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The Impact of Urbanization and Industrialization on Energy Security: A Case Study of China

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Abstract: Currently, due to the recent unprecedented urbanization and industrialization, energy consumption in China is increasing at an enormous speed. However, this process should go hand in hand with sustainable energy development that is based on three interconnected dimensions: (i) energy security, (ii) energy affordability, and (iii) environmental sustainability. It becomes very obvious that an increase in energy efficiency leads to the increase in both energy security and environmental sustainability. Therefore, inadequate energy efficiency causes energy security and environmental sustainability issues, and thus negatively influences economic development of China (or any other country for that matter). This paper explores the intrinsic relationship among urbanization, industrialization, and energy security, as well as the influencing mechanisms of urbanization and industrialization on energy efficiency using a fixed effect model. The paper employs panel data from 30 provinces in mainland China collected in the time range from 2006 to 2015. Our results demonstrate that urbanization and industrialization can significantly improve energy efficiency. Although energy security level decreases considerably with the rise of energy consumption and population growth, the increase in urbanization and industrialization levels can increase energy security through energy efficiency improvements. Moreover, it appears that changes in disposable income and population structure do not alter the effects of industrialization and urbanization on energy security. We conclude that Chinese provinces with high and low urbanization levels should focus on technological innovation and increase industrial development and technological input, respectively. Local governments in China can formulate policies and regulations and promote urbanization according to local economic development and industrial and population structure. The paper also presents theoretical references and decision support that might help in developing local laws and regulations promoting energy efficiency during urbanization and industrialization.

Keywords: urbanization; industrialization; energy efficiency; energy security; China

1. Introduction

Energy might be crucial for achieving sustainable development. There is no doubt that it is the main driver of economic growth and has significant impact on environment. Sustainable energy development is the main aim of energy policy in all countries in the world that are committed to sustainable development and climate change mitigation. There are three main dimensions of sustainable energy: (i) energy security, (ii) energy environmental sustainability, and (iii) energy equity [1]. This can be shown on an example of the World Energy Council's Energy Trilemma Index that ranks the energy performance of any given country based on global and national data using three dimensions: (i) energy security, (ii) energy equity, and (iii) environmental sustainability [2]. Formulation of a reasonable energy security development strategy and solving the related energy security problems became the primary task that needs to be solved urgently in the process of promoting the worldwide sustainable development. All countries around the world are actively exploring how to improve energy efficiency and promote the use of renewable energy systems [3].

Meanwhile, the rapid growth of economic development in China in the past 40 years led to problems such as total energy reserves, environmental pollution, and contradictions between energy supply and demand [4]. These contradictions continue to accumulate, which has caused energy security issues that present serious concerns both for the government and for the public. China issued six laws, two administrative regulations, and 28 departmental rules concerning energy since the era of reforms and opening-up policy [5]. However, many complicated factors influence energy consumption which appears to be related to urbanization and industrialization levels in addition to economic development [6]. An increase in urbanization rate implies an increase in the proportion of urban population and multiple changes in industrial structure, economic growth mode, and household consumption level. Urbanization evolves with industrialization and economic growth. Substantial increase in energy demands and consumption caused by urbanization and industrialization continuously raised total energy consumption [7]. Most recently, China is in the acceleration stage of urbanization and industrialization but still has lots of room for development. According to the statistical data, the urbanization rate in China reached 56.1% in 2015 which was 55% higher than that observed in 2000. The industrialization level remained stable from 40% to 45% marked by only a small fluctuation [8]. With economic and social developments and population growth, the energy security problem in China is becoming prominent as a response to the increasing pressing energy demand and per capita energy consumption.

According to the theoretical explorations, urbanization and industrialization exert impact on energy problems in two main ways: First, the construction and use of abundant infrastructures, buildings, and traffic facilities during urbanization increase energy consumption and have a negative impact on climate change [9]. Second, the economies of scale for energy supply and concentrated use of energy consumption caused by population agglomeration and urbanization, as well as industrial structure optimization, technological innovation, and updating of consumption brought by industrialization, increase energy utilization, thus affecting energy consumption [10]. However, the traditional extensive economic growth in China does not fully exploit the increase of energy utilization by spatial agglomeration of production elements. Recent changes in energy infrastructure and consumption modes during urbanization and industrialization improve energy efficiency and weaken dependence of population and industries on energy sources, thus reducing threats to energy security. The synchronous rise of energy consumption during urbanization and industrialization leads to the gradually increasing energy demands threatening energy security [11]. As a result, scholars neglect energy security problems to an extent [12]. Many relevant studies focus on the relationship among industrialization, urbanization, and energy intensity. The general belief stemming from those studies is that urbanization and industrialization can greatly influence energy intensity [13]. However, there is a dispute on whether such influence is positive, negative, or bidirectional. Are urbanization and industrialization the engine and accelerator of economic growth that can improve energy security and energy efficiency? What influences and effects of industrialization and urbanization result in energy security and sustainability issues? These problems are thoroughly explored in our paper in the context of positive impact of promotion of urbanization and industrialization. This paper has important theoretical values and practical implications for fast developing countries like China. Three major goals of our paper can be formulated as follows; (1) to assess the impact of urbanization and industrialization on energy security; (2) to assess how the changes in population structure and income levels during urbanization and industrialization affect energy security; and (3) to assess how the heterogeneity of different provinces influence the impact of urbanization and industrialization on energy security.

In order to fulfil the main objectives of this paper, we employed an empirical test of impact elasticity and influencing mechanism of urbanization and industrialization on energy security using the panel data of 30 provinces from China ranging from 2006 to 2015. In our opinion, this paper's scientific value-added is two-fold. First, unlike many scholars who studied the relationship of urbanization and industrialization with energy security, our paper carries out the empirical analysis using panel data supplementing research findings concerning energy security. Second, we analyze the elastic effects of population structure and disposable income on energy security by introducing their decomposition terms into a model. The key attention was paid to prove the existence of a U-shaped Kuznets curve relationship between disposable income and energy security.

The remainder of this paper is organized as follows. Section 2 provides literature review. Section 3 introduces model, data, and research variables, including construction of the research model and specifications of the variables. Moreover, a descriptive statistical analysis on sample data is described. Section 4 describes empirical results and analysis, including selection of models, robustness test, and regression analysis of samples. Section 5 further discusses empirical results. Section 6 concludes the paper with closing remarks and implications.

2. Literature Review

Academic research on the relationships among urbanization, industrialization, and energy problems focuses on influences of urbanization and industrialization on energy intensity. Only a handful of scholars studied the relationships among urbanization, industrialization, and energy security. According to them, urbanization and industrialization are believed to impact energy intensity. However, existing theories fail to shape up a uniform opinion on whether such effect is positive, negative, or bidirectional. Through empirical analysis, Jones [14] discovered the positive correlation between urbanization and energy intensity. The urbanization and industrialization elasticity of energy intensity are 0.35 and 1.35, respectively. Sadorsky [15] further proved that the industrialization elasticity of energy intensity fluctuates between 0.07 and 0.12 for a long period. Liddle and Lung [16], Zhang and Ding [17], Zhou and Wang [18], Wang and Zhang [19], and Sereewatthanawut et al. [20] verified the above opinions through multiple types of data and empirical methods. Ding [21] reported that energy intensity increases with industrialization, but the relationship between energy intensity and industrialization is not simply linear. Zhang and Ding [17] further confirmed that the positive effect of industrialization on energy intensity is stronger than the combined effects of income, industrialization, and urbanization, and ultimately energy intensity decreases. Li and Lin [22] used the Stochastic Impacts by Regression on Population, Affluence and Technology (STIRPAT) model and panel data of 73 countries from 1971 to 2010 to confirm that urbanization affects energy consumption with different stages of economic development, but the specific conclusions are different: (i) for low-income countries, urbanization reduces energy consumption and increases carbon emissions and (ii) for low- and middle-income countries, urbanization process increases energy consumption at the same time. In addition, it also brings about an increase in carbon emissions. Although urbanization can promote economic growth and improve the living standards of residents, it also leads to an increase in energy consumption. Urbanization in middle- and high-income countries does not lead to an increase in energy consumption. Zhang et al. [23] found a U-shaped relationship between total factor energy efficiency and per capita income in 23 developing countries, and the improvement of total factor energy efficiency in China turned out to be the most obvious one. Based on the panel data of 49 countries and regions from 1980 to 2010, Wang and Xie [24] estimated the total factor energy efficiency of each country or region and calculated the optimal energy structure of each country. The empirical results showed that the total factor energy efficiency of high-income countries and middle- and low-income countries is relatively high, while that of middle- and high-income countries it is relatively low. The relationship between the total factor energy efficiency and per capita income turned out to be a U-shaped curve. Onafowora and Owoye [25] used ARDL co-integration test parameter estimation method to reveal that the shape of environment Kuznets curve for the environment of Japan and Korea is significant, while for Brazil, China, Mexico, South Africa, Nigeria, and Egypt, energy consumption and economic growth show an N-shaped curve. Yang and Yuan [26] used the time series data of six pollutants in China from 1982 to 2006, and confirmed that China is different from other developed countries and emerging developing countries and its environmental Kuznets curve (EKC) curve is a positive U-shaped curve.

