationship between electricity consumption and GDP was found in China for a single-country analysis; panel causality test found bidirectional long-run causality and unidirectional short-run causality from economic growth to electricity consumption. |
| Cheng et al. (2013) [24] | China | Log-linear regression model | Growth in power generation led to GDP growth from 1953 to 2010, but not the other way around. |
| Karanfil and Li (2015) [22] | 160 countries | Panel unit root, cointegration, and causality tests | GDP and electricity consumption present only short-run or little causality for wealthy countries, whereas their relationship tends to be stronger in the long run for low-income economies. |
| Shiu and Lan (2004) [23] | China | Error-correction model | A unidirectional relationship running from electricity consumption to real GDP |
| Yuan et al. (2007) [25] | China | Co-integration test | There exists Granger causality running from electricity consumption to GDP, but not the other way around, from 1978 to 2004. |

*Note: OLS is ordinary least squares; GMM is generalized method of moments; PMGE is pooled mean group estimation; AMG is augmented mean group; MGE is mobile genome express; DFE is dynamic fixed-effect.*

## 2.2 Impact factors on electricity consumption, and electricity forecasting

### *2.2.1 Impact factors of electricity consumption*

A number of international, national-level studies have examined the impacts of GDP, electricity prices, and population on electricity consumption. Mohamed and Bodger (2005) applied multiple linear regression techniques to examine the impact of GDP, average price of electricity, and population on electricity consumption in New Zealand from 1965 to 1999 and found that all three had a significant effect [27]. Bianco, Manca and Nardini (2009) also used multiple linear regression models to investigate the GDP, electricity price, and GDP per capita elasticities of domestic and non-domestic electricity consumption in Italy [28]. Using national-level data over the period of 1970–2007, the study found that price elasticity of electricity consumption was limited, but GDP and GDP-per-capita elasticities showed higher values. The authors also developed different long-term forecasting models, which produced similar results on future electricity consumption.

Several national-level, China-specific studies have examined the impacts of GDP, population, price of electricity, economic structural change, energy efficiency, and reduction of heavy industry capacity on electricity consumption. Lin (2003) [13] applied a cointegration approach to evaluate the impacts of GDP, fuel price, population, economic structural change (subtracting heavy industry output from total industrial output), and energy efficiency on electricity consumption using national level-data from 1952 to 2001. The study found that all of the independent variables had long-term relationships with electricity consumption. Elasticities of GDP, fuel price, population, economic structural change, and energy efficiency on electricity consumption are 0.78, -0.016, 0.565, -0.527, and -0.332, respectively, for the period from 1978 to 2001. Song et al. (2017) [29] used a modified firefly algorithm to quantify the impact of policies to reduce heavy industry capacity on electricity consumption in China and found that electricity demand increased with the growth of GDP, industry capacity, and population, but that this demand growth could be reduced with capacity elimination policies.

In terms of provincial-level studies in China, two recent studies have explored the impacts of economic structural change on the growth of electricity consumption in the context of China's current economic transition. Ge et al. (2017) used multivariable regression to explore the reasons for the deviation between economic growth and electricity consumption in Anhui Province [30]. The analysis found that real GDP, industrial structure (the share of large industrial enterprises value-added of total GDP), heating degree days, cooling degree days, and investment in fixed assets all had positive effects on electricity consumption, while energy intensity and financial development are negative factors. The analysis found that industrial structure is the major contributor to the growth in electricity consumption, and the deviation between the economic growth rate and electricity consumption are due mainly to the reduction of energy intensity and the growth of China's financial industry. He et al. (2017) [31] quantified the impacts of the economic transition in China on electricity consumption in the city of Tianjin using econometric analysis for each sector, including the primary sector, sub-industrial sectors, sub-tertiary sectors, and the residential sector. This study included other factors of an economic "new normal" by adding independent variables such as the Internet age, marketization reform, technological progress, and consciousness of energy conservation and emissions reduction. The study found that in the new economic context the main driving force behind the growth of electricity consumption was the tertiary industry and the residential sector (proportion of output value 73 percent, 2035–2040), rather than the energy-intensive industries that had dominated in the past.

### *2.2.2 Electricity Forecasting*

Many studies have projected electricity consumption in China in 2020 to be in the range of 6,500 TWh to 7,800 TWh, using simulation models or econometric models [10–12,32,33]. China's National Energy Administration's newly released *National 13th Five-Year Plan for Electricity Development* has forecast future electricity consumption reaching 6,800 TWh to 7,200 TWh by 2020, with a projected annual growth rate of 3.6 percent to 4.8 percent, however, the approach used for this forecast was not mentioned [15]. Xu et al. projected much higher electricity consumption in 2020, of over 10,000 TWh, using an optimized hybrid grey projection model [34].

Figure 1 shows the electricity projections of the estimations in the *13th Five-Year Plan* and four recent studies: the International Energy Agency's (IEA) *World Energy Outlook 2014* [10], the *2050 China Economic Development and Electricity Demand Study* by the Intelligent Laboratory for Economy-Energy-Electricity-Environment (ILE4) [11], the Energy Research Institute's China *2050 High Renewable Energy Penetration Scenario and Roadmap Study* (High RE) [12], and Lin et al. (2015) [14].

