GFJMR
January-June 2024
Vol 28 (1) pp. 15-24

Mapping Renewable Trajectories: A Multidimensional Analysis of India and China's Energy Landscape

Geethalakshmi Kochi*
Assistant Professor, Ganpat University - V.M. Patel Institute of Management, Gujarat, India.
geeetk6@gmail.com

Gokul K
Research Scholar, Somaiya School of Humanities and Social Sciences, Somaiya Vidyavihar University.

Abstract

Amidst the threats of climate change, global conflicts and deterioration of fossil fuels Renewable energy is the future of the world. In this context India and China are two highest populous countries across the globe with higher electricity consumption. Thus this study is a comprehensive exploration of renewable energy dynamics in India and China spanning 2011 to 2022, this study employs a multifaceted approach. Utilizing statistical methodologies like the Kruskal-Wallis's test, we scrutinize disparities in renewable energy capacities. Simultaneously, our investigation incorporates sensitivity analysis to understand the intricate interlinkages within our key findings. Augmented by qualitative insights from policy analyses, this research integrates quantitative and qualitative dimensions, providing a nuanced understanding of the renewable energy landscapes in these pivotal nations. The paper postulates that substantial multivariate impacts of population and electricity use in both nations demonstrate how important consumption and demographic trends are in determining the overall dynamics of energy.

Keywords: Renewable Energy Capacity, Energy landscape, Electricity Consumption, Energy disparity, Multidimensional analysis

1. Introduction

The global energy landscape is experiencing significant twists and turns. The use of renewable energy has emerged as a vital solution to both the energy crisis and ecological concerns. Nations face two significant challenges on their path to an environmentally friendly future: securing energy supply and reducing the effect of climate change on the energy realm (Owusu & Sarkodie, 2016). Growing worries about energy reliance, climate change, and economic growth motivate rising economies to implement policies that encourage using renewable energy sources and foster energy-efficient energy to sustain economic expansion without negatively affecting the environment (Rafiq et al., 2014).

The swift expansion of the Chinese and Indian economies along with their population (i.e., these countries account for approximately 34.5% of the total world population) has driven up power demand, raising difficult concerns regarding the proper utilization of constrained non-renewable energy and the degree to which

*Corresponding author

renewable energy ought to be swapped (Rafiq et al., 2014).

The 2020, 2030 and 2050 predictions for China's electricity demand are 7.5, 10.3, and 13.6 trillion kWh, respectively. From 25.2% in 2020 to 30.4% in 2030 and 40.4% in 2050, electricity will account for the final energy demand (Global Sustainable Electricity Partnership). Since 2000, India's energy consumption has increased due to a growing population on track to become the world's largest and have strong economic growth. Nearly all households will have electricity by 2019, a fantastic feat. In emerging nations, tight legislation and renewable energy projects have improved air quality and lowered health risks, according to Ai and Tan (2021). Owusu and Sarkodie (2016) highlighted that switching to renewable energy supplies can reduce climate change, but it must be sustainable to provide energy to future generations. Energy policy uncertainty (EPU) had no negative impact on renewable energy expansion, according to Appiah-Otoo (2021). An econometric analysis by Dong et al. (2019) found that renewable energy may reduce world CO_2 emissions. Li et al. (2020) advised China to vigorously explore green energy policies and practices appropriate to its development stages and construct its renewable energy growth route based on global development experience. Paul et al. (2022) examined renewable energy potency and total factor productivity in Asia-Pacific nations and advised expanding industrial renewable energy use for sustainable growth. Rafiq et al. (2014) reflect that a positive trend can be noticed in the image of renewable energy deployment in India, where these technologies are helping the nation develop sustainably. However, in the case of China, due to the severe environmental harm brought on by human activity, more effort must be made by raising investments in renewable energy sources to decrease the negative impacts of carbon emissions and preserve economic growth. Finally, Wang and Kong (2021) discover that the energy stock exchange in China is negatively impacted by the uncertainties surrounding economic policy.

When we compare China and India, both located in the same geographical region, the specific interplay between renewable energy capacity, investments, energy demand, and other factors in these countries remains unknown. Understanding these relationships is critical for making informed policy decisions that address common trends and challenges.

