

ECONOMIC ANALYSIS OF ENERGY EFFICIENCY OF CHINA'S AND INDIA'S NATIONAL ECONOMIES*

Zihui Ji¹, Iryna M. Sotnyk²

The development of society is highly dependent on energy. However, the extensive use of power causes global problems such as resource exhaustion and climate warming. China and India are typical fast-growing developing countries whose economic advancement relies on traditional energy consumption. To realize the vision of sustainable development for these states, it is necessary to study the nations' economic efficiency of power use. Based on the analysis of energy consumption and gross domestic product trends in China and India from 1990 to 2019, this paper discusses the changes in the energy consumption index per unit of gross domestic product. The authors concluded that the power consumption in China and India is mainly concentrated in the industry, residential, and transport sectors. Divided by resource types, the energy consumed by China comes primarily from coal, oil products, and electricity, while the power consumed by India is mainly from coal, oil products, biofuels and waste. Since both countries mostly use coal and oil products which belong to fossil fuels, they emit large amounts of carbon dioxide, endangering the environment quality. Given this, China and India should focus on green power development. China's total energy consumption is much larger than India's, and China's gross domestic product is much larger than India's. However, China's energy consumption per unit of gross domestic product is less than India's. The higher the energy consumption per unit of gross domestic product is, the higher the dependence of economic development on energy is. The authors' suggestions are to develop non-fossil energy sources and adjust the energy mix, recycle solid wastes, and encourage carbon trading, climate investment and financing in the states to reach sustainable development targets.

Keywords: China, economic analysis, energy consumption, energy efficiency, GDP per unit of energy use, India, sustainable development.

JEL Classification: Q01, Q43, O14

Introduction. Human living and social development highly depend on natural resources. In this sense, the history of human society is a history of change concerning the development and utilization of energy. Two oil crises in 1973 and 1979 seriously hindered economic progress and promoted the rise of energy economics that gradually became the focus of the economic systems.

The massive development and utilization of traditional power have supported the high prosperity of society and the rapid growth of the economy. However, the extensive energy deployment has caused many problems worldwide, namely, resource depletion, ecological deterioration, environmental pollution, climate warming, etc. (Social inequality, 2021; Power supply, 2020; Economic strategies, 2020).

The global energy transition is imminent. Energy is the blood of modern society and closely relates to social, economic, ecological, and environmental dimensions. With the rapid development of society, power is being consumed rapidly. It is obvious that traditional energy from fossil fuels cannot meet the endless needs of humankind. As a result, people are trying to improve the economic effi-

ciency of energy use, also known as energy efficiency or energy intensity.

Literature review. Energy efficiency is a complex concept involving many disciplines, such as environmental science, economics, mathematics, physics, computer science, etc. Therefore, energy efficiency has become a hot topic for experts in various disciplines and countries (for example, (Sineviciene et al., 2017; Sotnyk et al., 2015; Energy consumption, 2018; International economic relations, 2017)).

The use of energy has a profound effect on economic development. Improving the economic efficiency of power use, with less energy to obtain the same output, contributes to reducing the use of natural resources and environmental damage. This effect has become the focus of attention of researchers worldwide. (Niu, 2011) evaluated the causal relationship between energy consumption, gross domestic product (GDP) growth, and carbon emissions in 8 countries in the Asia-Pacific region during 1971–2005. The author concluded that carbon emissions per unit of energy consumption and energy

* The paper is prepared within the research project “Fundamentals of the phase transition to the additive economy: from disruptive technologies to institutional socialization of decisions” (No. 0121U109557), and “Sustainable development and resource security: from disruptive technologies to digital transformation of Ukrainian economy” (No. 0121U100470)

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efficiency in developing countries were far lower than those in developed countries. Over time, however, the participation of developed countries in total world energy consumption has declined. In developing countries, relative participation has increased by more than 100% over the past 30 years.