However, Wei et al. [27] and Liu [28] pointed out that the contribution of urbanization to energy consumption remains limited and declines annually. The findings of this study are partly related to the development stage of the selected country in question. Using the fully modified ordinary least square (FMOLS) method and the time series data of 1980 to 2008 in seven major regions of the world, Al-mulali et al. [29] found a positive correlation between energy consumption and urbanization rates in 84% of countries over the long-term. But for low-income countries, there was no relationship between urbanization rates and energy consumption. Mishra et al. [30] used panel data of 13 Pacific island countries from 1980 to 2005 and confirmed that there is a negative correlation between urbanization and per capita energy consumption in this region. Newell et al. [31], Fisher-Vanden et al. [32], Li et al. [33], and Ma and Xu [34] believed that industrialization is not only the increase of proportion of industrial activity but also a process of structural transfer and updating brought by improvement of technological level and innovative input. This process can increase energy utilization and reduce energy intensity. Kasman and Duman [35] analyzed the relationship among energy consumption, carbon dioxide emissions, economic growth, openness, and urbanization in the EU Member States and confirmed that urbanization development is an important factor affecting energy consumption growth, but it is not the only one important factor. The role of urbanization in energy consumption varies with the different stages of national development. Therefore, in the analysis of energy consumption growth, the degree of industrialization and the stage characteristics of economic development need to be considered. Farhani and Ozturk [36] used time series data of 1971 to 2012 in Tunisia and employed the autoregressive distributed lag test to analyze the relationship between energy consumption, urbanization and other related variables. The results showed that there is a positive correlation between them in the long and short term, and the EKC curve between carbon dioxide emissions and real GDP per capita does not appear in Tunisia as envisaged, mainly because its economic development level does not reach its threshold level. In addition, Poumanyvong and Kaneko [37] found from the panel data of developing countries that urbanization can lower energy utilization of low-income groups but increase that of middle- and high-income groups. Kan and Luo [38] believed that effects of urbanization on energy intensity increases or fluctuates in the short-term, but such an effect presents a considerable reverse variation in the long-run. The increase in urbanization level might improve energy utilization through various channels and facilitate reduction of energy intensity greatly. Mulder and De Groot [39] discovered that facilitating industrialization can reduce the energy intensity of most manufacturing sectors to a great extent but in the same time slowly decrease that of service sectors.

Driven by both energy prices and greenhouse gas emissions reduction, scholars also attribute a lot of attention to energy security. However, there is no consensus on a widely accepted definition of energy security. Ang et al. [40] found that the definition of energy security in existing studies includes seven major themes, including energy availability, infrastructure, energy prices, social effects, environmental, governance, and energy efficiency. The coverage of different studies is different, but few studies cover all of the seven themes mentioned above. For example, Bohi and Toman [41] argued that energy security is a loss of economic welfare caused by fluctuations in energy prices or interruptions in energy supply. Dorian et al. [42] defined energy security as guaranteeing the sustainable supply of energy at a reasonable price to support the normal operation of industry and economy. Similar definitions are also discussed in the findings of Bielecki [43], Muleller-Kraenner [44], United Nations Development Programme [45], Chester [46], Cabalu [47], and Badea [48]. In addition, because the energy security level is also affected by supply chain and infrastructure, scholars further tie up the energy security definition to the energy supply chain and its infrastructure security [49]. However, this kind of definition pays more attention to the single dimension of energy supply, which is relevant for the assessment of energy security degree of energy exporting countries, but is not important for the objective evaluation of energy security degree of energy importing countries. Meanwhile, the energy security definition penetrates into the field of energy services, as Lesbirel [50] argued by showing that the energy security definition should take into account the level of national energy services. Some research institutes and scholars synthesize the existing research results and propose multidimensional energy security definitions. For example, the Asia Pacific Energy Resource Center (APERC) extended the energy security definition to four dimensions, including availability, accessibility, acceptability, and affordability [51]. Vivoda [52] put forward an energy security definition involving eleven dimensions: energy supply, demand management, energy efficiency, economic, environmental, human security, military–security, domestic socio-cultural-political, technological, international, and policy. On the basis of Vivoda's findings, Sovacool [53] further broadened the energy security definition to 20 dimensions through extensive consultation with experts.

In terms of energy security indicators, energy security covers a variety of indicators, including resources, environmental, economic, social, technological, policy, military, culture, and so on [54]. Therefore, it is still the most mainstream research to construct an evaluation index system to evaluate energy security comprehensively. Sovacool and Mukherjee [55] attributed five dimensions to energy security: (i) availability, (ii) affordability, (iii) technology development and efficiency, (iv) environmental and social sustainability, and (v) regulation and governance. They also split these five dimensions into 20 parts, 320 single indicators, and 52 complex indicators that might ease decision-makers and scholars in analyzing, evaluating, tracking, and comparing national energy security situation. The energy security evaluation index system proposed by Wu et al. [56] includes two aspects: (i) energy supply security and (ii) use security. It uses storage–production ratio, energy intensity, self-sufficiency rate, energy diversification index, and energy import diversification index to measure energy supply security. Six indicators including energy production security index, carbon emission intensity, sulfur dioxide emission per capita, carbon emission per capita, electricity consumption in the final energy consumption share, and the proportion of nuclear and renewable energy to evaluate energy use security. Martchamadol and Kumar [57] established a 19-indicator energy security evaluation system, which includes five dimensions: energy demand, energy availability, environmental issues, energy market, and energy price/expenditure. The energy security situation of Thailand from 1986 to 2030 was analyzed with situational analysis.

In terms of evaluation, existing studies on energy security evaluation methods can be divided into four types:

(1) Index weighted standardized index evaluation method: The Consulting and Research Center of the Ministry of Land and Resources of China in Beijing first set energy security as a dimensionless value within 0 and 1 which was equally divided into five subintervals to represent the state of energy security [58]. These five subintervals were used as the evaluation standards of degree of energy security. Second, influencing factors of energy security comprised 19 evaluation indexes, which were divided into five types to distinguish positive and negative correlations and setting security thresholds for them. Therefore, scores of all indexes were standardized. Finally, weights of different indexes were set through the Delphi method. The Delphi method chooses weights randomly but lacks economic meaning. For this reason, Badea [48] studied the sum rule of energy security indexes based on group decision theory. However, scholars continue to believe that group decision theory has inadequate explanatory power and doubt its applicability.
(2) Direct depiction risk evaluation method based on interrupt probability: Beccue et al. [59] depicted political risk factors of energy supply interruption by using the influencing diagram. Makarov et al. [60] estimated the reliability coefficient of energy security according to frequency of occurrence of interruption events in history. Winzer [61] chose a series of indexes to describe different risk states and calculated the interruption probability of energy supply with consideration to various risks. This method is mainly applicable to risk assessment before implementing actions. However, its application is further restricted by the difficulties in integrating assessments effectively.

(3) Indirect depiction risk evaluation methods based on diversity index: Stirling [62] proposed an ideal diversity index to reflect diversity, equilibrium, and differences of energy sources. The Herfindhal–Hirschman Index (HHI) and Shannon–Wiener Index (SWI) are common diversity indexes widely used in preassessment of energy security. Jasen et al. [63], Grubb et al. [64], Frondel and Schmidt [65], and Kruyt [66] carried out quantitative analyses on energy security based on HHI and SWI. They all concluded that HHI and SWI are strongly similar in evaluation of energy security. Zeng et al. [67] constructed energy security indicators using multicriteria decision-making techniques based on the priorities stipulated in EU energy policy, and described the energy security trends of Baltic countries from the economic, energy supply chain, and environmental dimensions.

(4) Expected welfare loss evaluation method: Yergins [68], Bohi and Toman [41], Winzer [61], Nikolaidis and Poullikkas [69], and Subashini and Ramaswamy [70] pointed out multiple layers of changing risk sources and influences of energy security which were manifested by significant differences during distinct periods and in different countries. These influences can be discussed under the uniform standards through expected welfare loss, thus enabling an overall evaluation on energy security. Although this method has complete theoretical basis and clear logic, it is relatively complicated. This method is mainly applicable to evaluation after the event.

Based on the reviewed literatures, most existing studies focus on analyzing influences of urbanization and industrialization based on energy intensity. Several studies discuss energy security from the perspective of energy security dentition, energy security indicators, and evaluation methods. However, the associated studies overlook influences of urbanization and industrialization on energy security in China. Although energy security is an important problem, it is easy to be ignored as scholars mainly concentrate on energy consumption and intensity but neglects the effects of urbanization and industrialization on energy security. To fill this gap, our paper investigated the effects of urbanization and industrialization on energy security. Solving energy shortage problems during fast economic development of China provides important references for developing governmental economic and energy policies.

