

Lawrence Berkeley National Laboratory

Energy Analysis Env Impacts

Title

Regional electricity demand and economic transition in China

Permalink

<https://escholarship.org/uc/item/3z1975bw>

Authors

Lin, Jiang

Liu, Xu

He, Gang

Publication Date

2020-06-01

DOI

10.1016/j.jup.2020.101047

Peer reviewed

Regional Electricity Demand and Economic Transition in China

Jiang Lin, China Energy Group, Lawrence Berkeley National Laboratory,
1 Cyclotron Road, Berkeley, CA, j_lin@lbl.gov, +1-510-495-8886
Xu Liu, China Energy Group, Lawrence Berkeley National Laboratory
Gang He, Department of Technology and Society, Stony Brook
University

Abstract

China's economy is undergoing a major transition. It is important to accurately forecast whether future electricity consumption will continue to grow rapidly or grow more slowly in the medium term. Our models showed that a structural shift to the tertiary sector and production reduction in heavy industries slow growth in electricity consumption, although GDP remains 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.

Keywords: Electricity consumption, economic structure, overcapacity

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 and fluctuated around 6.6 to 6.9 percent from 2015 to 2018 [1]. The contribution of the tertiary sector to total GDP has exceeded 50 percent since 2015 and grew to 52.2 percent in 2018 [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) continued to decrease, from 7.5 percent in 2014 to 6.3 percent in 2015, to 5.2 percent in 2016, and to 3 percent in 2017 [1-5].

These trends have a profound impact on China's energy demand and electricity consumption. As 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 1,900 gigawatts (GW) and a total generation of 6,994 terawatt-hours (TWh) in 2018 [6]. 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 [7] and 0.96 percent in 2015 [8]; however, it bounced back to 5 to 8 percent from 2016 to 2018, reaching 6845 TWh in 2018 [6,9-11].

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, that is, 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 hydropower [12-16]. A careful integrated resource planning process and methodology are 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 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 the output of heavy industrial products, 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 [17–19], econometric models using national-level data [20], or econometric models using provincial-level data without considering all three key factors of economic transition in China [21]. 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. This study supplements current literature in the area by uncovering the slow-down of electricity consumption growth due to a fundamental shift in economic transition in China.

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 are likely to continue in the foreseeable future, we tested whether their influence on the growth of electricity use is to keep it negative going forward and will result in slower growth of electricity consumption 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 *13th Five-Year Plan* [17,21,22]. 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 impact 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 [23]. 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 [24]. 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 [25]. Osman et al. (2016) investigated the relationship between electricity consumption and economic growth in the Gulf Cooperation Council countries using panel data analysis with annual data from 1975 to 2012 and found bidirectional causality between economic growth and electricity consumption [26].

International studies that included analysis of China include Cowan et al. (2014), Chen et al. (2007), and Karanfil and Li (2015) [27–29]. China-specific analyses include Shiu and Lam (2004), Yuan et al. (2007), and Cheng et al. (2013) [30–32]. Two of these studies found no

causal relationship between electricity consumption and GDP in China [27,28], one found short-run or little unidirectional causality from GDP to electricity [29], and three found unidirectional causality from electricity consumption to GDP [30–32].

Zhang et al.’s (2017) [33] 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 of electricity consumption in China is the result of economic structural optimization and industrial transformation. 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.

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) [23]	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) [25]	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
Osman et al. (2016) [26]	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) [24]	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
Chirwa and Odhiambo (2020) [34]	4 European countries, 4 Asian countries, and 4 African countries	Panel Autoregression	In the long term, electricity consumption is positively and significantly associated with economic growth; in the short-run, results show a positive relationship in ten countries and a negative relationship in two countries.

Studies including China			
Cowan et al. (2014) [27]	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) [28]	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) [31]	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) [29]	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) [30]	China	Error-correction model	A unidirectional relationship running from electricity consumption to real GDP
Yuan et al. (2007) [32]	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 a generalized method of moments; PMGE is pooled mean group estimation; AMG is an augmented mean group; MGE is a 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, the 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 [35]. Bianco et al. (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 [36]. Using national-level data over the period of 1970 to 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) [20] 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. For the period 1978 to 2001, the study found that all of the independent variables had long-term relationships with electricity consumption with the following elasticities: GDP (0.78), fuel price (-0.016), population (0.565), economic structural change (-0.527), and energy efficiency (-0.332). Song et al. (2017) [37] 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. Zhang et al. (2019) [33] used index decomposition and decoupling methods to analyze the factors impacting electricity consumption in China at both the national and sectoral levels. They found that economic activity was the key driver for total electricity consumption in China while energy intensity played the largest role in decoupling electricity consumption and GDP growth.