To reduce carbon dioxide emissions without harming economic growth, a country needs to decrease energy supply, boost energy efficiency investments, strengthen energy conservation policies, and reduce energy waste. (Zhang & Chen, 2018) calculated the total factor energy efficiency index of BRICS countries, using DEA analysis method and mathematical programming to solve different problems of efficiency evaluation. The authors concluded that the energy efficiency of a country or region is not only affected by economic benefits but also by the total amount of energy consumed, which involves the energy consumption per unit GDP.

(Otsuka & Goto, 2018) mentioned that Japan's economy is limited by the environment, and population density will affect energy intensity improvement. Therefore, it is necessary to control greenhouse gas emissions by improving energy intensity and providing the country's economic growth. (Sotnyk, 2016) indicated that establishing energy service companies in Ukraine can increase the energy efficiency of the country's economy. (Gielen, 2019) considered energy efficiency and renewable energy technologies implementation as essential factors for economic transformation. Many other scholars have obtained valuable results while analyzing energy efficiency. However, most studied the relationship between people and energy without paying sufficient attention to the connection between the fast-growing national economies and their power consumption.

With the development of economic globalization, developing countries must reform and apply innovative management approaches to maintain high economic growth rates and strengthen industrial structure and infrastructure to fight poverty (Vitenu-Sackey & Hongli, 2020). China and India are both developing economies with large populations and a considerable number of energy consumers. Therefore, it is of great significance to study the economic efficiency of energy use in these two states for the world's sustainable energy development.

In the past decade, China and India have attracted extensive attention from the international community and played an important role in energy consumption and carbon emissions. China and India have different economic, social, political, and cultural characteristics, as well as different histories, religions, geography, and climate. Both countries have peculiarities regarding economic growth, environmental governance, and energy resources (Banerjee et al., 2014; Junfeng, 2021). As a key issue for sustainable development, the economic efficiency of power use in these states will be discussed in this paper.

Methods. The study uses energy consumption per GDP unit as an evaluation index of economic efficiency for energy use in China's and India's national economies. Energy consumption per unit of GDP refers to the power

consumed to produce \$1 of GDP by a country (region) in a certain period. This indicator is the main index reflecting the level of energy consumption, energy conservation, and its reduction. Generally speaking, energy consumption per unit of GDP is the ratio of total energy consumption to GDP. This index shows the degree of energy use in a country's economic activities and changes in economic structure and energy use efficiency (The World Bank, 2022).

The data used for the analysis are China and India's total energy consumption and GDP between 1990 and 2019. Total energy consumption comes from the IEA database (IEA, 2022), while GDP and energy consumption per unit of GDP comes mainly from the World Bank (The World Bank, 2022). The total energy consumption is divided into total energy consumption by sector and total energy consumption by type. Since the data values of energy consumption per GDP unit published by the World Bank has only been updated to 2014. Therefore, the energy consumption per GDP unit from 2015 to 2019 was inferred by the quantitative relation of Formula (1):

$$\text{Energy Consumption per Unit of GDP} = \frac{\text{Total energy consumption}}{\text{GDP}} \quad (1)$$

In the Formula, total energy consumption refers to the total amount of all kinds of energy consumed by all sectors of the national economy and households in a certain period of time in a country (region) (The energy consumption, 2022). The total amount of energy here refers to the various resources that can be obtained directly or through processing and conversion from nature, including raw coal, crude oil, natural gas, water, wind, solar, biomass, etc., and total consumption by sectors. GDP data are presented in constant 2015 prices and expressed in U.S. dollars.

Results. Energy consumption by sector. Figure 1 shows the results of the analysis of total final consumption by sector in China's and India's economies in 1990-2019. As it can be seen from Figure 1, energy consumption per sector for both countries indicates an upward trend in the annual consumption of each sector from 1990 to 2019. Energy consumption is mainly concentrated in the industry, residential, and transport sectors.