2. Literature Review

In a time when the world is shifting towards renewable and sustainable energy sources to mitigate climate change, the trajectories taken by the world's most populous nations, India and China, have huge ramifications. A multifaceted approach that looks at the progress in renewable energy adoption, policy frameworks, technological advancements, and challenges they face is crucial for understanding the big picture. This literature review seeks to do just that by comprehending the challenges and opportunities faced by India and China in renewable energy adoption through a holistic lens.

At present, a lot of papers have been written on energy economics. This could be attributed to the rise in importance for renewable energy and a sustainable way of life. According to Ai and Tan (2021) strict legislation and the implementation of clean energy initiatives have improved air quality and reduced harmful health consequences in developing nations. Owusu and Sarkodie (2016) reiterated that reverting to renewable energy sources is a great way to slow down climate change, but it must be sustainable in order to supply energy to coming generations. Studying energy policy uncertainty (EPU), Appiah-Otoo (2021) came to a conclusion that EPU had little detrimental impact on the expansion of renewable energy. Dong et al. (2019) through an econometric study determined that global CO_2 emissions may drop as a result of renewable energy. They also observed that at the regional level, renewable energy has a notable and detrimental impact on CO_2 emissions only in two regions (South & Central America and Europe & Eurasia). Li et al. (2020) suggested that China should aggressively investigate green energy policies and methods tailored to its various phases of development and create its own renewable energy growth route based on worldwide development experience.

Paul et al. (2022) through their research study on renewable energy intensity and total factor productivity in countries of Asia-Pacific recommends increasing the industrial process's use of renewable energy, to ensure sustainable growth. Rafiq et al. (2014) reflects that an optimistic trend can be seen in the image of renewable energy deployment in India, where these technologies are helping the nation develop sustainably. But in the case of China, due to significant environmental damage brought on by human activity, more work must be done by boosting investments in renewable energy sources in order to lessen the negative consequences of carbon emissions to maintain economic growth. Finally, Wang and Kong (2021) discover that the energy stock market in China is negatively impacted by the uncertainties surrounding economic policies. Furthermore, the nation's general stock market has a favourable impact on the energy stock market.

Based on this literature review followed are the hypothesis of the study:

1. There are significant multivariate effects on population and electricity consumption across China and India, but the growth rates of Renewable Energy (RE) Capacity do not significantly differ between the two countries.
2. There is no difference between the renewable energy capacity growth rate between China and India.
3. GDP growth and electricity consumption are not correlated to each other.
4. Covariates (India's GDP, population, and electricity consumption) have no significant linear effect on India's Renewable Energy (RE)
5. Covariates (China's GDP, population, and electricity consumption) have no significant linear effect on India's Renewable Energy (RE)

3. Research Methodology: Data and Empirical Framework

This study explores the trajectory of renewable energy in China and India by considering key variables such as population, GDP, electricity consumption, investment in renewable energy, and capacity for renewable energy generation for the period of 2011-2022. The data for the study is compiled from statista.com, Indiastat.com, World bank report and MOSPI data base. Since there are multiple variables to be considered MANOVA is the test employed. MANOVA consists of a set of 4 tests within performed simultaneously- Pillai's trace, Wilks' Lambda, Hotelling's trace and Roy's largest root. They all range from 0 to 1 (0 shows no effect, 1 shows a perfect effect) and equations for these tests are as follows:

Pillai's Trace = $V = \sum_{i=1-}^{P} {}^{tr(Si)}/_{tr(Si+E)}$ --(1a)

Pillai's Trace is a measure of the effect size in MANOVA. It assesses the overall significance of the independent variable(s) on the dependent variable(s).

Wilks' Lambda (Λ): Λ\=∏i\=1p | E | | Si+E | ---(1b)

Wilks' Lambda tests the null hypothesis that group means are equal. A significant value rejects this hypothesis, suggesting that at least one group mean is different.

Hotelling's Trace$(T^2) = n \cdot (\bar{X}1-\bar{X}2)^T \cdot (S1+S2)^{-1} \cdot (\bar{X}1-\bar{X}2)$ ---(1c)

Hotelling's Trace is used in multivariate hypothesis testing. It is particularly relevant when comparing two groups on multiple dependent variables.

Roy's Largest Root= Largest Eigenvalue of (S1−1 ▪ SW) Largest Eigenvalue of (S1−1 ▪ SB)----------(1d)

Roy's Largest Root is a statistic used to test the null hypothesis that group means are equal. It considers the ratio of the largest eigenvalue of the within-group covariance matrix to the largest eigenvalue of the between-group covariance matrix.