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 the Anhui Province [38]. 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) [39] quantified

the impacts of the economic “new normal” in China on electricity consumption in the Tianjin Province 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 [17–19,40,41]. 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 at all [22]. Xu et al. projected much higher electricity consumption in 2020, of over 10,000 TWh, using an optimized hybrid grey projection model [42].

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 (WEO)-2014* [17], the *2050 China Economic Development and Electricity Demand Study* by the Intelligent Laboratory for Economy-Energy-Electricity-Environment (ILE4) [18], the Energy Research Institute’s *China 2050 High Renewable Energy Penetration Scenario and Roadmap Study* (High RE) [19], and Lin et al. (2015) [21].

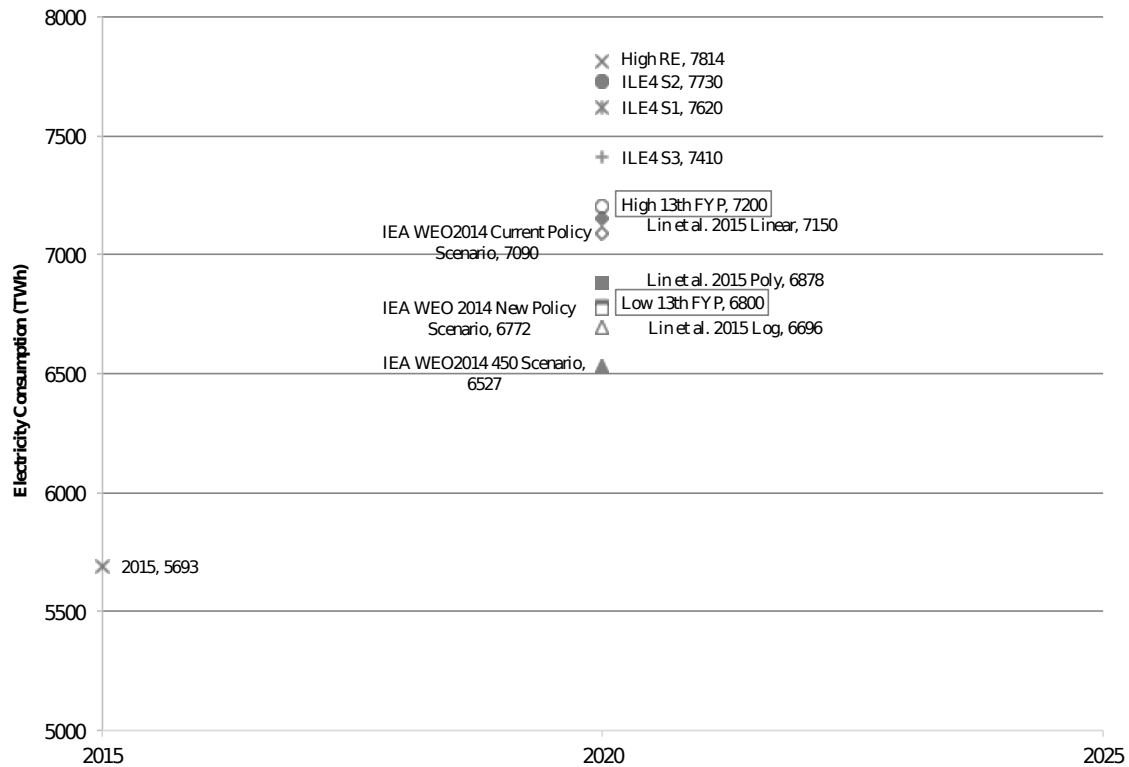


Figure 1. Electricity consumption in 2015 and its projection in 2020 in China

Note: S1, S2, and S3 are three scenarios presented by ILE4 [18]. The IEA and High RE reports only provide electricity generation; we subtracted transmission and distribution losses (assumed at 6 percent) and import/export balances which are negligible in China [17,19]. The IEA provides 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 IEA 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) report three functional forms: linear, polynomial, and logarithm [21]. Low 13th FYP and High 13th FYP are the two scenarios indicated in the *13th Five-Year Plan* [22].

This analysis provides an invaluable perspective on future electricity consumption in China by considering all three key features of the 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 [39]. We did not include electricity price in the model, as the literature has found that electricity consumption is relatively price-inelastic [20,36].