Energy consumption trends of different sectors in China. The Industry sector decreased its consumption slightly from 1995 to 2000 and increased it by 26.02 million TJ from 2000 to 2010. Moreover, the energy consumption of this sector increased by 4.3 times in 30 years, making the largest contribution among other sectors. The Transport sector demonstrated the fastest relative growth in energy consumption, increasing nearly tenfold in 29 years. The energy consumption growth rate in the Residential sector tended to be stable all year round. Energy consumption in the Commercial and public services sector was on the rise and has increased fivefold in 29 years. The energy consumption of the Agriculture/forestry sector, Non-specified and Non-energy use, had a small

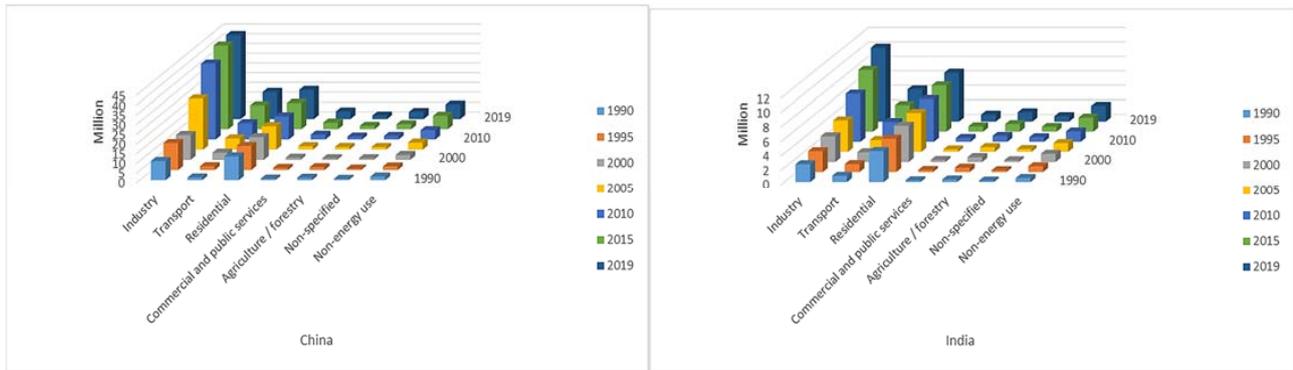


Figure 1 – Total final consumption by sector of China's and India's economies in 1990-2019, TJ

Source: calculated by the authors based on (IEA, 2022)

annual growth rate in 29 years, but the Non-energy use sector showed a fast growth rate after 2000.

Energy consumption trends of different sectors in India. The energy consumption of India's Industry sector has increased by 7684239 TJ in 29 years or about four times. The Transport sector's energy consumption rose yearly, with a momentum smaller than that of the Industry and Residential sectors. The energy consumption of the Residential sector increased year after year, accounting for a large proportion of the total energy consumption. The energy consumption of Commercial and public services, Agriculture/forestry sector, and non-specified has been rising, but the growth rate tends to be small. Non-energy use has increased every year for 29 years. Its growth rate between 2010 and 2019 was relatively large, and the energy consumption in 2019 was about 3.8 times higher than in 1990.

Energy consumption by source. Figure 2 presents the results of the analysis of total final consumption by source in China's and India's economies in 1990-2019. As shown in Figure 2, divided by resource types, the energy consumed by China's economy came mainly from Coal, Oil products, and Electricity. At the same time, India used power mainly from Coal, Oil products, and Biofuels and waste. Between 1990 and 2019, China's total energy consumption increased by 602,246,74 TJ and India's by 17,365,5551 TJ.

Trends of energy consumption from different sources in China. From 1990 to 2019, coal, oil products, and electricity were the most popular resources in China. However, wind, solar, and other renewables have become the resources with the fastest consumption growth, having increased from 1349 TJ to 1743660 TJ or about 1292 times. The natural gas consumption rose from 384953 TJ to 7518606 TJ, or 18.53 times. Heat consumption has grown from 553267 TJ to 4660966 TJ, with an average annual increase of about 141644 TJ. The consumption of Biofuels and waste, and Crude oil increased rapidly from 2000 to 2015 and decreased after 2015.