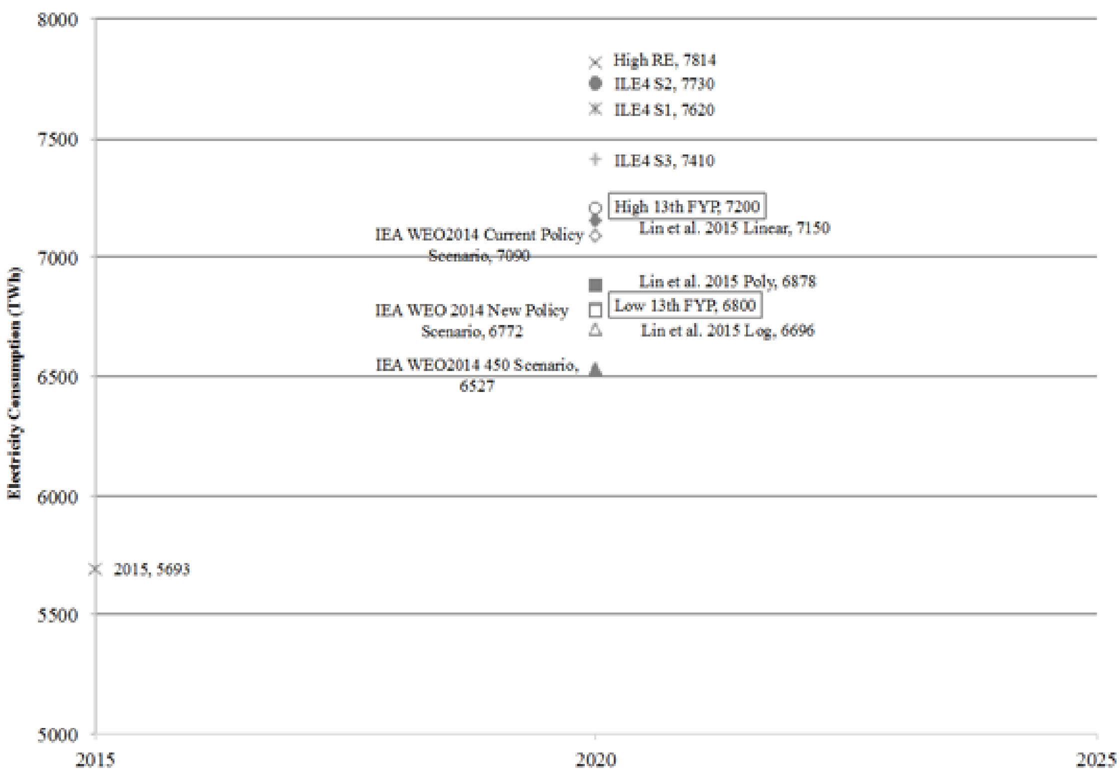


**Figure 1. Electricity consumption in 2015 and its projection in 2020 in China**

*Note: S1, S2, and S3 are three scenarios presented by ILE4 [11]. The IEA and High RE reports only provide electricity generation; we subtracted transmission and distribution losses (6 percent assumed) and import/export balances which are negligible in China [10,12]. The IEA has three scenarios: the current policy scenario, where policies enacted as of mid-2014 were considered; the new policy scenario, where both existing policies and proposed policies were considered; and the 450 scenario, in which the goal of limiting the long-term increase in average global temperature to 2°C is achieved.*

*Lin et al. (2015) has three functional forms: linear, polynomial, and logarithm [14]. Low 13th FYP and High 13th FYP are the two scenarios indicated in the 13th Five-Year Plan [15].*

This analysis provides an invaluable perspective on future electricity consumption in China by considering all three key features of economic transition in China. It applies econometric models using provincial-level time series data, with the aim of capturing the impacts of time and regional differences. The analysis is unique among electricity growth studies of China because it: (1) uses provincial panel data analysis in China to examine the relationship between electricity consumption and economic growth; (2) captures both structural change and heavy industry overcapacity reduction to reflect the current economic transition in China; (3) and provides insights on regional patterns of electricity growth in China.

# 3 Methods

## 3.1 Econometric model

In our evaluation of the relationship between economic growth and electricity consumption, we used linear and log-linear regressions, an effective way to deal with the relationship between variables [31]. We did not include electricity price in the model, as its elasticity on electricity consumption was found to be small in the literature [28,13].

We considered the following econometric model [27]:

$$y_{i,t} = Z_{i,t}\beta + \eta_i + \varepsilon_{i,t}$$

where $y_{i,t}$ is total electricity consumption (***TotalETWh***) of province *i* in year *t*; $Z_{i,t}$ is a vector of exogenous variables, including total GDP, industry composition, heavy industry capacity, and population; $\beta$ is a vector of parameters; $\eta_i$ represents the individual effect, capturing the idiosyncratic characters of each province; and $\varepsilon_{i,t}$ is the error term.