We considered the following econometric model [35]:

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

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; β is a vector of parameters; η_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 [20,36]:

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

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 2010 constant yuan. This variable describes economic development, which drives 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 the 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 [11].

Total GDP and tertiary sector value-added were deflated using a national GDP deflator using 2005 constant yuan, from the World Bank [43]. Data for provincial total electricity consumption were extracted from the Energy Balance Sheet for each province in the China Energy Statistical Yearbooks [44]. Data for crude steel output at the provincial level were from the online database of the National Bureau of Statistics of China [11].

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

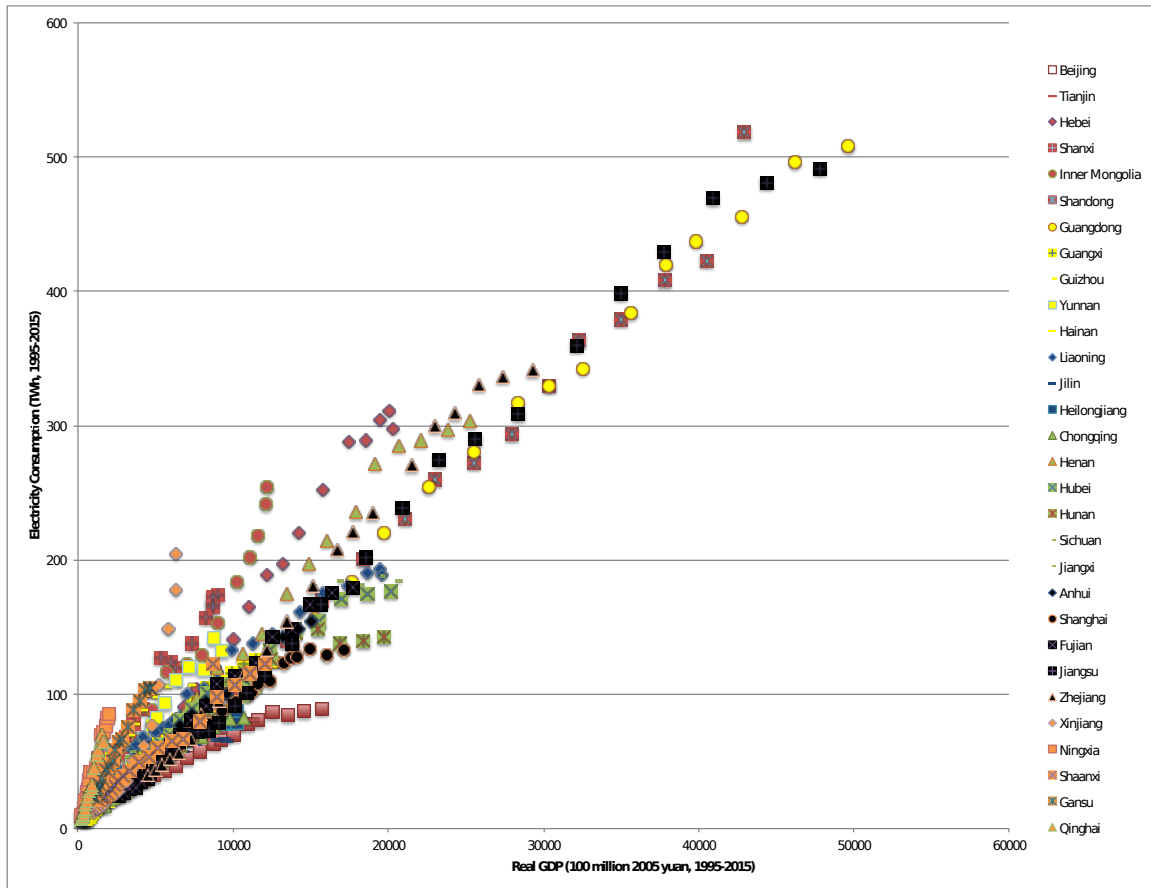


Figure 2. Provincial-level electricity consumption and total real GDP from 1995 to 2015

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.

Table 4. Descriptive statistics of variables

Variables	Definition	Units	Obser	Mean	S.D.	Min	Max
-----------	------------	-------	-------	------	------	-----	-----

¹ Chongqing was part of the 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.

			- vation				
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 the time trend. For model 2 we could use fixed effects estimators or random-effects estimators; Hausman tests showed that fixed effects estimators are preferred. The 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 the 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.