Trends of energy consumption from different sources in India. From 1990 to 2019, Coal, Oil products, and Biofuels and waste were the most consumed resources in India. Wind, solar, etc. have become the resources with the fastest consumption growth, which increased from 321 TJ to 46270 TJ, or about 143 times in 29 years. The Natural gas consumption increased from 255052TJ to 1437254 TJ, with an average annual increase of 40765 TJ. The Electricity consumption has increased nearly fivefold.

Economic indicators of energy use. Let us consider the economic indicators of both countries. Fig. 3 and Fig. 4 show that China's GDP was larger than India's in general and per unit of energy use from 1990 to 2019.

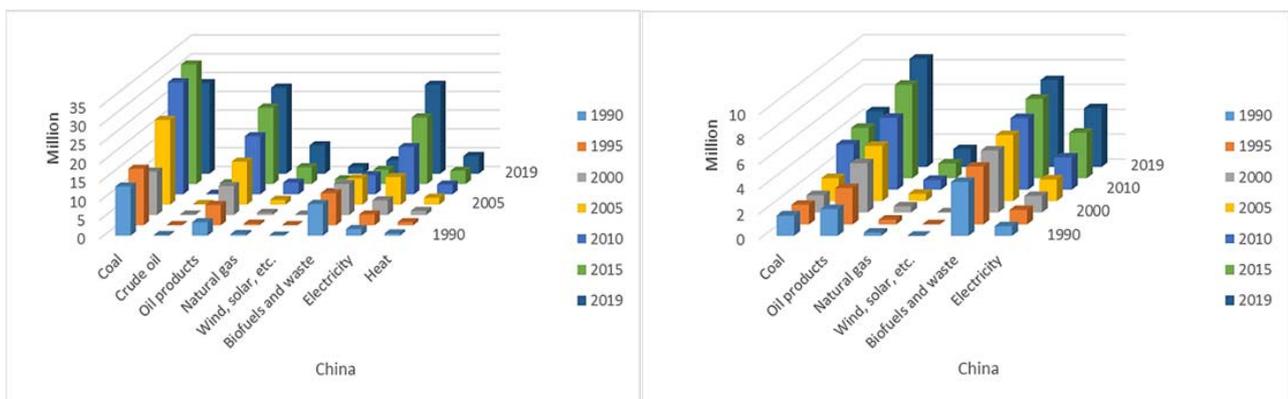


Figure 2 – Total final consumption by source of China's and India's economies in 1990-2019, TJ

Source: calculated by the authors based on (IEA, 2022)

Energy consumption per GDP unit is closely related to the total energy consumption and GDP. Based on calculations using Formula 1, it can be concluded that China's total energy consumption per GDP unit is smaller than India's indicator.

Fig. 4 demonstrates that India's energy consumption per GDP unit was always higher than China's. Combined with the growing trend of GDP from 1990 to 2014, it can be boldly inferred that from 2015 to 2019, India's energy consumption per GDP unit was also higher than those of China.

Conclusion. In this study, energy consumption per unit of GDP has been used as an indicator to measure the economic efficiency of energy use. China and India's total energy consumption and GDP from 1990 to 2019 have been analyzed. The main conclusions are as follows:

1. China's energy consumption per unit of GDP is less than India's one. It means that India's economy is more dependent on energy consumption as a developing

country with a large population. The country's rapid economic growth has led to rising demand for electricity, which relies on coal, but electricity generation is poorly equipped and technologically outdated. China is one of the world's largest carbon emitters. Still, it is transitioning by investing heavily in renewable energy generation and putting forward the national strategic goal to achieve carbon neutrality by 2060.