We also estimated the elasticity of economic growth on electricity consumption [28,13]:

$$\ln(y_{i,t}) = \ln(Z_{i,t}\beta) + \eta_i + \varepsilon_{i,t}$$

The exogenous variables contained in the model were as follows:

Total GDP (denoted as ***TotalGDPReal***) is the total provincial GDP for a specific year that was deflated using a national GDP deflator from 2005 constant yuan. This variable describes economic development, which pushes up electricity consumption.

Population (denoted as ***Population***) is the total population for each province at a specific year. As an explanatory variable, the larger the population, the more electricity demand there will be. At the same time, this variable can control the size (weight) of different provinces.

Heavy industry capacity (denoted as ***CrudeSteelOutput***) is used to measure the overcapacity of heavy industry in China. We used crude steel output for each province as a proxy for heavy industry capacity. We expect heavy industry growth to drive up electricity consumption.

Economic structure (denoted as ***TertiaryShare***) affects electricity consumption through transformation of economic structure. In our analysis, we measured the effects of structural change by the share of tertiary industry total valued added of total GDP.

## 3.2 Data sets

Total GDP, value-added of the tertiary industry, and population data for 30 provinces in China for 1995–2015 were from China Statistical Yearbooks, accessed from the China Data Online [35].

Total GDP and tertiary sector value-added were deflated using a national GDP deflator using 2005 constant yuan, from the World Bank [36]. Data for provincial total electricity consumption were extracted from the Energy Balance Sheet for each province in the China Energy Statistical Yearbooks

[37]. Data for crude steel output at the provincial level were from the online database of the National Bureau of Statistics of China [35].

Total electricity consumption of each province for selected years are listed in Table 2, and trends of electricity consumption and total real GDP of each province from 1995 to 2015 are shown in Figure 2. Significant growth in electricity consumption took place in all provinces.

**Table 2. Total electricity consumption by province in 1995, 2000, 2005, 2010, and 2015**

| Province | Total Electricity Consumption (TWh) | | | | |
|---|---|---|---|---|---|
| | 1995 | 2000 | 2005 | 2010 | 2015 |
| **Eastern Region** | | | | | |
| Anhui | 26 | 34 | 58 | 100 | 154 |
| Fujian | 24 | 37 | 70 | 123 | 180 |
| Jiangsu | 64 | 91 | 202 | 360 | 492 |
| Shanghai | 38 | 53 | 87 | 123 | 133 |
| Zhejiang | 40 | 67 | 154 | 270 | 342 |
| **Northern Region** | | | | | |
| Beijing | 24 | 35 | 53 | 78 | 89 |
| Hebei | 57 | 76 | 140 | 252 | 298 |
| Inner Mongolia | 19 | 26 | 67 | 154 | 254 |
| Shandong | 74 | 100 | 200 | 330 | 518 |
| Shanxi | 37 | 48 | 89 | 27 | 164 |
| Tianjin | 17 | 22 | 37 | 17 | 80 |
| **Central Region** | | | | | |
| Chongqing | | 30 | 32 | 60 | 83 |
| Henan | 52 | 67 | 130 | 235 | 304 |
| Hubei | 37 | 50 | 80 | 133 | 177 |
| Hunan | 34 | 37 | 62 | 126 | 143 |
| Jiangxi | 17 | 20 | 38 | 65 | 102 |
| Sichuan | 54 | 48 | 85 | 140 | 184 |
| **Northwestern Region** | | | | | |
| Gansu | 23 | 28 | 47 | 76 | 105 |
| Ningxia | 9 | | 29 | 53 | 85 |
| Qinghai | 6 | 11 | 21 | 45 | 64 |
| Shaanxi | 22 | 29 | 49 | 80 | 122 |
| Xinjiang | 12 | 17 | 28 | 61 | 205 |
| **Southern Region** | | | | | |
| Guangdong | 72 | 124 | 254 | 384 | 507 |
| Guangxi | 20 | 30 | 47 | 93 | 125 |
| Guizhou | 19 | 32 | 52 | 77 | 107 |
| Hainan | 3 | 4 | 8 | 15 | 26 |
| Yunnan | 21 | 29 | 51 | 93 | 132 |
| **Northeastern Region** | | | | | |
| Heilongjiang | 41 | 38 | 53 | 75 | 87 |
| Jilin | 26 | 27 | 38 | 58 | 65 |
| Liaoning | 59 | 75 | 105 | 161 | 189 |