3. Model, Data, and Research Variables

3.1. Setting Up the Model

All in all, it becomes obvious that improving of energy efficiency is an important means for ensuring energy security. For our empirical model, we constructed a series of demand-side indicators relevant for the size of impacts of energy shortages and related to energy security. Among the key indicators are the energy or fuel intensity of the economy, which are relevant since they mark the economic dependence on energy and the sensitivity to price changes. In addition, we employ energy intensity indicators that are relative to a benchmark. Similar to Ding [71], we use energy efficiency (*Ense*) as a proxy variable of energy security. Generally, two standards are used to measure energy efficiency: (1) the gross domestic product (*Gdp*) is produced by unit energy consumption. The ratio between gross domestic product (*Gdp*) and total energy consumption (*Enco*) is used to express energy productivity. This indicator is created by dividing the gross domestic product (GDP) by the gross inland consumption of energy in each given calendar year. The indicator measures the productivity of energy consumption and shows the degree of decoupling of energy use from GDP growth. The *Gdp/Enco* is positively correlated with energy efficiency level. (2) The quantity of energy consumption per unit production; the *Enco/Gdp* can also be applied to express energy efficiency. The *Enco/Gdp* is negatively correlated with energy efficiency level.

In this study, energy security was measured by energy productivity–*Gdp/Enco* (see (1)):

$$Ense_{it} = Gdp_{it}/Econ_{it} \tag{1}$$

The STIRPAT model for evaluation of environmental effects was applied in this study to investigate influences of urbanization and industrialization rates, affluence, and population factor on energy security during urbanization. The STIRPAT model was improved based on IPAT model and widely applied. The specific expression form of STIRPAT model is as follows (2)

$$I = aP^bA^cT^de \tag{2}$$

where I denotes the environmental assessment variable that has to be studied. P, A, and T are population, finance, and technology, respectively, which influence the environment. b, c, and d are the indices of population, finance, and technology, respectively. a is the coefficient of the STIRPAT model and e is the error term. By calculating logarithms at two sides of the STIRPAT model, the transformed result is expressed as

$$lnI = lna + blnP + clnA + dlnT + lne \tag{3}$$

At the construction of the IPAT model, the environmental influence (I) is attributed to the product of population (P), affluence (A), and technology (T). Based on the previous research, in this study we chose population size (*Tpe*) and old coefficient (*Oldco*) as the gross index and structural index, respectively, in population; consumption expenditure (*Pcs*) and disposable income (*Pdi*) as affluence; and urbanization level (*Urb*) and industrialization level as representative indexes of technology. The influence of these factors on energy security (*Ense*) is studied. Among them, *Oldco* and *Pdi* are substitution variables of population size and consumption expenditure, respectively, which are introduced to verify robustness of the model. After urbanization and industrialization rates, consumption expenditure and population size are introduced and Equation (3) is transformed into (see (4))

$$lnEnse_{it} = \beta_0 + \beta_1 lnIndu_{it} + \beta_2\ lnUrb_{it} + \beta_3 lnPcs_{it} + \beta_4 lnTpe_{it} + u_{it} + \varepsilon_{it} \tag{4}$$

where *Ense* reflects the explained variable of energy security level. *Ense* is the ratio between GDP and total energy consumption. *Indu*, *Urb*, *Pcs*, and *Tpe* are explanatory variables, which denote industrialization rate, urbanization rate, per capita consumption expenditure, and per capita disposable income, respectively. β_1, β_2, β_3, and β_4 are elasticity coefficients of industrialization rate, urbanization rate, per capita consumption expenditure, and per capita disposable income, respectively. Changes in energy security level (*Ense*) per 1% variation of *Indu*, *Urb*, *Pcs*, and *Tpe* are expressed as β_1%, β_2%, β_3%, and β_4%, respectively. i and t express provinces and time (i = 1, 2, . . . , 30; t =2006, 2007, . . . , 2015), respectively. β_0 is the intercept term. u_{it} is a random variable that cannot be observed and presents heterogeneity of different provinces. ε_{it} is the disturbing term, which changes with individuals and time. Owing to provincial heterogeneity, ε_{it} further reflects the influences of other random factors that cannot be observed in different provinces on energy security. Here, ε_{it} is assumed independently identical in distribution and is unrelated with u_{it}: $Cov(u_{it}, \varepsilon_{it}) = 0$.

In addition, influences of geographical position, industrialization, and urbanization of different provinces on energy security were considered in model estimation. Samples were then classified and analyzed accordingly.

3.2. Data Source and Description of Variables

3.2.1. Sample Selection and Data Processing

In this study, we employed the panel data of 310 samples in 31 provinces in mainland China (except Hong Kong, and Macao) from 2006 to 2015. The data on Tibet Autonomous Region was eliminated during data processing due to missing energy consumption data. Specifically, an empirical analysis using panel data of 300 observation samples in 30 provinces, autonomous regions, and municipalities, except Tibet in mainland China, was performed. All data were collected from China Statistical Yearbook, China Energy Statistical Yearbook, China Population Statistical Yearbook, and statistical yearbooks of different provinces from 2007 to 2016. According to our research specifics, the study area was divided into North, Northeast, East, Central South, Southwest, and Northwest in accordance with general geographic zoning in China. Samples were classified and processed according to urbanization and industrialization.

3.2.2. Main Variables and Descriptive Statistical Analysis

Table 1 lists the variables involved in this study and their explanations.

Table 1. Specifications of variables and descriptive statistics.

Variables	Name of Variables	Sample Size	Mean	Standard Deviation	Minimum	Maximum
Ense	Energy productivity	300	1.16	0.55	0.24	3.36
Enco	Energy consumption	300	12,914.11	8059.83	920.00	38,899.00
Indu	Industrial added value	300	674.01	614.11	23.83	3025.95
Urb	Urbanization rate	300	0.52	0.14	0.27	0.90
Tpe	Population size	300	4428.19	2673.12	324.00	10,849.00
Pcs	Per capita consumption expenditure	300	11,934.49	4769.89	5836.24	34,783.55
Pdi	Per capita disposable income	300	16,358.87	7012.81	7183.55	49,867.17

Source: Own results.

Ense: Energy efficiency in this study refers to gross domestic product (unit: 10,000 RMB/ton of standard coal) per unit ton of standard coal. *Ense* is expressed by the ratio between GDP and total energy consumption, which is expressed by a logarithmic form in the analysis. *Enco:* Energy consumption mainly refers to the total amount of energy consumption (unit: 10,000 tons of standard coal) and equals the total consumption of coal, oil, gas, and electricity. GDP refers to actual GDP and is adjusted based on the value in 1978 (unit: 100 million RMB).

Population size (*Tpe*): The population size determines total energy consumption and influences *Ense* level in one country or region. In this study, permanent resident population was used, and its logarithmic form is applied in analysis.

Urbanization rate (*Urb*): It can be measured by urbanization rate. Urbanization is the process whereby urbanization level increases gradually. *Urb* refers to the ratio between permanent resident population in urban areas and total population in the region. Population agglomeration effect formed by urbanization will profoundly impact on energy consumption and *Ense*.

To discuss influences of urbanization changes on energy consumption and *Ense* as well as its marginal effect, urbanization level is divided into two types according to China's National New Urbanization Planning (2014–2020), namely, high urbanization level (urbanization rate >60%) and low urbanization level (urbanization rate <60%).

Industrial added value (*Indu*) and industrial rate (*Indra*): Previous studies [1–7] reported that industrial added value is proportional to energy consumption. However, only few studies have discussed influences of industrialization level on energy consumption.

In the present study, *Indra* was used to express industrialization level of one country or region and is equal to *Indu/Gdp*. High *Indu/Gdp* indicates high industrialization level and low *Indu/Gdp* reflects low industrialization level. The logarithmic form of *Indu* is applied in the analysis.

The industrialization level is evaluated by *Indra*. According to international classification standard, high and low industrialization levels are defined. The high industrialization level (*Indra* > 40%) and low urbanization level (*Indra* < 40%). Logarithmic form of *Indu* is used in the analysis.

Per capita energy consumption expenditure (*Pcs*): *Pcs* refers to the ratio between total energy consumption expenditures by population with its logarithmic form applied in the analysis. The consumption expenditure is positively related with affluence. *Pcs* can be used as one variable to represent affluence. According to previous academic studies, *Pcs* is proportional to energy consumption and is inversely proportional to *Ense*. Nevertheless, given a fixed income level, *Pcs* differs significantly in different regions, which is mainly attributed to influences of income level, local customs, and consumption preference on consumption expenditures. Consumption expenditure presents great regional differences even under the same per capita disposable income.

Per capita disposable income (*Pdi*): *Pdi* can reflect affluence of one region or another, thus enabling to reflect effects of consumption expenditures on energy consumption and *Ense*. According to economic theory, marginal propensity to consume decreases progressively in macro-level, but is relatively fixed in micro-level due to influences of custom, culture, and related preferences. Marginal propensity to consume refers to the ratio between the growth of consumption expenditure and growth of disposable income. A strong linear relationship exists between consumption expenditure and disposable income. In the analysis, *Pdi* is used as a substitutive variable of *Pcs* and its logarithmic form is applied.

Considering regional heterogeneity and differences in urbanization and industrialization, another three dummy variables were introduced to explore influences of such heterogeneity and differences on *Ense*. These three dummy variables are region (*Region*), urbanization level (*h_urb*), and industrialization level (*h_indu*). *Region* values within 1 to 6 represent North, Northeast, East, Central South, Southwest, and Northwest China, respectively. *h_urb* values can be 1 or 0. When *Urb* is higher or equal to 60%, *h_urb* value is 1, otherwise, *h_urb* value is 0. *h_indu* values can be 1 or 0. When *Indra* is higher than 0.4, *h_indu* is 1, otherwise, *h_indu* is 0.