2. Energy consumption in China and India is mainly concentrated in the industrial, residential, and transport sectors. China's transport sector demonstrates the largest and fastest growth in energy consumption. The energy consumption trends in these three sectors are consistent with the status of developing countries for both states. Under the current conditions, these countries should boost the heavy industry to achieve rapid economic development, as well as boost commodity contract factories in other countries. Express delivery, take-out, and other services, which sym-

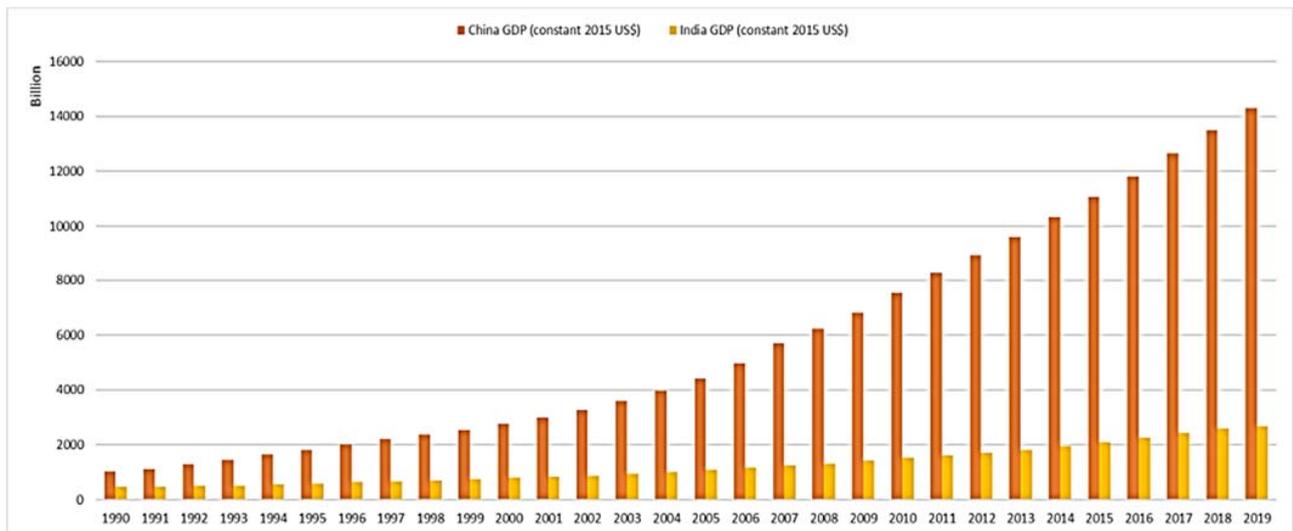


Figure 3 – GDP of China's and India's economies in 1990–2019, bln \$

Source: calculated by the authors based on (The World Bank, 2022)

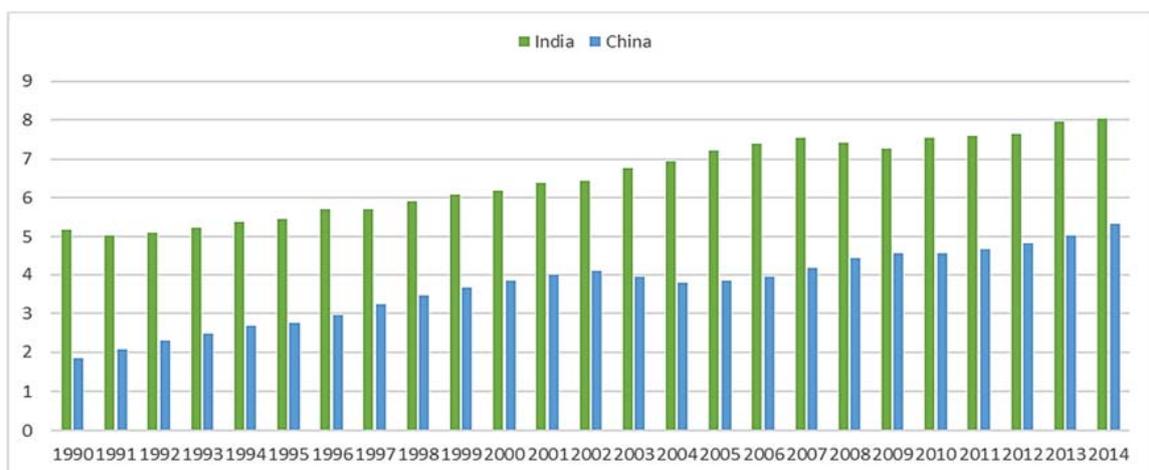


Figure 4 – GDP per unit of energy use (constant 2017 PPP \$ per kg of oil equivalent) in China's and India's economies in 1990–2014

Source: calculated by the authors based on (The World Bank, 2022)

bolize the fast pace of life, significantly impact the transport sector. Therefore, the increase in energy consumption in this sector is consistent with the law of development.