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

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

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

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 available for future production projections 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 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 [45]. 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.

To provide a longer-term electricity demand in China, we used model 1 and model 3 to project electricity demand in 2030. We assumed that average annual growth rates of provincial-level GDP and population from 2021 to 2030 would be half of those from 2016 to 2020. We assumed tertiary share would increase by half of the percent of 2016 to 2020 each year from 2021 to 2030, except for Beijing because Beijing's tertiary share is already high. We assume Beijing increases by a quarter of the annual increase from 2016 to 2020. We fix the crude steel production in each province at its 2016 level. The linear model (Model 1) and log-linear model (Model 3) estimate a total of 8,757 to 10,450 TWh electrical usage in 2030 in China. The lower bond is close to LBNL's China 2050 Demand Resource Energy Analysis Model's reference scenario (8,946 TWh) and to IEA WEO 2018's new policies scenario (8,508 TWh) [46,47]. The upper bond is close to the China State Grid Energy Research Institute's normal transition scenario (10,300 TWh) [48].

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 in 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.

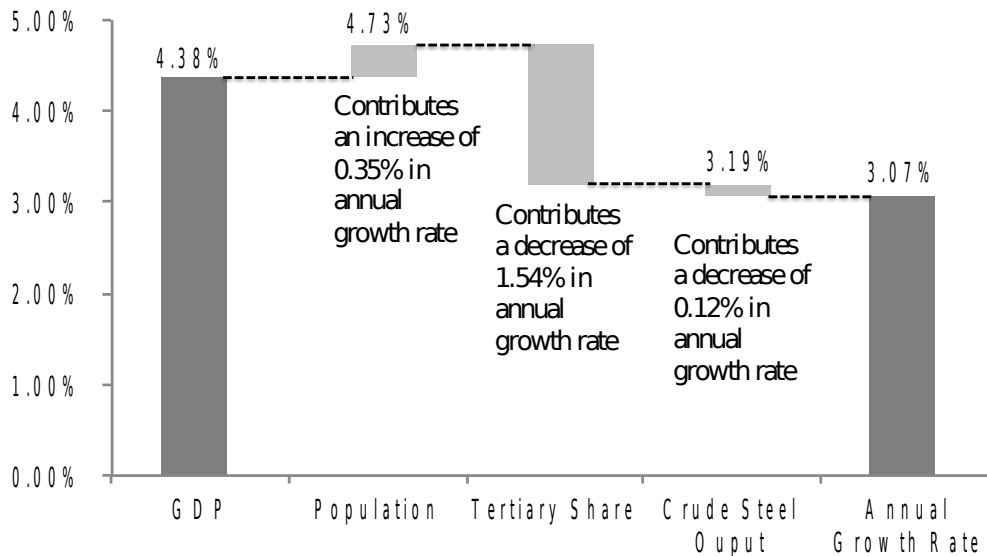


Figure 3. Contribution of GDP, economic structural change, industrial overcapacity, and population to electricity demand, based on model 3

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 the 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 Real (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 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 suited for regions in different stages of development. 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.

5. Conclusion and Policy Implications

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 was 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 plateauing in demand growth in electricity is China's ongoing economic transition and restructuring. Our regression analysis shows that GDP, population, economic structural change, and industrial capacity all have a statistically significant influence on electricity demand. Among the leading factors driving electricity demand growth, GDP continues to be the most significant driver. Our elasticity results for GDP, structural shift, and population 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 driver of slowing electricity growth in China. The reduction in heavy industry capacity also is having a negative influence 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 China.

In 2017 and 2018, electricity consumption showed strong growth (at an annual growth rate of 7 to 8%) driven in particular by steel and other energy-intensive sectors, which were largely a result of economic stimulus policies from the government. We believe the overall trend of electricity consumption growth will continue to slow down because stimulus measures by nature are temporal, while the transition to less energy-intensive industrial sectors and the service sector is the secular trend. As a matter of fact, the electricity consumption growth rate in 2019 was reported to be back down to 4.5% [49].

Given future electricity consumption, capacity expansion modeling and electricity dispatch modeling work can be done to answer some key questions for policymakers. For example, what is the amount of the new capacity required to reliably meet future electricity demand? Is the current investment in power capacity enough or excessive for future demand? What level of stranded assets is implied if there does exist over-investment in power capacity? Answers to those questions would vary depending on future electricity demand. The slow-down of electricity consumption growth as a result of economic transition discovered by this study underscores the importance of power system planning in guiding power sector investment, resource allocation, and capacity expansion.