3.3. Descriptive Statistical Analysis

The statistical results of main variables are shown in Table 1. Table 1 indicates that the national average energy efficiency in China is 1.16 tons of standard coal/10,000 RMB. This ratio is far lower than the level in developed countries, indicating low energy utilization in China and manifested by great energy waste and low *Ense*. However, great regional differences among different provinces exist; the standard error is 0.55 tons of standard coal. In 2015, the lowest energy consumption per unit GDP in Beijing was 0.3 tons of standard coal, but reached 4.18 tons of standard coal in Xinjiang in 2014. The minimum and maximum *Indu* in observation samples of different provinces were 23.83 and 3025.95 billion RMB, respectively, indicating the significant difference among the provinces. However, the regional difference of *Indra* that reflects the industrialization level (*Indu/Gdp*) is smaller. Although urbanization rate is different in the provinces, urbanization has been progressing continuously around the whole China. Furthermore, Table 1 (above) shows that the national average urbanization rate has reached 52%, which was close to the urbanization level in middle developed countries. However, significant difference exists in urbanization level. Provinces in Southwest and Northwest China still have significantly lower urbanization level than provinces in East China and developed coastal provinces. Guizhou is the province with the lowest urbanization level in China, where the urbanization rate was lower than 40% for successive years. The urbanization rate of Guizhou from 2006 to 2009 was lower than 30% and reached the valley (27.45%) in 2006. On the contrary, the urbanization rate in developed provinces in Eastern China like Beijing, Shanghai, and Tianjin, exceeded 70% for many years. The average urbanization rate of Beijing was 85.62%. The average urbanization rate of Shanghai was the highest in China (88.93%) and even reached 89.61% in 2013, which reached the national urbanization level of developed countries.

In addition, energy utilization in different provinces in China increased annually in the past 10 years. In particular, the energy utilization of provinces with high economic development level (e.g., Beijing, Tianjin, and Guangdong) increased more quickly. However, energy utilization increased slowly in Western China which has low economic development level, industrial structure, and technological level (e.g., Gansu, Qinghai, and Ningxia). Particularly, energy utilization in the Xinjiang Autonomous Region was stable. Based on comparison of industrialization and urbanization rates in different provinces in China, facilitating urbanization may not increase industrialization level. This observation reflects no evident linear correlation between urbanization and industrialization rates. This effect may be due to unstable changes of economic and industrial structures among different provinces. The optimization of economic structure and updating of industrial structure accelerate the growth of added value of the tertiary industry. The growth of GDP and industrial added value reduce industrialization rate.

No evident linear relationship is found between urbanization and industrialization rates. What, and how great, is the impact of urbanization and industrialization rates on *Ense* of different provinces? To address these questions, an empirical analysis on panel data of 30 provinces was carried out.

4. Result Analysis

4.1. Model Selection

In order to choose an appropriate estimation model, the hybrid, fixed, and random effect models were employed simultaneously for the regression analysis. The clustering robust standard error method was applied in regression analysis of the fixed and random effect models to eliminate influences of heteroscedastic disturbance on estimation judgment. Finally, the optimal estimation model was chosen according to comprehensive comparison and reasonable judgment. The regression results of the three effect models are listed in Table 2.

Table 2. Comparison of estimation results of three regression models.

	Explained Variable: Energy Security		
	Hybrid Effect Model	**Fixed Effect Model**	**Random Effect Model**
ln*Indu*	−0.199	0.291 ***	0.276 ***
	(0.187)	(0.064)	(0.057)
ln*Urb*	0.795 **	0.698 ***	0.693 ***
	(0.384)	(0.216)	(0.168)
ln*Tpe*	0.459 **	−0.079 *	−0.071 *
	(0.208)	(0.045)	(0.041)
ln*Pcs*	−0.829 ***	−0.292 **	−0.312 ***
	(0.160)	(0.115)	(0.114)
_cons	−9.235 ***	−4.017 ***	−4.149 ***
	(1.457)	(1.135)	(1.031)
rho		0.953	0.936
P		0.000	0.000
theta			0.918
N	300	300	300
F	30.443	135.916	
R-Square	0.588	0.886	

Note: *, **, and *** are significant at 10%, 5%, and 1% levels, respectively. Number in parentheses is standard error. *_cons* is a constant term. Source: Own results

In Table 2, all variables can influence energy efficiency significantly in all three regression models, despite industrialization rate being insignificant in the hybrid effect model. In particular, the industrialization and urbanization rates have significantly positive impact on energy security at the 1% level of the fixed and random effect models. This result conforms to the empirical results of Xie [72] with great accuracy. Economic and industrial structures are improved or updated as a result of increased industrialization and urbanization levels. New, efficient energy generation technologies can be developed and implemented in the population agglomeration areas that have impact on energy productivity increase. Given the premise of fixed resources, energy efficiency is improved which will subsequently increase energy security.

In the hybrid effect model, the data meet simple OLS regression requirements under all classical hypothesis conditions. In fact, data hardly can meet classical hypotheses and are only used as reference in this study. After the control variables are added in, *rho* = 0.953 for the fixed effect model. The result is closer to 1 compared with that of the hybrid effect model which uses simple OLS regression. Strong fixed effect is indicated among different provinces. Moreover, $P = 0$ reveals that such fixed effect is significant at the 1% level which reflects provincial heterogeneity. Provinces variables in our model are then allowed to have an independent intercept term. The fixed effect model is significantly superior to the hybrid effect model. For the random effect model, *theta* = 0.918 and *rho* = 0.936, indicating the strong random effect among different provinces. According to $P = 0$ in LM test, this random effect is significant at the 1% level. This result further demonstrates that compared with the hybrid regression, the original hypothesis of "no individual random effect" is to be rejected. The random effect model is significantly superior to the hybrid effect model. Based on the above analysis, fixed and random effect models are superior to the hybrid effect model. Whether the fixed effect model or random effect model is superior is discussed further down the text.

The Hausman and Sargan–Hansen tests are implemented on the fixed and random effect models. The Hausman test shows $p = 0.0137$, which indicates that the original hypothesis of existing random effect is rejected with a great degree of certainty and the fixed effect model is chosen. In the Sargan–Hansen test, $p = 0.0019$ indicated that the model has no excessive identification. Based on the above comprehensive comparative analyses, an empirical analysis of influences of urbanization and industrialization on energy security was carried out in this study by choosing the fixed effect model. The second column in Table 2 shows the regression results based on the fixed effect model which uses clustering robustness standard error. The elasticity coefficient of industrialization rate (ln*Indu*) is 0.291 and the elasticity coefficient of urbanization rate (ln*Urb*) is 0.698 which are significant at the 1% level. The elasticity coefficient of per capita energy consumption expenditure (ln*Pcs*) is −0.292 which is significant at the 5% level. The elasticity coefficient of population size (ln*Tpe*) is −0.079 which is significant at the 10% level.

4.2. Robustness Test

In this study, robustness test is performed based on the following three considerations.

(1) In the chosen fixed effect model, the provincial heterogeneity problem, which is independent from time but changes with individuals, is solved by the individual fixed effect after the robust standard error is added. However, the provincial heterogeneity problem has individual and time effects. The individual fixed effect model cannot solve the provincial heterogeneity problems which are independent from individuals but change with time. Introducing the time effect is necessary to verify the robustness of the above model. This step verifies whether influences of urbanization and industrialization levels on energy security are robust under the existence of time effect.

(2) Currently, China has entered into a new state of economic development. When the proportion of urban population changes during urbanization, the age structure of population is changed accordingly. Subsequently, this change can influence energy consumption. The variable *Oldco*, which refers to the ratio between old population size (>64 years old) and total permanent resident population, is introduced to verify whether aging has changed effects of urbanization and industrialization on energy security.

(3) To verify whether the Kuznets curve relation between affluence and energy security existed, the per capita disposable income was decomposed in this study into *Pdi* and the quadratic term *Pdi2* in order to replace the per capita consumption expenditure *Pcs*. In the analysis, logarithmic forms of *Pdi* and *Pdi2* were applied. If the coefficient of *Pdi2* is negative, an inverted U-shaped Kuznets curve relation exists between per capita disposable income and energy security. If the coefficient of *Pdi2* is positive, a U-shaped Kuznets curve relation between per capita disposable income and energy security will emerge. Table 3 provides the regression estimation on the robustness test of the time fixed effect of population structural changes.

Table 3. Regression results of time effect and age structure.

	(1) **Time Fixed Effect**	(2) **Population Structure Effect**
ln*Indu*	0.296 ***	0.385 ***
	(0.043)	(0.040)
ln*Urb*	0.321 *	0.690 ***
	(0.165)	(0.128)
ln*Tpe*	−0.066 *	−0.103 ***
	(0.037)	(0.036)
ln*Pdi*	−3.133 ***	−5.313 ***
	(0.669)	(0.622)
ln*Pdi2*	0.162 ***	0.284 ***
	(0.034)	(0.031)
Oldco		0.034 ***
		(0.006)
_cons	13.235 ***	22.635 ***
	(3.422)	(3.073)
N	300	300
F	251.114	491.701
R-Square	0.932	0.918

Note: *, **, and *** are significant at 10%, 5%, and 1% levels, respectively. Number in parentheses is standard error. *_cons* is a constant term. Source: Own results.