3. China mainly consumes energy from coal, oil products, and electricity, while India uses energy from coal, oil products, biofuels and waste.

Based on these conclusions, we can make the following suggestions for China and India to improve their energy efficiency:

1. Involve more non-fossil energy sources in the energy mix. Developing renewables and constructing new green power plants will allow less greenhouse gas emissions from national power systems and more effective energy use.

2. Adjust the energy mix by reducing the coal share. In China and India, where coal accounts for a relatively

large percentage of energy, reducing coal use in energy production is the first step to becoming carbon-neutral.

3. Increase recycling of solid wastes. Since many types of solid wastes can be recycled, it is urgent to ensure the growth of recycling share and energy generation from wastes. It will help generate green energy and cut the areas of landfills.

4. Encourage carbon trading and climate investment and financing. Trading can give companies an additional source of profit and encourage them to reduce carbon emissions. If carbon emissions are below the target, the company's revenue is generated. If carbon emissions exceed the target, there is the company's expenditure. Trading in this way will help decline carbon emissions in national economies.

Developing strategies and practical mechanisms for implementing the suggestions mentioned above are the further prospect for research.

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ЕКОНОМІЧНИЙ АНАЛІЗ ЕНЕРГЕТИЧНОЇ ЕФЕКТИВНОСТІ НАЦІОНАЛЬНИХ ЕКОНОМІК КИТАЮ ТА ІНДІЇ

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Розвиток суспільства сильно залежить від енергії. Однак екстенсивне використання енергії викликає глобальні проблеми, такі як виснаження ресурсів і потепління клімату. Китай та Індія є типовими швидкозростаючими країнами, що розвиваються, економічний прогрес в яких залежить від традиційного споживання енергії. Для реалізації бачення сталого розвитку цих держав необхідно вивчити економічну ефективність використання енергії цими націями. На основі аналізу тенденцій енергоспоживання та валового внутрішнього продукту в Китаї та Індії з 1990 по 2019 роки в цій статті обговорюються зміни індексу енергоспоживання на одиницю валового внутрішнього продукту. Автори дійшли висновку, що споживання енергії в Китаї та Індії здебільшого здійснюється промисловістю, житловим сектором і транспортом. Якщо аналізувати за типами ресурсів, Китай споживає переважно вугілля, нафтопродукти та електроенергію, тоді як Індія живиться здебільшого вугіллям, нафтопродуктами, біопаливом та відходами. Оскільки обидві країни переважно використовують вугілля та нафтопродукти, які належать до викопного палива, вони викидають велику кількість вуглекислого газу, що загрожує якості навколишнього середовища. Зважаючи на це, Китай та Індія повинні зосередитися на розвитку зеленої енергетики. Загальне споживання енергії в Китаї набагато більше, ніж в Індії, а валовий внутрішній продукт Китаю перевищує індійський. Однак енергоспоживання Китаю на одиницю валового внутрішнього продукту менше, ніж в Індії. Чим вище споживання енергії на одиницю валового внутрішнього продукту, тим більша залежність економічного розвитку країни від енергії. Тож пропозиції авторів полягають у стимулюванні розвитку невикопних джерел енергії та коригуванні енергетичного балансу досліджуваних країн, переробки твердих відходів та заохоченні торгівлі відходами, кліматичних інвестицій та фінансування в державах для досягнення цілей сталого розвитку.

Ключові слова: Китай, економічний аналіз, споживання енергії, енергоефективність, ВВП на одиницю використання енергії, Індія, сталий розвиток.

Стаття надійшла до редакції 20.01.2023

The article was received January 20, 2023

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