Kruskal Wallis test = H = N(N+1)12∑ni Ri_2−3(N+1) ---(2)

Pearson Correlation = a [n∑(xy) - (∑x) (∑y)] / [√(n∑(x^2) - (∑x^2)) * √(n∑(y^2) - (∑y^2))] ----------------(3)

Pearson correlation is utilized to understand the relationship between GDP and Electricity Consumption, GDP and Renewable energy capacity, and Population and Electricity Consumption.

4. Data Analysis and Interpretation:

TABLE 1: MANOVA

Multivariate Tests		value	F	df1	df2	p
China Population	Pillai's Trace	0.9953	425.3206	2	4	< .001
	Wilks' Lambda	0.00468	425.3206	2	4	< .001
	Hotelling's Trace	212.6603	425.3206	2	4	< .001
	Roy's Largest Root	212.6603	425.3206	2	4	< .001
India population	Pillai's Trace	0.8240	9.3640	2	4	0.031
	Wilks' Lambda	0.17599	9.3640	2	4	0.031
	Hotelling's Trace	4.6820	9.3640	2	4	0.031
	Roy's Largest Root	4.6820	9.3640	2	4	0.031
China Electricity Consumption	Pillai's Trace	0.8545	11.7428	2	4	0.021
	Wilks' Lambda	0.14553	11.7428	2	4	0.021
	Hotelling's Trace	5.8714	11.7428	2	4	0.021
	Roy's Largest Root	5.8714	11.7428	2	4	0.021
India Electricity Consumption	Pillai's Trace	0.7695	6.6778	2	4	0.053
	Wilks' Lambda	0.23047	6.6778	2	4	0.053
	Hotelling's Trace	3.3389	6.6778	2	4	0.053
	Roy's Largest Root	3.3389	6.6778	2	4	0.053
China RE Capacity	Pillai's Trace	0.0189	0.0384	2	4	0.963
	Wilks' Lambda	0.98114	0.0384	2	4	0.963
	Hotelling's Trace	0.0192	0.0384	2	4	0.963
	Roy's Largest Root	0.0192	0.0384	2	4	0.963

Multivariate Tests		value	F	df1	df2	p
India RE Capacity	Pillai's Trace	0.2059	0.5184	2	4	0.631
	Wilks' Lambda	0.79414	0.5184	2	4	0.631
	Hotelling's Trace	0.2592	0.5184	2	4	0.631
	Roy's Largest Root	0.2592	0.5184	2	4	0.631

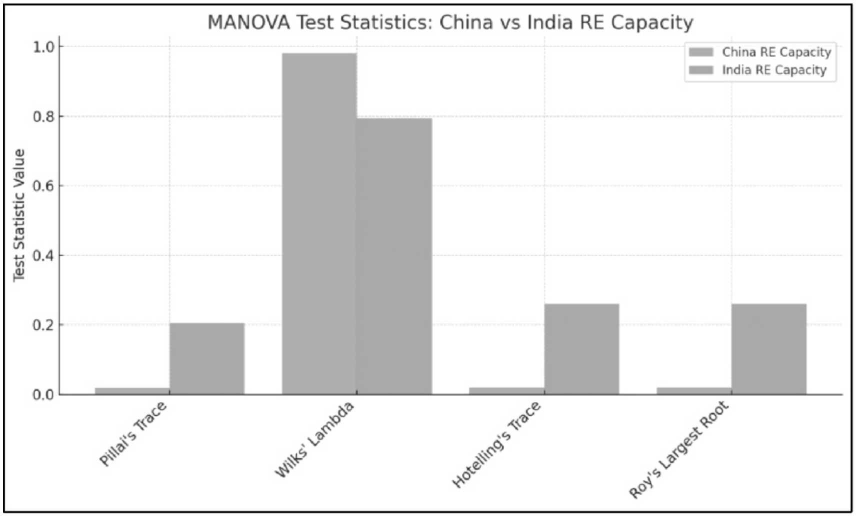

Fig 1: MANOVA Test Statistics

TABLE 2: Kruskal Wallis
One-Way ANOVA (Kruskal-Wallis)

	χ^2	df	P	ε^2
India RE Capacity	11.0	11	0.443	1.00
China RE Capacity	11.0	11	0.443	1.00

When comparing China and India separately, the findings of the multivariate analysis of variance (MANOVA) i.e. Table 1, demonstrate that the population and power consumption have significant multivariate effects on the system as a whole. In particular, there are highly significant multivariate effects for China's population (Pillai's Trace = 0.9953, $p < .001$) and electricity consumption (Pillai's Trace = 0.8545, $p = 0.021$), suggesting that these covariates are important in influencing the dependent variables being studied. In a similar vein, India's population has a large multivariate effect (Pillai's Trace = 0.8240, $p = 0.031$), but the country's electricity usage only minimally impacts the multivariate effect (Pillai's Trace = 0.7695, $p = 0.053$).