The regression results in Column 1 of Table 3 reveal that coefficients of industrialization and urbanization rate are positive after the time fixed effect is introduced. Moreover, the coefficient of industrialization rate is significant at the 1% level and the coefficient of urbanization rate is significant at the 10% level. Hence, industrialization and urbanization levels can improve energy security significantly. Compared with the coefficient in the individual fixed effect model, the coefficient of industrialization rate in the time fixed effect model is stable at 0.296, whereas the coefficient of urbanization rate is reduced by 50% to 0.321. Evident provincial differences are implied on initial urbanization level. Under these differences, although urbanization level can improve energy security, the overall effect declines to some extent. In the time fixed effect model, the elasticity coefficient of population size is −0.066, indicating that energy security is decreased by 0.066% upon the increase of 1% of population size. Such reduction is significant at the 10% level.

According to regression results in Column 2 in Table 3, the coefficient of *Oldco* is significant at the 1% level and its elasticity coefficient is 0.034. This result proves that in the aging society, the growth of the old population can improve energy security. As the elderly population in China is willing to reduce various consumptions including energy, energy security is improved. After the variable of population age structure is involved in the elasticity coefficients of industrialization rate, urbanization rate and population size are 0.385, 0.69, and −0.103, which are all significant at the 1% level. This further confirms the significant impacts of industrialization rate, urbanization rate and population size on energy security. Compared with coefficient of individual fixed effect, the elasticity coefficient of industrialization rate is increased to some extent. Energy security is increased by 0.109% by increasing industrialization level by 1% in the aging society.

To sum up, the constructed fixed effect model passes the test and shows good robustness. In addition, the elasticity coefficients of *Pdi* and *Pdi*2 (when replacing the per capita consumption expenditure (*Pcs*)) are significant at the 1% level. The coefficient of ln*Pdi* is negative and the coefficient of ln*Pdi2* is positive. Moreover, the absolute value of the coefficient of ln*Pdi* is significantly higher than that of ln*Pdi2* which proves the U-shaped curve relationship between per capita disposable income and energy security. However, this curve is not an inverted U-shaped Kuznets curve, but a positive U-shaped Kuznets curve. It further indicates that when ln*Pdi* is low, *Ense* is relatively low and energy security level is not high because urbanization level is in a low-efficiency state. With the increasing of ln*Pdi*, the growth rate of energy consumption will be faster than that of GDP, but *Ense* will decrease further. When ln*Pdi* increases to a certain point, the technological efficiency improved by the upgrading of industrialization level will reduce the growth rate of energy consumption and make it lower than the growth rate of GDP. At this time, *Ense* will start to increase gradually. The Kuznets curve relationship between *Ense* and ln*Pdi* is shown in Figure 1.

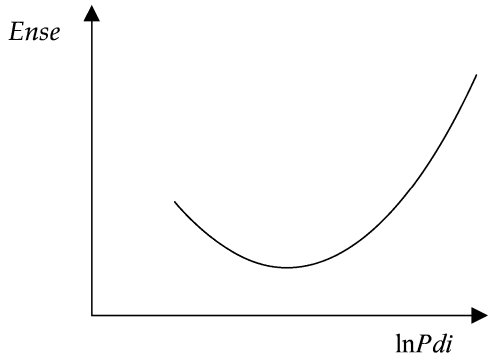

Figure 1. The Kuznets curve relationship between *Ense* and ln*Pdi.* Source: Own results.

4.3. Subsample Regression Analysis

Heterogeneity problems are common among different provinces in terms of industrialization and urbanization levels. These problems are caused by different geographical positions, economic, industrial, population structures, and technological levels. To verify further the influencing mechanism and effect of urbanization and industrialization rates, population size, and affluence on energy security in urbanization, samples were classified and processed according to urbanization and industrialization levels as well as geographic positions. This relationship is convenient for a comparative analysis.

4.3.1. Sample Classification Based on Industrialization Level

Internationally, four major indices are applied to measure industrialization level, namely, per capita GDP, industrialization rate, tertiary industrial, and employment structures, as well as urbanization rate. In this study, samples of different provinces were classified according to industrialization level by using industrialization rate. Specifically, samples with industrialization rate lower and higher than 40% were classified into low and high industrialization levels, respectively. Regression results of classified samples based on industrialization rate are listed in Table 4.

Our results demonstrate that (1) the elasticity coefficients of industrialization and urbanization rates are positive and significant at the 1% level, indicating that industrialization and urbanization under the given energy resources can improve energy security. The elasticity coefficient of population size is negative. This result reflects that the growth of population size can decrease energy security significantly which conforms to previous analysis. (2) The elasticity effect of industrialization rate on energy security in provinces with high industrialization level is 0.504, which is significantly higher than that in provinces with low industrialization level (0.366). The elasticity effect of urbanization on energy security in provinces with low industrialization level is 1.087, which is significantly higher compared with that in provinces with low industrialization level (0.673). The elasticity effect of population size on energy security shows significant differences among provinces with different industrialization levels. The elasticity effect is −0.647 in provinces with low industrialization level and the elasticity effect is −0.105 in provinces with high industrialization level, showing a difference of 0.542%. (3) When other variables are controlled, the elasticity effect of industrialization rate on energy security in provinces with high industrialization level is 1.38 (0.504/0.366) times that in provinces with low industrialization level. The elasticity effect of urbanization on energy security in provinces with low industrialization level is 1.6 (1.087/0.673) times that in provinces with high industrialization level. The growth of population in provinces with low industrialization level can reduce energy security by 6.16 (0.647/0.105) times compared with that in provinces with high industrialization level.

Table 4. Estimation results of samples with different industrialization levels.

	(1) Low Industrialization Level	(2) High Industrialization Level
ln*Indu*	0.366 ***	0.504 ***
	(0.050)	(0.064)
ln*Urb*	1.087 ***	0.673 ***
	(0.160)	(0.176)
ln*Tpe*	−0.647 **	−0.105 **
	(0.245)	(0.042)
ln*Pdi*	−3.958 ***	−5.956 ***
	(0.693)	(1.027)
ln*Pdi2*	0.210 ***	0.305 ***
	(0.036)	(0.052)
_cons	11.463 **	25.955 ***
	(4.555)	(4.971)
N	105	195
F	524.840	248.900
R-Square	0.970	0.883

Note: *, **, and *** are significant at 10%, 5%, and 1% levels, respectively. Number in parentheses is standard error. *_cons* is a constant term. Source: Own results.

4.3.2. Sample Classification Based on Urbanization Level

Typically, multiple indexes are used to measure urbanization level. Urbanization rate is one of the important indexes widely accepted by scholars. In this study, the population index of urbanization rate was applied. According to regulations of the National Bureau of Statistics of China, urbanization rate refers to the ratio between urban population and permanent resident population. In this study, provinces were classified according to urbanization level by using the urbanization rate. According to the National New Urbanization Planning (2014–2020), samples with urbanization rate lower than 60% and higher than 60% were classified into low and high urbanization levels, respectively. Table 5 presents the regression results of the sample classification based on urbanization rate.

Table 5. Estimation results of samples based on urbanization level.

	(1) Low Urbanization Level	(2) High Urbanization Level
ln*Indu*	0.333 ***	0.182 **
	(0.048)	(0.138)
ln*Urb*	1.018 ***	1.506
	(0.154)	(0.594)
ln*Tpe*	−0.158 ***	0.192
	(0.043)	(0.262)
ln*Pdi*	−3.988 ***	−4.685 ***
	(1.530)	(1.561)
ln*Pdi2*	0.214 ***	0.254 ***
	(0.080)	(0.074)
_cons	17.821 **	19.130 **
	(7.196)	(8.150)
N	235	65
F	336.206	264.432
R-Square	0.892	0.964

Note: *, **, and *** are significant at 10%, 5%, and 1% levels, respectively. Number in parentheses is standard error. *_cons* is a constant term. Source: Own results.

The elasticity coefficient of effect on energy security shows that (1) in provinces with low urbanization level, the elasticity coefficients of industrialization and urbanization rates and population size are 0.333, 1.018, and −0.158, respectively, which are all significant at the 1% level. When other variables are controlled, energy security has increased by 0.333% for every 1% growth of industrialization rate and by 1.018% for every 1% increase in urbanization rate. However, energy security has decreased by 0.158% for every 1% increase in population size. The overall effect of industrialization and urbanization rates and population size on energy security reaches 1.193%. In provinces with low urbanization level, the energy security is improved by 1.193% by facilitating industrialization and urbanization. (2) In provinces with high urbanization level, the elasticity effect of urbanization rate on energy security is 0.182, which is significant at the 5% level. This result implies that energy security is improved significantly by 0.182% for every 1% growth of industrialization rate. The regression results of sample classification based on urbanization level are consistent with the regression results using the fixed and time effect as well as population structural models.

4.3.3. Sample Classification Based on Geographical Positions

According to existing regions in China, the study area was divided into North, Northeast, East, Central South, Southwest, and Northwest. North China covers Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia. Northeast China includes Liaoning, Jilin, and Heilongjiang. East China has Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, and Shandong. Central South of China comprises Henan, Hubei, Hunan, Guangdong, Guangxi, and Hainan. Southwest China covers Chongqing, Sichuan, Guizhou, and Yunnan (Tibet is excluded due to missing data). Northwest China includes Shanxi, Gansu, Qinghai, Ningxia, and Xinjiang. Regression results on sample classification based on geographical positions are listed in Table 6.