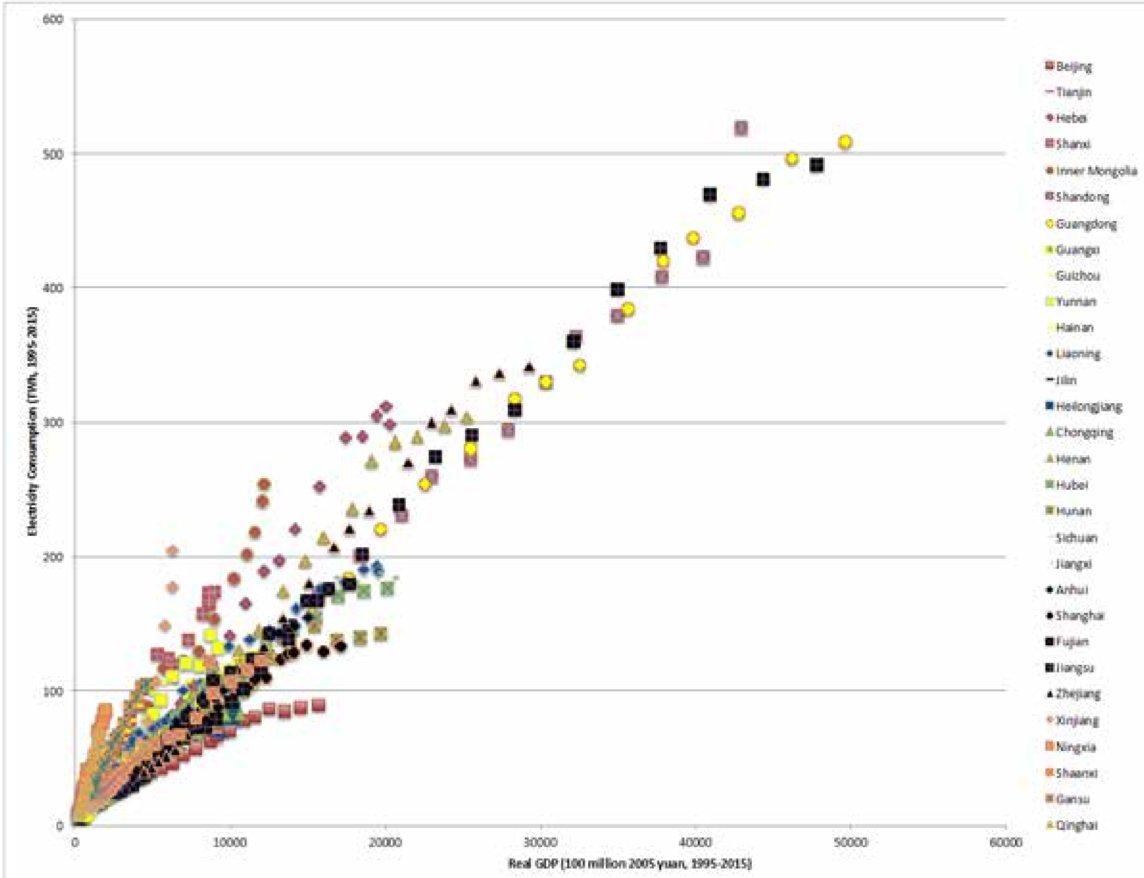


**Figure 2. Provincial-level electricity consumption and total real GDP from 1995 to 2015**

Some total electricity consumption and crude steel output data were missing; these are presented in Table 3.[1]

**Table 3. Data not available in the databases used**

| Variables | Province | Year |
|---|---|---|
| **Total electricity consumption** | Chongqing | 1995, 1996 |
| **Crude steel output** | Chongqing | 1995 |
| **Crude steel output** | Hainan | 2010–2013 |
| **Crude steel output** | Ningxia | 2001, 2008–2010 |

The descriptive statistics of the dependent and independent variables are summarized in Table 4.

[1] Chongqing was part of Sichuan Province before 1997; therefore, total electricity consumption in Chongqing for the years 1995 and 1996 is assumed to be included in the data for Sichuan Province. As a result, Chongqing and Sichuan were taken as one province in the analysis for 1995 and 1996. Starting from 1997, Chongqing and Sichuan were analyzed separately as tww provinces.

**Table 4. Descriptive statistics of variables**

| Variables | Definition | Units | Observation | Mean | S.D. | Min | Max |
|---|---|---|---|---|---|---|---|
| **TotalETWh** | Total electricity consumption | TWh | 628 | 92.09 | 90.02 | 2.8 | 518 |
| **TotalGDPReal** | Total real GDP | 100 million 2005 yuan | 630 | 7778 | 8086 | 222 | 49662 |
| **Population** | Population | 10,000 people | 630 | 4,300 | 2,624 | 481 | 11,430 |
| **CrudeSteelOutput** | Heavy industry capacity | 10,000 tons | 621 | 1,336 | 2,292 | 0.01 | 18,850 |
| **TertiaryShare** | Economic structure | | 630 | 0.4033 | 0.0772 | 0.2766 | 0.7965 |

# 4 Results

## 4.1 Estimation results (Models 1 and 2)

We first regressed electricity consumption on total GDP, tertiary share, crude steel output, and population in a linear form using least squares with dummy variable (LSDV) to control for the unobserved heterogeneity for each province by introducing a province dummy. To control for common and exogenous shocks for all provinces, such as the entrance of China into the World Trade Organization in 2001 and the global financial crisis in 2008, years were included in model 1. Table 5 lists the regression results (models 1 through 4). All factors considered had significant and expected effects on electricity consumption.

In the LSDV model, the degree of freedom was reduced by N variables of province dummy. To avoid introducing too many constraints in the regression model, we applied a fixed effects model (FE) which used within-group estimates to deal with individual fixed effects. As with the previous models, year variables were used to control time trend. For model 2 we could use fixed effects estimators or random effects estimators; Hausman tests showed that fixed effects estimators are preferred. Estimated parameters for all independent variables were the same, but the tertiary share did not have a significant negative effect on electricity consumption.