Nonetheless, there are no appreciable variations in the growth rates of renewable energy (RE) capacity in China ($p = 0.963$) or India ($p = 0.631$), confirming the premise that there are no appreciable disparities in RE capacity growth rates between the two nations. Additionally, the non-significant results for RE capacity show that, when taken into account separately, factors like GDP, population, and energy consumption do not significantly affect India's RE capacity in a linear fashion. This implies that although consumption and demographic considerations have a significant impact on overall energy dynamics, they do not directly propel the linear expansion of renewable energy capacity in these nations.

The Kruskal-Wallis tests for China's and India's RE capacity ($\chi^2 = 11.0$, df = 11, $p = 0.443$) support these findings by confirming that there were no appreciable variations in the growth of RE capacity between the groups under investigation. The idea that RE capacity growth rates are statistically comparable across samples within each nation is supported by the high p-value, which shows that we are unable to reject the null hypothesis. A value of 1.00 for the $\varepsilon 2$ effect size indicates that there are very little practical differences between the groups. All things considered, these results support the conclusion that, despite the stark differences in population and electricity consumption between China and India, the development of renewable energy capacity in both nations has a comparable trajectory that is not directly impacted by these covariates.

Renewable Energy Landscape: Infrastructure, Targets and Policies in China and India

Even though India and China have certain historical and developmental parallels, making a thorough comparison necessitates the examination of other elements (Desai, 2003). Both entities possess extensive historical backgrounds and have had periods of colonisation. A communist one-party government characterises China's political system, whereas India follows a federal democracy. The Chinese government takes a more proactive approach in guiding investment and exerting control over crucial industries. A relatively non-interventionist stance characterises India's strategy, yet it nevertheless entails implementing rules and providing subsidies. These disparities are also reflected in the energy sector, thus understand the influences on renewable energy adoption.

Below is the analysis of renewable energy transition in India and China considering parameters such as policies, infrastructure, targets, and energy transition momentum based on report by (World Economic Forum,2023) and (International Energy Agency, 2021).

Table 3: Renewable Energy Transition Analysis of China and India

	China	India
Energy Transition Index Ranking and factors contributing to ETI	Rank: 17/120 Score:64.9 China has reached the top 20 ranks in ETI this year, and has maintained an upward trajectory in renewable energy production since past 10 years. Yet it is one of the largest GHG emitter along with being top producer and consumer of energy.	Rank: 61/120 Score: 54.3 Achieving the universal access to electricity, replacing solid fuels with liquid petroleum gas and progress in renewable energy deployment are the factors contributing to India’s ETI.

	China	India
Key Highlights	As indication of its progress toward facilitating the energy transition, China plans to attain carbon neutrality by 2060 and peak its carbon emissions before 2030. Since 2014, China's public spending on R&D has increased by 35%, positioning it as a global leader in innovation. Reaching carbon neutrality requires maintaining energy security while moving away from fossil fuels. China has demonstrated its commitment to green development in the energy sector, as evidenced by its high ETI score for political commitment and regulation.	With doubling energy demand, energy import has increased which is a risk considering global energy market volatility. Nevertheless, India has pledged to achieving Net zero emissions by 2070 in COP-26.
Key Policies & Imperatives	China's Renewable Energy Law promotes the growth of renewable energy resources such as ocean, geothermal, wind and solar power. Research, industrial development and high-tech innovation in renewable energy are prioritised. The State Council sets goals and plans in partnership with regional governments and manages renewable energy development. Projects may be subject to open tendering and require administrative approvals. Producers benefit from grid access and fixed energy pricing. Pipelines are open to gas and heat producers who meet specific criteria. Local governments must establish plans for renewable energy in rural regions, including monetary support. Standardisation bodies establish technological standards. If government agencies or energy firms violate the law, higher authorities may punish them. China provides subsidies, tax breaks, customs duty exemptions, and pricing incentives, among other financial incentives, to encourage the growth of renewable energy sources.	India plans to substitute 250 million conventional meters with smart meters as part of the world's most extensive smart metering programme. The proposed Electricity (Amendment) Bill 2022 aims to enhance distribution businesses' competitiveness and financial performance. India is able to effectively use unevenly distributed renewable energy now that interregional transmission capacity has increased to 112 GW. Standards for renewable energy are set by the Energy Conservation (Amendment) Bill 2022 for large energy consumers, in line with the National Green Hydrogen Mission of India. The India program called Lifestyle for Environment (LiFE) encourages sustainable consumption efforts.