Table 6. Estimation results of samples in different geographical regions.

	(1) North China	(2) Northeast China	(3) East China	(4) Central South of China	(5) Southwest China	(6) Northwest China
ln*Indu*	0.268 ***	0.602 ***	0.220 ***	0.389 ***	0.272 **	0.251
	(0.069)	(0.105)	(0.066)	(0.075)	(0.103)	(0.159)
ln*Urb*	1.392 ***	3.287 ***	1.099 ***	1.496 ***	1.662 ***	1.485 ***
	(0.275)	(1.058)	(0.228)	(0.229)	(0.307)	(0.499)
ln*Tpe*	0.075	−17.742 ***	0.462	−2.300 ***	−1.805 ***	−0.194 **
	(0.206)	(4.081)	(0.313)	(0.486)	(0.641)	(0.088)
ln*Pdi*	−5.271 ***	−2.095	−3.232 ***	−1.860	−2.159	−9.479 *
	(1.413)	(2.746)	(1.061)	(1.780)	(3.538)	(5.294)
ln*Pdi2*	0.283 ***	0.114	0.176 ***	0.082	0.106	0.520 *
	(0.069)	(0.148)	(0.052)	(0.093)	(0.187)	(0.280)
_cons	22.259 ***	151.414 ***	9.813	−11.225	−5.035	−42.906 *
	(7.742)	(34.454)	(6.624)	(10.857)	(19.590)	(24.497)
N	50	30	70	60	40	50
F	260.840	120.553	439.731	256.676	169.818	30.968
R-Square	0.970	0.965	0.974	0.963	0.965	0.795

Note: *, **, and *** are significant at 10%, 5%, and 1% levels, respectively. Number in parentheses is standard error. *_cons* is a constant term. Source: Own results.

Looking at the results presented in Table 6, one can see that horizontally

(1) The elasticity effect of urbanization rate on energy security is positive and it is significant at the 1% level, indicating that urbanization can improve energy security in all regions. When other variables are controlled, the elasticity effect of urbanization on energy security in northeast China with low urbanization level is highest (3.278), but the elasticity effect of urbanization on energy security in East China with the highest urbanization level is lowest (1.099).

(2) The elasticity effect of industrialization rate on energy security is positive. This effect is significant in other five regions except for Northwest China. The elasticity effect of industrialization rate on energy security is significant at the 1% level in North, Northeast, East, and Central South of China, and is significant at the 5% level in Southwest China. This result indicates that increasing industrialization level can improve energy security greatly, which conforms to earlier analysis. The elasticity effect in Northeast China reaches the highest (0.602), and the elasticity effect is higher than 0.25 in other regions.

(3) The elasticity effect of population size on energy security is significantly negative in Northeast, Central South, Southwest, and Northwest China, indicating that increase in population size can decrease energy security significantly. This result conforms to the earlier analysis. In addition, the regression results in Table 4, Table 5, and Table 6 show that the coefficient of *Pdi* is significantly negative at the 1% level and the coefficient of *Pdi2* is significantly positive at the 1% level (insignificantly positive in Northeast, Central South, and Southwest China), indicating the positive U-shaped Kuznets curve relationship between disposable income and energy security remains the same. This result conforms to the robustness test results involving the time fixed and population structural effects in Table 3. A positive U-shaped Kuznets curve relationship exists between disposable income and energy security.

5. Discussions

Based on the empirical results, one can conclude that urbanization and industrialization rates, income, energy consumption expenditures, and population greatly affect energy security during urbanization. However, such effect varies according to provincial heterogeneity.

First, the involvement of time effect and population structure in the fixed effect model may not change the influence directions of industrialization and urbanization rates, population size, and consumption expenditure on energy security, but only trigger a small fluctuation of elasticity coefficients. These observations are supported by the analysis of results in Column 2 in Tables 2 and 3. When other factors are fixed, energy security is increased by 0.291% and 0.698% for every 1% increase of industrialization and urbanization rates, respectively. The elasticity effect of urbanization rate is 0.4% higher than that of industrialization rate. Although industrialization will increase energy consumption to a certain extent, the intensive guidance of urbanization development on energy consumption, as well as technological progress and technological innovation in the process of economic growth and social progress, will lead to the improvement of production efficiency and comprehensive utilization efficiency of energy, thus helping to reduce the risk level of energy security. Furthermore, energy security is decreased by 0.079% and 0.292% upon a 1% increase of population size and energy consumption expenditure, respectively. Moreover, the elasticity effect of energy consumption expenditure is 0.213% higher than that of population size. Energy consumption expenditure is the major cause of decreasing energy security. This indicates that the population density is gradually increasing, which promotes the increase of energy-intensive infrastructure. At the same time, urbanization leads to increase of household income and the change of lifestyle. The energy consumption of transportation and communication activities will also increase. This means that the high concentration of economic activities, such as consumption in urban areas, lead to an increase in energy consumption and a decrease in energy security level. However urbanization and industrialization also mean the emergence of economies of scale and industrial agglomeration in production and consumption, and the promotion of optimizing industrial structure, product structure, and technological progress. The threats of increasing population size and energy consumption expenditure to energy security can be offset by improved energy efficiency caused by urbanization and industrialization. The collaborative effect of simultaneous increasing of energy consumption and energy efficiency influences the energy security.

Second, our results reported in Table 3 confirm the U-shaped Kuznets curve relation between per capita disposable income and energy security. When per capita disposable income is low, economic and industrial structures, as well as industrialization and urbanization levels, are in a low-efficiency state. The extensive mode of economic growth forms the development of heavy industrialization. The insufficiency of energy technology leads to the low output per unit energy consumption and low energy efficiency. The growth rate of energy consumption is faster than that of economic growth. This relationship thereby decreases energy security under limited energy resources. Continuous increase of per capita disposable income gradually improves the economic and industrial structures and industrial level. Subsequently, technological development and innovation are accelerated. Energy utilization begins to develop a turning point in certain situations. When the per capita disposable income is increased to one node, the growth of economic growth is far higher than the growth rate of energy consumption brought by increase in disposable income. Under this circumstance, energy efficiency is increased with the increase of per capita disposable income, thus improving energy security.

Third, our results depicted in Table 4 show that given the same other variables, the overall elasticity effect on energy security for 1% growth of industrialization rate, 1% growth of urbanization rate, and 1% growth of population size reaches 2.1% in provinces with low industrialization level. In provinces with high industrialization level, the rate is 1.072%, which shows a difference of 1.028%. This result reveals that promoting urbanization and industrialization in provinces with low industrialization level can positively affect energy security more significantly. Due to the fact that the energy efficiency is low in provinces with low industrialization level due to the extensive industrial growth mode and old industrial equipment and obsolete technologies, the difference between the effects on energy efficiency and consumption is higher compared with that in provinces with high industrialization level.

Fourth, the results shown in Tables 5 and 6 indicate that the elasticity effect of urbanization rate on energy security is influenced by urbanization level. Such elasticity effect decreases gradually with the increase in urbanization level. This conclusion conforms to the empirical results of Jing [73]. In provinces with low urbanization level, the elasticity effect of urbanization rate is 0.775% higher than the elasticity effect of industrialization rate. Provinces with a low urbanization level should promote urbanization more, while improving industrialization level. In provinces with high urbanization level, effects of urbanization rate and population size are not significant. Therefore, provinces with high urbanization level should increase technological input and innovation while assuring energy security. In addition, these areas should increase energy efficiency based on technological innovations.

Fifth, the results reported in Table 6 show that given the same other variables, every 1% increase of industrialization rate can improve energy security by at least 0.25%. This relationship further verifies the findings of Qi and Luo [74]. As population sizes of North and East China are nearly saturated and the population agglomeration effect has almost disappeared, the effects of population size on energy security are not significant in these regions. When other factors are fixed, the elasticity effect of urbanization rate on energy security is higher than the elasticity effect of industrialization rate in all regions. This finding proves that reasonable acceleration of urbanization is an important means to improve energy security during implementation of policies to promote industrialization.

6. Conclusions

In order to assess the effect of industrialization and urbanization on energy security, we constructed a STIRPAT model using energy efficiency as a proxy variable of energy security and choosing industrialization and urbanization rates, consumption expenditure, and population size as variables.

In addition, we carried out an empirical analysis of the effects of industrialization and urbanization rates, energy consumption expenditure, and population size on energy security using panel data of 30 provinces (except Tibet) of mainland China from 2006 to 2015. The fixed effect model applies clustering robust standard error. Robustness of empirical analysis results was verified at the same time. Finally, samples were classified and analyzed independently. Differences of effects of provincial heterogeneity on energy security were discussed from the perspectives of industrialization and urbanization levels as well as geographical positions. There are several major conclusions that can be drawn from our results:

(1) Industrialization and urbanization rates have positive effects on energy security. Although an increase in energy consumption expenditures and population size decreases energy security, the

positive effect of industrialization and urbanization rates on energy security is stronger than the negative effect of the increase in energy consumption expenditure and population size on energy security. The overall effect of the four factors is positive. The increase in urbanization and industrialization levels, energy consumption expenditure, and urban population yearly can improve energy security during the process of urbanization in developing economies significantly.