## 4.2 Elasticity estimation (Models 3 and 4)

We then used the log-log function form to test elasticity of electricity demand as a function of GDP, crude steel production, population, and tertiary share.[2] Model 3 used LSDV to capture differences among the provinces. Gross domestic product, crude steel production, and population all had significant positive effects on electricity consumption, and the tertiary share had a significant negative effect on electricity consumption. Model 4 could be estimated by the fixed effects estimator or the random effects estimator; the results of Hausman tests showed that fixed effects estimators are preferred. All independent variables had significant effects on electricity consumption.

[2] Tertiary share was not transformed into log form, as the coefficient of it means the change in electricity consumption to 1 percent change in tertiary value-added share.

**Table 5. Regression results**

| | Model 1 LSDV | Model 2 FE | Model 3 LSDV | Model 4 FE |
|---|---|---|---|---|
| **GDP** | 0.0095*** (0.0003) | 0.0095*** (0.0006) | 0.882*** (0.022) | 0.882*** (0.050) |
| **Tertiary share** | -64.96*** (22.25) | -64.96 (55.03) | -0.881*** (0.177) | -0.881** (0.388) |
| **Crude steel output** | 0.0049*** (0.00039) | 0.0049*** (0.0009) | 0.056*** (0.012) | 0.056** (0.021) |
| **Population** | 0.0097*** (0.0019) | 0.0097** (0.0036) | 0.588*** (0.119) | 0.588* (0.308) |
| **Year** | 0.91*** (0.23) | 0.91 (0.57) | | |
| **Province dummy** | Yes | | Yes | |
| **Constant** | -1856*** (457.6) | -1827 (1147) | -8.71*** (0.97) | -8.13*** (239) |
| **R-squared** | 0.9684 | 0.9039 | 0.9777 | 0.7859 |
| **No. observations** | 620 | 620 | 620 | 620 |
| **Individuals** | | 30 | | 30 |
| **Estimation** | LSDV | FE | LSDV | FE |
| **Functional Form** | linear | linear | log-linear | log-linear |

*Note: Robust standard errors are reported in parentheses. *, **, *** indicate significance at the 10 percent, 5 percent, and 1 percent level, respectively.*

## 4.3 Discussion

We used models (model 1 and model 3) with provincial fixed effects to forecast future electricity consumption for each province in 2020, then used the sum of electricity consumption in each province as the total electricity consumption for China. Assumptions for GDP growth rates, tertiary share and population at the provincial level were based on provincial *13th Five-Year Plans*.[3] Based on the provincial-level plans, in 2020 national GDP grows at an annual rate of 7.5 percent, much higher than the goal of 6.5 percent in the national *13th Five-Year Plan*, and tertiary share is about 54 percent, lower than the national goal of 56 percent. For population, the sum of provincial-level populations is approximately the same as the national goal of 1.42 billion people in 2020. To compare our forecast with the estimate of electricity demand in the national *13th Five-Year Plan*, we adjusted provincial-level GDP, tertiary share, and population to be consistent with the national *13th Five-Year Plan*. GDP growth rate for each province was multiplied by a factor to slow it down to the national goal of 6.5 percent annual growth rate. Similar adjustments were made to tertiary share so that national tertiary share reached 56 percent.

For crude steel production, there is little reference for future production projection for each province. Therefore, we first kept crude steel production for each province at 2015 levels. Under this assumption and after adjustment of GDP, tertiary share, and population, model 1 projects total electricity

[3] For provinces for which we could not find numbers, we kept them the same as the 2015 level for population and tertiary share, and assumed a 6.5 percent growth rate for GDP.

consumption to be 7328 TWh, and model 3's projection is 6661 TWh, with annual growth rates of 3.2 percent and 5.2 percent, respectively.

However, total crude steel production at the national level has been estimated to decrease to 725 million tons, about a 10 percent reduction compared to the 2015 level [38]. This will further contribute to a 0.99 percent and 0.57 percent reduction to total electricity demand by 2020 based on model 1 and model 3, respectively, assuming all provinces have the same percentage of reduction of crude steel production by 2020. Electricity consumption in 2020 is projected to be 7290 TWh and 6623 TWh, with annual growth rates of 5.1 percent and 3.1 percent, respectively.

A better illustration of the contribution of each factor to the total electricity demand is shown in Figure 3 (results based on model 3). Here, the growth of GDP contributes to 4.4 percent annual growth in electricity consumption by 2020. Adding the population growth, the annual growth rate of electricity consumption increases to 4.7 percent. A structural shift to the tertiary sector contributes a 1.5 percent decrease of the growth rate. Including the 0.57 percent decrease resulting from the reduction of crude steel production, the annual growth rate of electricity demand is 3.1 percent.