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 resource planning are thus appropriate for China at this time.

Although our forecast results of electricity consumption in China are within the range of recent forecasts of other studies and the national plan [17,21,22,46-48], 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. Moreover, temperature changes, behavior changes, and application of demand responses are all factors that could influence electricity demand and require further analysis. To understand and manage these uncertainties, more transparent, robust, and dynamic planning methodologies and processes are essential.

References

- [1] National Bureau of Statistics of China. Statistical Communiqué of the People's Republic of China on the 2018 National Economic and Social Development 2019.
http://www.stats.gov.cn/tjsj/zxfb/201902/t20190228_1651265.html (accessed February 26, 2020).
- [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] 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).
- [5] National Bureau of Statistics of China. Statistical Communiqué of the People's Republic of China on the 2017 National Economic and Social Development 2018.
http://www.stats.gov.cn/tjsj/zxfb/201802/t20180228_1585631.html (accessed February 26, 2020).
- [6] China Electricity Council. Yearly Statistics of China Power Industry 2018 2019.
- [7] China Electricity Council. Yearly Statistics of China Power Industry 2014. 2015.
- [8] China Electricity Council. Yearly Statistics of China Power Industry 2015 2016.
- [9] China Electricity Council. Yearly Statistics of China Power Industry 2016 2017.
- [10] China Electricity Council. Yearly Statistics of China Power Industry 2017 2018.
- [11] National Bureau of Statistics of China. National Data Database n.d. <http://data.stats.gov.cn/english/easyquery.htm?cn=C01> (accessed January 5, 2017).
- [12] 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.
- [13] 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.
- [14] 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.
- [15] Feng Y, Wang S, Sha Y, Ding Q, Yuan J, Guo X. Coal power overcapacity in China: Province-Level estimates and policy implications. *Resour Conserv Recycl* 2018;137:89–100. doi:10.1016/j.RESCONREC.2018.05.019.
- [16] Yuan J, Li P, Wang Y, Liu Q, Shen X, Zhang K, et al. Coal power overcapacity and investment bubble in China during 2015–2020. *Energy Policy* 2016;97:136–44. doi:10.1016/j.ENPOL.2016.07.009.
- [17] International Energy Agency. *World Energy Outlook 2014*. 2014.
- [18] Hu Z, Tan X, Xu Z. *2050 China Economic Development and Electricity Demand Study (In Chinese)*. Beijing: China Electric Power Press; 2011.
- [19] Energy Research Institute of National Development and Reform Commission. *China 2050 High Renewable Energy Penetration Scenario and Roadmap Study*. 2015.
- [20] Lin B. Structural Changes , Efficiency Improvement and Electricity Demand Forecasting (In Chinese). *Econ Res* 2003;5:57–66.
- [21] 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.
- [22] 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).
- [23] 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.
- [24] 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.
- [25] 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.
- [26] 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.
- [27] 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.

- [28] 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.
- [29] 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.
- [30] 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.
- [31] 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.
- [32] 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.
- [33] 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.
- [34] Chirwa TG, Odhiambo NM. Electricity consumption and economic growth : New evidence from advanced, emerging and developing economies. *Int J Energy Sect Manag* 2020;14:1–19.
- [35] 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.
- [36] 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.
- [37] 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.
- [38] 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.
- [39] 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.
- [40] 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.
- [41] 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.

- [42] 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.
- [43] World Bank. World Bank World Development Indicators n.d. <http://data.worldbank.org/indicator/NY.GDP.DEFL.ZS?locations=CN> (accessed May 1, 2017).
- [44] National Bureau of Statistics of China. China Energy Statistical Yearbook. n.d.
- [45] Trading Economics. China Steel Production 2017. <https://tradingeconomics.com/china/steel-production> (accessed June 1, 2017).
- [46] International Energy Agency. World Energy Outlook 2018. 2018.
- [47] Zhou N, Price L, Yande D, Creyts J, Khanna N, Fridley D, et al. A roadmap for China to peak carbon dioxide emissions and achieve a 20% share of non-fossil fuels in primary energy by 2030. *Appl Energy* 2019;239:793–819. doi:10.1016/j.APENERGY.2019.01.154.
- [48] China State Grid Energy Research Institute. China Energy and Electricity Outlook 2018. China Electric Power Press; 2018.
- [49] China Electricity Council. Yearly Statistics of China Power Industry 2019 2020.