(2) Changes in the population structure will not change the influence direction of industrialization and urbanization rates, energy consumption expenditure, and population size on energy security, but will only cause a small fluctuation of effects. The aging society is conducive to improving energy security due to consumption preference of the elderly linked to savings.

(3) In the view of overall effects, promoting research and technological development as well as innovation in provinces with low industrialization level and accelerating urbanization to develop the population agglomerations in provinces with high industrialization level can significantly improve energy security.

(4) Provinces with high urbanization level should pay more attention to technological development and innovation, whereas provinces with low urbanization level should promote urbanization and increase industrial development and technological innovations at the same time. These strategies can greatly improve energy security.

(5) After per capita energy consumption expenditure is replaced by per capita disposable income, which can represent affluence and its quadratic term, the elasticity effect of per capita energy consumption expenditure becomes negative. However, the elasticity effect of the quadratic term of per capita disposable income is positive which confirms the U-shaped Kuznets curve relationship between disposable income and energy security.

All in all, sustainable energy development is the main condition of national security and social stability. In addition, energy plays a vital role in economics, politics, and people's livelihoods. Energy security and environmental sustainability become a fundamental strategic task of China. Therefore, there is an urgent need to solve energy security problems by laws and long-term policies and strategies. The conclusions presented in our paper can help local governments to formulate local policies and regulations and promote urbanization with comprehensive consideration of local economic development, industrial structure, financial balance of citizens, as well as population size and structures. First of all, local governments should optimize the industrial structure and increase the industrial output value in economic development while paying attention to improving the technology content, increasing the use of technology, reducing energy consumption, and taking an energy-saving industrialization road, which can effectively reduce energy consumption and energy use. Secondly, some energy-intensive industries should be effectively transformed, such as industrial upgrading, industrial transfer, reducing the number of high energy-consuming industries, which will effectively save energy. Finally, local governments should further promote the process of urbanization, establish a supply system of renewable energy resources, ensure the stability of the energy supply system, guide the intensive and clean development of energy consumption, strengthen the optimization role of urbanization on energy consumption, and form a low-energy urbanization development path.

Surely, this study has some limitations. For example, data from some regions are missing, and the time span only covers 10 years due to imperfect statistical data. Both limitations may influence consistency and validity of estimations. The indicators of energy productivity applied in this study as proxy for energy security also have some limitations as they do not fully address other important issues linked to energy security like energy import dependency or energy prices. There is no one ideal indicator, as the notion of energy security is highly context-dependent. Rather than that, applying multiple indicators leads to a broader understanding. More comprehensive and appropriate energy security indicators should be designed in future research, according to the connotation and expansion of energy security concept. On the time scale, further research needs to strengthen the organic combination of short-term, medium-term, and long-term energy security, urbanization, and industrialization research, and explore the differences of energy security, urbanization, and industrialization in different time scales, so as to help the government understand the energy security situation and avoid energy risks.

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References

1. Siksnelyte, I.; Zavadskas, E.; Streimikiene, D.; Sharma, D. An overview of multi-criteria decision-making methods in dealing with sustainable energy development issues. *Energies* **2018**, *11*, 2754. [CrossRef]
2. Shortall, R.; Davidsdottir, B. How to measure national energy sustainability performance: An Icelandic case-study. *Energy Sustain. Dev.* **2017**, *39*, 29–47. [CrossRef]
3. Campisi, D.; Gitto, S.; Morea, D. An evaluation of energy and economic efficiency in residential buildings sector: A multi-criteria analisys on an Italian case study. *Int. J. Energy Econ. Policy* **2018**, *8*, 185–196.
4. Li, L.; Chi, T.; Wang, S. Is energy utilization among Chinese provinces sustainable? *Technol. Forecast. Soc. Chang.* **2016**, *112*, 198–206. [CrossRef]
5. Zhang, L. The establishment and development of China's energy legal system. *J. Beijing Inst. Technol.* **2011**, *13*, 107–111.
6. Li, K.; Fang, L.; He, L. How urbanization affects China's energy efficiency: A spatial econometric analysis. *J. Clean. Prod.* **2018**, *200*, 1130–1141. [CrossRef]
7. Garcia-de-Vinuesa, A.D.L.; Aguayo-Gonzalez, F.; Cordoba-Roldan, A. Proposal of A Framework for the Evaluation of the Sustainability of Products from the Paradigm of the Circular Economy Based on Industry 4.0 (2nd part). *DYNA* **2018**, *93*, 488–492.
8. National Bureau of Statistics of China. *Statistical Bulletin on China's National Economic and Social Development in 2015*; NBS: China, Beijing, 2016. Available online: http://www.stats.gov.cn/tjsj/zxfb/201602/t20160229_1323991.html (accessed on 12 May 2019).
9. Morcillo-Bellido, J.; Prida-Romero, B. Sustainability is Changing the Way that We Innovate in the Energy Sector through Energy Service Companies (ESCO). *DYNA* **2018**, *93*, 246.
10. Protić, M.; Fathurrahman, F.; Raos, M. Modelling Energy Consumption of the Republic of Serbia using Linear Regression and Artificial Neural Network Technique. *Tehnički Vjesn.* **2019**, *26*, 135–141.
11. Balitskiy, S.; Bilan, Y.; Strielkowski, W. Energy security and economic growth in the European Union. *J. Security. Sustain. Issues* **2014**, *4*, 125–132.
12. Szulc, P.; Tietze, T. Recovery and Energy Use of Flue Gas from A Coal Power Plant. *J. Power Technol.* **2017**, *97*, 135–141.
13. Zupancic, D.; Buchmeister, B.; Aljaz, T. Reducing the Time of Task Execution with Existing Resources-Comparison of Approaches. *Int. J. Simul. Model.* **2017**, *16*, 484–496. [CrossRef]
14. Jones, D.W. How Urbanization Affects Energy-Use in Developing Countries. *Energy Policy* **1991**, *19*, 621–630. [CrossRef]
15. Sadorsky, P. The Effect of Urbanization and Industrialization on Energy Use in Emerging Economies: Implications for Sustainable Development. *Am. J. Econ. Soc.* **2014**, *73*, 392–409. [CrossRef]
16. Liddle, B.; Lung, S. Age-Structure, Urbanization and Climate Change in Developed Countries: Revisiting Stirpat for Disaggregated Population and Consumption-Related Environment Impacts. *Popul. Environ.* **2010**, *31*, 317–343. [CrossRef]
17. Zhang, R.; Ding, R.J. The Impact of Industrialization and Urbanization on Energy Intensity: An Empirical Study Based on China's Interprovincial Dynamic Panel Data. *Inq. Econ. Issues* **2015**, *36*, 11–15.
18. Zhou, S.F.; Wang, Y.N. The Impact of China's Industrialization and Urbanization on Energy Intensity: Based on a Dynamic Panel Data Model. *Ecol. Econ.* **2015**, *31*, 317–343.