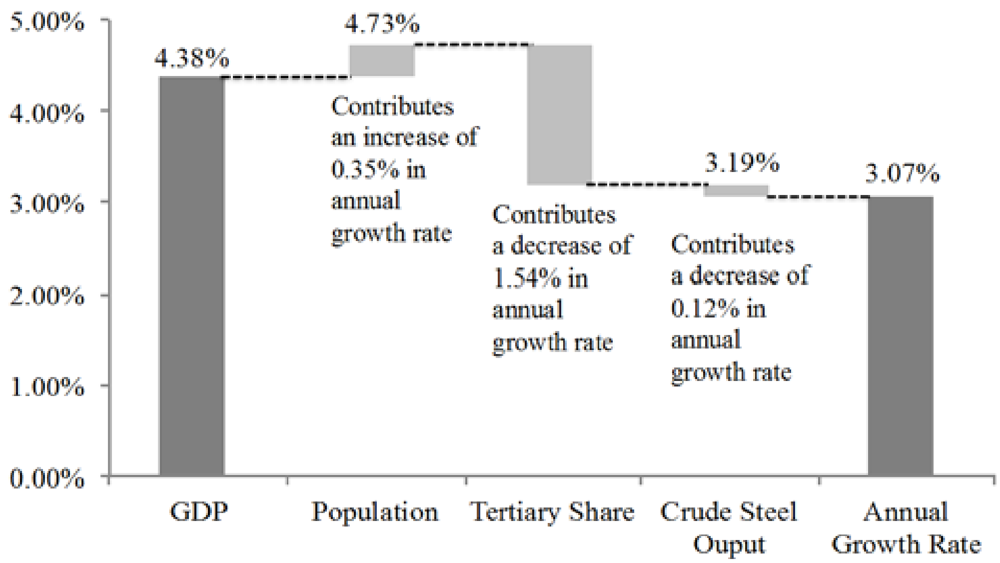


**Figure 3. Contribution of GDP, economic structural change, industrial overcapacity, and population to electricity demand, based on model 3**

To take a closer look at the electricity forecast at the provincial level, we compared the annual growth rate (AGR) under model 1 and model 3 for each province (Table 6). For the great majority of provinces, the log-linear model predicted lower growth rates as expected. However, for a few provinces—Gansu, Ningxia, and Qinghai—the opposite was true. For Qinghai and Ningxia provinces, AGRs based on the log-linear model (model 3) were more than 100% higher than those based on the linear model (model 1). This can potentially be explained by the low GDP per capita and total electricity consumption in these least-developed provinces in China that are currently undergoing rapid industrial growth (Figure 2).

**Table 6. Provincial-level electricity annual growth rates in 2020 compared to 2015 under different model forecasts**

| Province | 2015 Actual (TWh) | AGR based on Model 1 | AGR based on Model 3 |
|---|---|---|---|
| **Eastern Region** | | | |
| Anhui | 154 | 6.5% | 5.3% |
| Fujian | 180 | 6.8% | 6.1% |
| Jiangsu | 492 | 5.5% | 4.0% |
| Shanghai | 133 | 5.5% | 3.5% |
| Zhejiang | 342 | 4.5% | 1.6% |
| **Northern Region** | | | |
| Beijing | 89 | 6.2% | 4.0% |
| Hebei | 298 | 3.4% | 3.9% |
| Inner Mongolia | 254 | 4.3% | 4.3% |
| Shandong | 518 | 5.6% | 3.0% |
| Shanxi | 164 | 3.6% | 4.8% |
| Tianjin | 80 | 6.8% | 6.4% |
| **Central Region** | | | |
| Chongqing | 83 | 7.6% | 6.2% |
| Henan | 304 | 6.4% | 6.0% |
| Hubei | 177 | 6.4% | 4.5% |
| Hunan | 143 | 7.3% | 5.9% |
| Jiangxi | 102 | 8.0% | 7.9% |
| Sichuan | 184 | 6.1% | 4.6% |
| **Northwestern Region** | | | |
| Gansu | 105 | 3.9% | 4.7% |
| Ningxia | 85 | 1.6% | 4.1% |
| Qinghai | 64 | 2.1% | 4.3% |
| Shaanxi | 122 | 6.9% | 6.6% |
| Xinjiang | 205 | 4.3% | 4.5% |
| **Southern Region** | | | |
| Guangdong | 507 | 5.5% | 3.7% |
| Guangxi | 125 | 5.2% | 4.4% |
| Guizhou | 107 | 5.9% | 6.4% |
| Hainan | 26 | 4.0% | 3.5% |
| Yunnan | 132 | 5.2% | 4.6% |
| **Northeastern Region** | | | |
| Heilongjiang | 87 | 4.8% | 2.7% |
| Jilin | 65 | 5.2% | 3.7% |
| Liaoning | 189 | 4.5% | 3.7% |

As eastern and southern China are more developed and transitioning into the post-industrialization stage, while central, northeastern, and northwestern China are still in the process of industrializing, we examined whether there are regional similarities or differences in electricity demand growth patterns, adding regional grid dummy variables to model 1 and model 3. Compared with the central China grid, our results showed that the eastern China grid, the northern China grid, and the southern China grid have statistically significant differences, while no statistically significant differences were found in the northeastern China grid and northwestern China grid in both models. Results also show that all grids except for the southern grid have statistically significant differences with the eastern China grid. These findings illustrate that the southern, northern, and eastern China grid regions show somewhat different patterns of electricity demand compared with central China, whereas central China may have similar patterns as northeastern and northwestern China, and southern China and eastern China may also have more similarity to one another. These results are consistent with the development stages of different areas in China.