	China	India
Way Ahead	To improve resource productivity and energy efficiency, China's energy transition will need a significant resource shift as well as innovation and new technologies. A recent World Bank report appraises that China will require an additional $14 trillion to $17 trillion in outlays up to 2060 for green infrastructure and technology in the power and transport segments alone.	To facilitate India's energy transition, the country needs a trained labour force, public-private partnerships in innovation, and funding for low-carbon technology R&D. The creation of high-quality jobs for a growing working-age population and robust economic growth will be two major macrotrends that will test continued progress. One important avenue for future growth may be the development of globally competitive manufacturing skills in cutting-edge low-carbon niche technologies. Building globally competitive manufacturing skills in cutting-edge low-carbon niche markets may prove to be a potent growth engine in the future.

5. Conclusion

The research findings give insights into the intricate relationship between demographic factors, electricity consumption, and Renewable Energy (RE) capacity in China and India. Multivariate analyses underscored the significant influence of population and electricity consumption on shaping the energy landscape in both nations. The robust correlation between GDP and electricity consumption in both countries emphasizes the interconnectedness of economic development and energy demand. Linear regression models illuminated India's need-based capacity development, with GDP and population emerging as significant contributors. In contrast, China exhibited an innovation-oriented approach, where RE capacity development was less influenced by the considered variables. While there is no significant variance in both the growth trends of renewable energy in both countries, the Kruskal-Wallis's test supports this observation, suggesting a synchronized growth pattern in renewable energy infrastructure across the specified years. Though, there are notable differences due to volatility in global energy market, infrastructure facility and framework. While China has been adapting innovation, there is much more to leapfrog for India and labour market too is important in this context. Yet we conclude that with several similarities from demographics to geographics both the countries are attempting at increasing renewable capacity and they have a long way to go ahead.

6. Implications of the study

The results of this research have significant ramifications for China's and India's energy policies and sustainable development plans. The substantial multivariate impacts of population and electricity use in both nations demonstrate how important consumption and demographic trends are in determining the overall dynamics of energy. However, the lack of a substantial correlation between these factors and the increase of renewable energy (RE) capacity implies that patterns of power demand and population growth are not the primary drivers of current RE expansion methods.

This suggests that rather than being solely driven by internal socioeconomic factors, the development of renewable energy in China and India may be more impacted by technology developments, international commitments (like climate agreements), or policy initiatives. Therefore, regardless of broader economic or demographic trends, policymakers should understand that increasing the capacity of renewable energy requires specific incentives, subsidies, and supportive regulatory frameworks.

Furthermore, despite their disparate economic sizes and levels of energy consumption, China and India have comparable growth rates of RE capacity, showing that, with the right policies and investments, India has the potential to overtake China in the deployment of renewable energy. Without being limited by its current economic size, this presents India with a chance to quicken its energy transition and improve energy security.

These findings suggest that rather than depending only on macro-level factors like GDP or population, future strategies should incorporate localized evaluations of technological viability, infrastructure preparedness, and regional resource availability to increase the efficacy of renewable energy policies. This customized strategy may make it easier for both nations to achieve their sustainability and carbon neutrality objectives.

7. Limitation of the Research

There are a number of restrictions on this study. First, the analysis makes extensive use of secondary data, which could be impacted by disparities in reporting, data accessibility, and statistical definitions between China and India. Despite being important, the variables selected do not account for all factors affecting the capacity of renewable energy, such as cultural acceptance, environmental externalities, or regional differences in the implementation of policies. Although the regression models explain a significant amount of variance, particularly in the case of India, they might leave out latent factors that influence the expansion of renewable energy capacity, which could result in specification mistakes. Additionally, because the study period ends in 2022, it does not take into consideration current advancements such as revised national commitments under the Paris Agreement, new technical advancements, or pandemic recovery measures.