19. Wang, K.Y.; Zhang, H.W. An Empirical Research on the Effects of Urbanization and Industrialization on Energy Intensity. *China Popul. Res. Environ.* **2016**, *26*, 122–129.
20. Sereewatthanawut, I.; Ferreira, F.C.; Hirunlabh, J. Advances in Green Engineering for Natural Products Processing: Nanoseparation Membrane Technology. *J. Eng. Sci. Technol. Rev.* **2018**, *11*, 196–214.
21. Ding, C.C. The Dynamic Effect and Regional Difference of the Industrialization and Urbanization on the Energy Consumption Intensity in China. *J. Hebei Univ. Econ. Bus.* **2015**, *36*, 47–54.
22. Li, K.; Lin, B. Impacts of urbanization and industrialization on energy consumption/CO2 emissions: Does the level of development matter? *Renew. Sustain. Energy Rev.* **2015**, *52*, 1107–1122. [CrossRef]
23. Zhang, X.P.; Cheng, X.M.; Yuan, J.H.; Gao, X.J. Total-factor energy efficiency in developing countries. *Energy Policy* **2011**, *39*, 644–650. [CrossRef]
24. Wang, B.; Xie, J. International comparison of total factor energy efficiency: An empirical research from the perspective of energy structure. *Ind. Econ. Rev.* **2015**, *2*, 72–86.
25. Onafowora, O.A.; Owoye, O. Bounds testing approach to analysis of the environment Kuznets curve hypothesis. *Energy Econ.* **2014**, *44*, 47–62. [CrossRef]
26. Yang, W.P.; Yuan, X.L. Hypothesis of environmental Kuznets curve and its test in China. *Res. Environ. Yangtze Basin* **2009**, *18*, 704–710.
27. Wei, B.R.; Yagita, H.; Inaba, A.; Sagisaka, M. Urbanization Impact on Energy Demand and CO_2 Emission in China. *J. Chongqing Univ. Eng. Ed.* **2003**, *2*, 46–50.
28. Liu, Y.B. Exploring the Relationship between Urbanization and Energy Consumption in China Using ARDL (Autoregressive Distributed Lag) and FDM (Factor Decomposition Model). *Energy* **2009**, *34*, 1846–1854. [CrossRef]
29. Al-mulali, U.; Sab, C.N.B.C.; Fereidouni, H.G. Exploring the bi-directional long run relationship between urbanization, energy consumption, and carbon dioxide emission. *Energy* **2012**, *46*, 156–167. [CrossRef]
30. Mishra, V.; Sharma, S.; Smyth, R. Are fluctuations in energy consumption per capita transitory? Evidence from a panel of Pacific Island countries. *Energy Policy* **2009**, *37*, 2318–2326. [CrossRef]
31. Newell, R.G.; Jaffe, A.B.; Stavins, R.N. The Induced Innovation Hypothesis and Energy-Saving Technological Change. *Q. J. Econ.* **1999**, *114*, 941–975. [CrossRef]
32. Fisher-Vanden, K.; Jefferson, G.H.; Liu, H.; Tao, Q. What is Driving China's Decline in Energy Intensity? *Res. Energy Econ.* **2006**, *26*, 77–97. [CrossRef]
33. Li, B.; Wu, J.; Chen, Z.X. Urbanization, Industrialization, Informatization and Chinese Energy Intensity. *China Popul. Res. Environ.* **2015**, *25*, 69–76.
34. Ma, Y.; Xu, L.L. Research on the Influence of Industrialization and Urbanization on Energy Intensity: An Empirical Analysis of FGLS and SYS-GMM Based on Xinjiang Panel Data. *Ecol. Econ.* **2017**, *33*, 66–70.
35. Kasman, A.; Duman, Y.S. CO_2 emissions, economic growth, energy consumption, trade and urbanization in new EU member and candidate countries: A panel data analysis. *Econ. Model.* **2015**, *44*, 97–103. [CrossRef]
36. Farhani, S.; Ozturk, I. Causal relationship between CO_2 emissions, real GDP, energy consumption, financial development, trade openness, and urbanization in Tunisia. *Environ. Sci. Pollut. Res.* **2015**, *22*, 15663–15676. [CrossRef] [PubMed]
37. Poumanyvong, P.; Kaneko, S. Does Urbanization Lead to Less Energy Use and Lower CO_2 Emissions? Across-Country Analysis. *Ecol. Econ.* **2010**, *70*, 434–444. [CrossRef]
38. Kan, D.X.; Luo, L.W. The Impact of China's Urbanization on Energy Intensity: Based on A Space Econometric Analysis. *Contemp. Financ. Econ.* **2010**, *3*, 83–88.
39. Mulder, P.; De Groot, H.L.F. Structural change and convergence of energy intensity across OECD countries. *Energy Econo.* **2012**, *34*, 1910–1921. [CrossRef]
40. Ang, B.W.; Choong, W.L.; Ng, T.S. Energy security: Definitions, dimensions and indexes. *Renew. Sustain. Energy Rev.* **2015**, *42*, 1077–1093. [CrossRef]
41. Bohi, D.R.; Toman, M.A. *The Economics of Energy Security*; Springer Science & Business Media: New York, NY, USA, 2012.
42. Dorian, J.P.; Franssen, H.T.; Simbeck, D.R. Global challenges in energy. *Energy Policy* **2006**, *34*, 1984–1991. [CrossRef]
43. Bielecki, J. Energy security: Is the wolf at the door? *Q. Rev. Econ. Financ.* **2002**, *42*, 235–250. [CrossRef]
44. Muller-Kraenner, S. *Energy Security*; Routledge: London, UK, 2015.

45. United Nation Development Programme (UNDP). *UNDP and Climate Change*; United Nations: New York, NY, USA, 2015; Available online: https://www.undp.org/content/undp/en/home/librarypage/climate-and-disaster-resilience-/undp-and-climate-change.html (accessed on 13 May 2019).
46. Chester, L. Conceptualising energy security and making explicit its polysemic nature. *Energy Policy* **2010**, *38*, 887–895. [CrossRef]
47. Cabalu, H. Indicators of security of natural gas supply in Asia. *Energy Policy* **2010**, *38*, 218–225. [CrossRef]
48. Badea, A.C.; Tarantola, S.; Bolado, R. Composite indicators for security of energy supply using ordered weighted averaging. *Reliab. Eng. Syst. Saf.* **2011**, *96*, 651–662. [CrossRef]
49. Radovanović, M.; Filipović, S.; Pavlović, D. Energy security measurement–A sustainable approach. *Renew. Sustain. Energy Rev.* **2017**, *68*, 1020–1032. [CrossRef]
50. Lesbirel, S.H. Diversification and energy security risks: The Japanese case. *Jpn. J. Polit. Sci.* **2004**, *5*, 1–22. [CrossRef]
51. Sun, H.; Nie, F.F.; Hu, X.Y. Evaluation and difference analysis of energy security in China based on entropy-weight TOPSIS modeling. *Res. Sci.* **2018**, *40*, 477–485.
52. Vivoda, V. Evaluating energy security in the Asia-Pacific region: A novel methodological approach. *Energy Policy* **2010**, *38*, 5258–5263. [CrossRef]
53. Sovacool, B.K. Evaluating energy security in the Asia pacific: Towards a more comprehensive approach. *Energy Policy* **2011**, *39*, 7472–7479. [CrossRef]
54. Ren, J.; Sovacool, B.K. Quantifying, measuring, and strategizing energy security: Determining the most meaningful dimensions and metrics. *Energy* **2014**, *76*, 838–849. [CrossRef]
55. Sovacool, B.K.; Mukherjee, I. Conceptualizing and measuring energy security: A synthesized approach. *Energy* **2011**, *36*, 5343–5355. [CrossRef]
56. Wu, G.; Liu, L.C.; Han, Z.Y.; Wei, Y.M. Climate protection and China's energy security: Win–win or tradeoff. *Appl. Energy* **2012**, *97*, 157–163. [CrossRef]
57. Martchamadol, J.; Kumar, S. Thailand's energy security indicators. *Renew. Sustain. Energy Rev.* **2012**, *16*, 6103–6122. [CrossRef]
58. Su, M.; Zhang, Y.S. Review of energy security assessment research. *Zhejiang Soc. Sci.* **2007**, *4*, 126–132.
59. Beccue, P.C.; Huntington, H.G.; Leiby, P.N.; Vincent, K.R. An Assessment of Oil Market Disruption Risks. *Energy Policy* **2018**, *115*, 456–469. [CrossRef]
60. Makarov, Y.V.; Moharari, N.S. A Generalized Power System Reliability and Security Index. In Proceedings of the IEEE Power Tech99 Conference, Budapest, Hungary, 29 August–2 September 1999.
61. Winzer, C. Conceptualizing Energy Security. *Energy Policy* **2012**, *46*, 36–48. [CrossRef]
62. Stirling, A. *On the Economics and Analysis of Diversity*; Science Policy Research Unit, University of Sussex: Sussex, UK, 1998; p. 28. Available online: http://www.sussex.ac.uk/spru/1-6-1-2-1.html (accessed on 13 May 2019).
63. Jansen, J.C.; Van Arkel, W.G.; Boots, M.G. *Designing Indicators of Long-Term Energy Supply Security*; Energy Research Centre of the Netherlands: Petten, The Netherlands, 2004; Available online: http://www.ecn.nl/docs/library/report/2004/c04007.pdf (accessed on 14 May 2019).
64. Grubb, M.; Butler, L.; Twomey, L. Diversity and Security in UK Electricity Generation: The Influence of Low-Carbon Objectives. *Energy Policy* **2006**, *34*, 4050–4062. [CrossRef]
65. Frondel, M.; Schmidt, C.M. *Measuring Energy Security: A Conceptual Note*; Ruhr economic papers; University Essen: Essen, Germany, 2008; p. 52.
66. Kruyt, B. Indicators for Energy Security. *Energy Policy* **2009**, *37*, 2166–2181. [CrossRef]
67. Zeng, S.; Streimikiene, D.; Baležentis, T. Review of and comparative assessment of energy security in Baltic States. *Renew. Sustain. Energy Rev.* **2017**, *76*, 185–192. [CrossRef]
68. Yergings, D. Energy Security in the 1990s. *J. Foreign Aff.* **1988**, *67*, 110–132. [CrossRef]
69. Nikolaidis, P.; Poullikkas, A. A comparative Review of Electrical Energy Storage Systems for Better Sustainability. *J. Power Technol.* **2017**, *97*, 220–245.
70. Subashini, M.; Ramaswamy, M. Bifurcation and Chaos in Converter Interfaces in Solar PV Systems-A Review. *J. Eng. Sci. Technol. Rev.* **2017**, *10*, 90–97. [CrossRef]
71. Ding, Y.L. Study of Regional Differences of Energy Security and Coordination with Urbanization in China. *J. Dalian Univ. Technol.* **2013**, *34*, 24–27.
72. Xie, L.P. Energy Consumption and Urbanization, Industrialization. *J. Ind. Technol. Econ.* **2015**, *34*, 95–100.

73. Jing, X.Q. The Urbanization and Energy Intensity in the Western China: Empirical Analysis Based on the Province Panel Data from 1996 to 2011. *China Popul. Res. Environ.* **2014**, *24*, 261–264.
74. Qi, S.Z.; Luo, W. Regional Economic Growth and Differences of Energy Intensity in China. *Econ. Res. J.* **2007**, *42*, 74–81.