Considering the differences and similarities between different regions, future research is needed to develop different sets of models for forecasting demand suited for regions in different stages of development. For example, one model is needed for eastern and southern China, another is needed for northern China, and a third is needed for the remaining areas that are under industrialization. However, these regional analyses need to be incorporated into national electricity demand and supply analysis, and planning for generation, transmission and distribution resources.

# 5 Conclusions

After 35 years of rapid growth, China's economy is going through a major transition, characterized by a slower growth rate, a structural shift to the tertiary sector, and industrial deleveraging—a process to reduce overcapacity that has built up in key industrial sectors over the past decades. All of these trends have contributed to a significant slowdown in demand growth for electricity in China in recent years. It is important to determine whether the slowdown is a fundamental part of the economic shift, however, in order for the country to avoid overinvestment in coal-fired power plants and unnecessary curtailment of renewable energy and to achieve the multiple objectives of economic efficiency, power system reliability, and environmental goals. Our hypothesis was that the cause of slower growth in electricity demand is China's ongoing economic transition and restructuring. The results of our regression analysis show that GDP, population, economic structural change, and industrial capacity all have statistically significant influence on electricity demand. Among factors correlating with electricity demand growth, GDP shows the strongest positive correlation. Our results on GDP elasticity, structural shift elasticity, and population elasticity on electricity consumption are consistent with those results from Lin (2003), who used national data with earlier years. Our results indicate that the economic structural change toward the tertiary sector is a key factor of the slowing electricity growth in China. The reduction in heavy industry capacity also is having a negative correlation on electricity demand, although not as substantially as the structural change. Overall, our analysis suggests that electricity demand growth is likely to continue its slow-down in the near future due to the ongoing economic structural change.

In addition, we see clear regional patterns of demand growth separating the more-developed regions along the eastern coast and the less-developed inland regions, especially those in northwestern and northeastern China, due to different economic and demographic trends. Regional approaches for demand forecasting and integrated resource planning are thus more appropriate for China at this time, until mechanisms for inter-regional transfer are further developed.

Although our forecast results of electricity consumption in China are within the range of recent forecasts of other studies and the national plan [10,14,15], differences in electricity demand projections between the linear model and the log-linear model indicates significant uncertainty in our ability to forecast future electricity growth. Such uncertainty implies great risks in decisions around investing in new generation and transmission capacity, especially under the conditions of excess generating capacity that already exist in China today. Further, continued technological progress will improve the efficiency of energy use, which will further dampen demand growth, while the electrification of end-use energy could stimulate demand—factors deserving further analysis in future studies. To manage these risks, a more transparent, robust, and dynamic planning methodology and process is essential.

# References

[1] National Bureau of Statistics. Statistical Communiqué of the People's Republic of China on the 2016 National Economic and Social Development 2017. http://www.stats.gov.cn/tjsj/zxfb/201702/t20170228_1467424.html (accessed May 1, 2017).

[2] National Bureau of Statistics of China. Statistical Communiqué of the People's Republic of China on the 2014 National Economic and Social Development 2015. http://www.stats.gov.cn/tjsj/zxfb/201502/t20150226_685799.html (accessed May 1, 2017).

[3] National Bureau of Statistics of China. Statistical Communiqué of the People's Republic of China on the 2015 National Economic and Social Development 2016. http://www.stats.gov.cn/tjsj/zxfb/201602/t20160229_1323991.html (accessed May 1, 2017).

[4] China Electricity Council. Yearly Statistics of China Power Industry 2016 2017.

[5] China Electricity Council. Yearly Statistics of China Power Industry 2014. 2015.

[6] China Electricity Council. Yearly Statistics of China Power Industry 2015 2016.

[7] Lin J, Kahrl F, Liu X. A regional analysis of excess capacity in China's power systems. Resour Conserv Recycl 2018;129. doi:10.1016/j.resconrec.2017.10.009.

[8] Li C, Shi H, Cao Y, Wang J, Kuang Y, Tan Y, et al. Comprehensive review of renewable energy curtailment and avoidance: A specific example in China. Renew Sustain Energy Rev 2015;41:1067–79. doi:10.1016/J.RSER.2014.09.009.

[9] Luo G, Li Y, Tang W, Wei X. Wind curtailment of China׳s wind power operation: Evolution, causes and solutions. Renew Sustain Energy Rev 2016;53:1190–201. doi:10.1016/J.RSER.2015.09.075.

[10] International Energy Agency. World Energy Outlook 2014. 2014.

[11] Hu Z, Tan X, Xu Z. 2050 China Economic Development and Electricity Demand Study (In Chinese). Beijing: China Electric Power Press; 2011.

[12] Energy Research Institute of National Development and Reform Commission. China 2050 High Renewable Energy Penetration Scenario and Roadmap Study. 2015.

[13] Lin B. Structural Changes , Efficiency Improvement and Electricity Demand Forecasting (In Chinese). Econ Res 2003;5:57–66.