8. Scope for Future Research

Although the dynamics of renewable energy in China and India from 2011 to 2022 are compared in this paper, there is still much need for further investigation. Incorporating other factors, such as international cooperation agreements, environmental policy strictness, and technological advancement indices, could be one way to better understand their impact on the uptake of renewable energy. The changing policy effects, technology developments, and geopolitical changes can be better captured by longitudinal studies that include data after 2022, particularly in light of international climate pledges. A more thorough picture of each nation's preparedness for a full energy transition would also be possible by combining grid integration efficiency and renewable energy storage capability.

References

Ai, H., & Tan, X. (2021). A Literature Review of the Effects of Energy on Pollution and Health. Energy Research Letters, 2(4). https://doi.org/10.46557/001c.28135

Appiah-Otoo, I. (2021). Impact of Economic Policy Uncertainty on Renewable Energy Growth. Energy Research Letters, 2(1). https://doi.org/10.46557/001c.19444

Bhattacharya, S. C., & Jana, C. (2009). Renewable energy in India: historical developments and prospects. Energy, 34(8), 981-991.

Chang, J., Leung, D. Y., Wu, C. Z., & Yuan, Z. H. (2003). A review on the energy production, consumption, and prospect of renewable energy in China. Renewable and Sustainable Energy Reviews, 7(5), 453-468.

Desai, M. (2003). India and China: An Essay In Comparative Political Economy. In IMF. https://www.imf.org/external/np/apd/seminars/2003/newdelhi/desai.pdf

Dong, K., Dong, X., & Dong, C. (2019). Determinants of the global and regional CO2 emissions: What causes what and where? Applied Economics, 51(46), 5031–5044. https://doi.org/10.1080/00036846.2019.1606410

Li, L., Lin, J., Wu, N., Xie, S., Meng, C., Zheng, Y., Wang, X., & Zhao, Y. (2020). Review and Outlook on the International Renewable Energy Development. Energy and Built Environment, 3(2). https://doi.org/10.1016/j.enbenv.2020.12.002

Owusu, P. A., & Sarkodie, S. A. (2016). A Review of Renewable Energy sources, Sustainability Issues and Climate Change Mitigation. Cogent Engineering, 3(1). https://doi.org/10.1080/23311916.2016.1167990

Paul, A., Behera, J., & Sahoo, D. (2022). Do Renewable and Non-Renewable Energy Have Asymmetric Impacts on Total Factor Productivity Growth? Evidence From 17 Asia-Pacific Countries. Energy Research Letters, 3(4). https://doi.org/10.46557/001c.32613

Peidong, Z., Yanli, Y., Jin, S., Yonghong, Z., Lisheng, W., & Xinrong, L. (2018). Opportunities and challenges for renewable energy policy in China. Renewable Energy, Vol4_486-Vol4_503.

Rafiq, S., Bloch, H., & Salim, R. (2014). Determinants of renewable energy adoption in China and India: a comparative analysis. Applied Economics, 46(22), 2700–2710. https://doi.org/10.1080/00036846.2014.909577

Sen, S., Ganguly, S., Das, A., Sen, J., & Dey, S. (2016). Renewable energy scenario in India: Opportunities and challenges. Journal of African Earth Sciences, 122, 25-31.

Tripathi, L., Mishra, A. K., Dubey, A. K., Tripathi, C. B., & Baredar, P. (2016). Renewable energy: An overview on its contribution in current energy scenario of India. Renewable and Sustainable Energy Reviews, 60, 226-233.

Wang, Y., & Kong, D. (2021). Economic Policy Uncertainty and the Energy Stock Market: Evidence from China. Energy Research Letters, 3(1). https://doi.org/10.46557/001c.28171

World Economic Forum. (2023, June 28). Fostering Effective Energy Transition 2023. World Economic Forum. https://www.weforum.org/publications/fostering-effective-energy-transition-2023/

Yang, X. J., Hu, H., Tan, T., & Li, J. (2016). China's renewable energy goals by 2050. Environmental Development, 20, 83-90.

Zheng, H., Song, M., & Shen, Z. (2021). The evolution of renewable energy and its impact on carbon reduction in China. Energy, 237, 121639.

Zhang, D., Wang, J., Lin, Y., Si, Y., Huang, C., Yang, J., ... & Li, W. (2017). Present situation and future prospect of renewable energy in China. Renewable and Sustainable Energy Reviews, 76, 865-871.