[14] Lin J, He G, Yuan A. Economic rebalancing and electricity demand in China. Electr J 2016;29:48–54. doi:10.1016/j.tej.2016.03.010.

[15] National Energy Administration. News Release for the 13th FYP for Electricity Development (In Chinese) 2016. http://www.nea.gov.cn/xwfb/20161107zb1/index.htm (accessed November 1, 2016).

[16] Acaravci A, Ozturk I. Electricity consumption-growth nexus: Evidence from panel data for transition countries. Energy Econ 2010;32:604–8. doi:10.1016/j.eneco.2009.10.016.

[17] Wolde-Rufael Y. Electricity consumption and economic growth in transition countries: A revisit using bootstrap panel Granger causality analysis. Energy Econ 2014;44:325–30. doi:10.1016/j.eneco.2014.04.019.

[18] Ciarreta A, Zarraga A. Economic growth-electricity consumption causality in 12 European countries: A dynamic panel data approach. Energy Policy 2010;38:3790–6. doi:10.1016/j.enpol.2010.02.058.

[19] Osman M, Gachino G, Hoque A. Electricity consumption and economic growth in the GCC countries: Panel data analysis. Energy Policy 2016;98:318–27. doi:10.1016/j.enpol.2016.07.050.

[20] Cowan WN, Chang T, Inglesi-Lotz R, Gupta R. The nexus of electricity consumption, economic growth and CO2 emissions in the BRICS countries. Energy Policy 2014;66:359–68. doi:10.1016/j.enpol.2013.10.081.

[21] Chen ST, Kuo HI, Chen CC. The relationship between GDP and electricity consumption in 10 Asian countries. Energy Policy 2007;35:2611–21. doi:10.1016/j.enpol.2006.10.001.

[22] Karanfil F, Li Y. Electricity consumption and economic growth: Exploring panel-specific differences. Energy Policy 2015;82:264–77. doi:10.1016/j.enpol.2014.12.001.

[23] Shiu A, Lam P-L. Electricity consumption and economic growth in China. Energy Policy 2004;32:47–54. doi:10.1016/S0301-4215(02)00250-1.

[24] Cheng YS, Wong WK, Woo CK. How much have electricity shortages hampered China's GDP growth? Energy Policy 2013;55:369–73. doi:10.1016/j.enpol.2012.12.015.

[25] Yuan J, Zhao C, Yu S, Hu Z. Electricity consumption and economic growth in China: Cointegration and co-feature analysis. Energy Econ 2007;29:1179–91. doi:10.1016/j.eneco.2006.09.005.

[26] Zhang C, Zhou K, Yang S, Shao Z. On electricity consumption and economic growth in China. Renew Sustain Energy Rev 2017;76:353–68. doi:10.1016/j.rser.2017.03.071.

[27] Mohamed Z, Bodger P. Forecasting electricity consumption in New Zealand using economic and demographic variables. Energy 2005;30:1833–43. doi:10.1016/j.energy.2004.08.012.

[28] Bianco V, Manca O, Nardini S. Electricity consumption forecasting in Italy using linear regression models. Energy 2009;34:1413–21. doi:10.1016/j.energy.2009.06.034.

[29] Song Z, Niu D, Dai S, Xiao X, Wang Y. Incorporating the influence of China's industrial backward capacity elimination policies in electricity demand forecasting. Util Policy 2017;47:1–11. doi:10.1016/j.jup.2017.05.004.

[30] Ge F, Ye B, Xing S, Wang B, Sun S. The analysis of the underlying reasons of the inconsistent relationship between economic growth and the consumption of electricity in China – A case study of Anhui province. Energy 2017;128:601–8. doi:10.1016/j.energy.2017.04.056.

[31] He Y, Jiao J, Chen Q, Ge S, Chang Y, Xu Y. Urban long term electricity demand forecast method based on system dynamics of the new economic normal: The case of Tianjin. Energy 2017;133:9–22. doi:10.1016/j.energy.2017.05.107.

[32] Jiang K, Zhuang X, Miao R, He C. China's role in attaining the global 2°C target. Clim Policy 2013;13:55–69. doi:10.1080/14693062.2012.746070.

[33] Wang T, Watson J. Scenario analysis of China's emissions pathways in the 21st century for low carbon transition. Energy Policy 2010;38:3537–46. doi:10.1016/j.enpol.2010.02.031.

[34] Xu N, Dang Y, Gong Y. Novel grey prediction model with nonlinear optimized time response method for forecasting of electricity consumption in China. Energy 2017;118:473–80. doi:10.1016/j.energy.2016.10.003.

[35] National Bureau of Statistics of China. National Data Database n.d. http://data.stats.gov.cn/english/easyquery.htm?cn=C01 (accessed May 1, 2017).

[36] World Bank. World Bank World Development Indicators n.d. http://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?locations=CN (accessed May 1, 2017).

[37] National Bureau of Statistics of China. China Energy Statistical Yearbook. n.d.

[38] Trading Economics. China Steel Production 2017. https://tradingeconomics.com/china/steel-production (accessed June 1, 2017).