# Transitioning China to Renewable Energy: Economic, Health, and Environmental Benefits

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**Abstract.** Air pollution and global warming are urgent global problems, largely driven by the use of fossil fuels. It is important to consider methods of transitioning away from fossil fuels to clean, renewable energy. This study investigates the costs, land use, and health and climate benefits of moving China’s energy system from fossil fuels to a completely wind-water-solar (WWS) system. The findings indicate that such a transition would reduce China's energy needs by 34%, require only 0.21% of the country's land area, and decrease private energy costs by approximately 34%. The total social cost of energy, encompassing private energy costs, climate costs, and health costs, would drop by 97%. The transition could prevent about 1.1 million premature deaths annually due to air pollution. To achieve this, China must install around 202,000 new 5-MW onshore wind turbines, 48,000 5-MW offshore wind turbines, 18 million 100-kW rooftop solar PV systems, and 16,000 100-MW utility-scale solar PV systems. The required land area for these installations would be minimal, with utility-scale solar and onshore wind turbines occupying 2,780 km² and 16,800 km², respectively. Transitioning to WWS would reduce private energy costs from $696 billion to $462 billion annually and yield health and climate cost savings of $9.7 trillion and $3.8 trillion annually, respectively. In conclusion, transitioning China to 100% clean, renewable energy not only offers substantial health and environmental benefits but also delivers significant economic savings while using minimal land.

**Keywords:** China; Energy; Transition; Benefits.

## 1. Introduction

China, with rapid economic growth and industrialization over the past decades, has become heavily reliant on Business-As-Usual (BAU) energy sources, primarily fossil fuels. This dependence on fossil fuels creates significant cost to the environment. Fossil fuels include coal, oil, and natural gas, whose combustion releases large amounts of carbon dioxide (CO2), other greenhouse gases, and air pollutants into the atmosphere. The greenhouse gases trap heat and cause the Earth's average temperature to rise, contributing directly to global warming and other types of climate change. Fossil fuel extraction is also a highly disruptive process. Mining coal, drilling for oil, and extracting natural gas often lead to the destruction of wildlife habitat and biodiversity loss. In addition, the chemicals used during extraction can leak into drinking-water sources, causing contamination that harms aquatic life and human populations. Air pollution from burning those unrenewable energy resources also contributes to respiratory illnesses and smog in urban areas. Furthermore, as finite resources, fossil-fuels are often concentrated in specific regions, and their extraction creates imbalances in the global energy supply. This dependence on a limited resource can lead to energy insecurity and volatility in energy prices. Moreover, fossil fuel reserves are often located in geopolitically unstable regions, which can lead to conflicts and heighten global tensions over access to energy.

As global concerns about climate change intensify, there is an urgent need for China to transfer to cleaner and more sustainable energy, such as wind-water-solar (WWS) energy. Additionally, in response to these negative impacts, humanity has already made some significant strides. For example, the growth of renewable energy sources, alongside collective actions, such as the Kyoto Protocol and the Paris Agreement, aim to reduce global carbon emissions and thus global warming. Energy efficiency improvements and carbon pricing mechanisms encourage lower emissions. Technological advancements, such as electric vehicles, electric heat pumps, and energy efficiency improvements, are further reducing our reliance on fossil fuels. These efforts have proved necessary for China’s

WWS system. Around 2013, China began making great efforts in energy conservation, reducing emissions from some sources, and developing new energy sources. The scale of new energy sources in China ranked it among the world's largest [1]. In the past, China was the country with the largest coal resources in the world, and coal-based thermal power used to be the most important energy source in China. However, due to pollution and concern about resource depletion, China has started to vigorously promote the development of wind power and photovoltaic resources in the past decade [2].

The motivation for this research stems from the recognition of the urgent need to improve China’s current energy infrastructure, changing it to a WWS infrastructure. WWS includes electricity generation, storage, appliances, machines, and grids. WWS electricity generators include on-shore and off-shore wind, rooftop and utility solar PV, geothermal, hydroelectric, tidal, and wave generators. WWS storage includes batteries, hydroelectric, pumped hydroelectric, and other storage technologies. WWS appliances and machines include electric heat pumps, eclectic induction cooktops, LED lights, electric vehicles, and more.

## 2. Literature Review

Previous studies have examined energy transitions in China and point to the necessity of a transition. For example, Li et al. explored ways to develop Sichuan's hydro energy resources, starting with the design and planning of hydropower plants [3]. Against the background of China's “Belt and Road” initiative, Xue Min analyzes the energy cooperation between China and the countries of the Central and Southern Peninsula based on international cooperation in hydroelectricity, solar energy and wind energy of the countries of the Central and Southern Peninsula [4]. Zhai et al. summarize the commonly used indicators and methods for assessing hydro, wind, and solar energy resources by combing the relevant literature and summarizing the impact of climate change on China's hydro, wind, and solar energy resources in the historical period, as well as the changes in China's hydro, wind, and solar energy resources in the context of future climate change [5]. Nee et al. developed a monitoring device for a hybrid power generation system, namely WWS, based on the climatic conditions in Malaysia, using LabVIEW system design software, to explore how to maximize the savings and provide sufficient power [6]. He explored, from a practical point of view, how PV technology can be utilized in three regions, Beijing, Inner Mongolia and Northeast China, to provide residents with the most convenient and healthy energy sources [7].

Meanwhile, some research has focused on the effect of traditional energy. Xue explores the positive impacts of China's environmental target constraints on the low-carbon transition of energy structure, analyzes its potential challenges, and puts forward suggestions to cope with them, aiming to provide a better boost to the low-carbon transition of energy structure and improve the level of ecosystem construction [8]. Xia et al. start from China’s overseas energy investment, arguing that China's energy global layout has an implied carbon transfer effect, traditional energy global layout has an oil and gas import effect, and renewable energy global layout has an energy transition effect [9]. From a strategic point of view, Xiao points out that China's energy security strategy has gradually evolved from focusing on traditional “supply”-oriented energy security to emphasizing a composite energy security covering “supply plus use” and further expanding to a comprehensive energy security of “supply plus use plus competition” [10].

However, this study applied the up-to-date data to examine the advantages and the energy transition trend of the aforementioned novel energy system. Hence, in this research, I will start by comparing the traditional non-renewable energy sources with novel green energy sources, highlighting the advantages of the WWS energy system from three main dimensions and the necessity of energy transition.

## 3. Methodology

In this study, I analyzed International Energy Agency (IEA) 2021 BAU energy consumption data for China, converted the BAU consumption data into WWS consumption data, then compared the two. The methodology is similar to that of Jacobson et al. [11, 12], who analyzed energy transitions in 145 and 149 countries, respectively, including China, in 2050. IEA data include BAU energy consumption data in six sectors: industry, transport, residential, commercial, agriculture and forestry. Data in each sector are segregated by fuel type: coal, oil products, natural gas, solar/geothermal or heat, biofuels and waste for heat, electricity, and waste heat for sale. After obtaining these data, I marked the energy consumption figures for each sector were taken directly from the IEA 2021 data for the BAU model, and using conversion factors (based on WWS efficiency), these values were adjusted to reflect the energy consumption under the WWS system. The percentage difference between WWS and BAU was calculated using the formula: Percentage Difference=(WWS Energy－BAU Energy)/BAU Energy×100%, so the result is as in Table 1.

The second step was to calculate the cost of energy for each technology type under the WWS system and compare it with the BAU system. First, I obtained existing WWS generator data in China for 2022. Then, I also obtained capacity factor data for each generator type. On top of that, I estimated the energy produced by existing generators in China and subtracted that from the overall energy needed to transition China to 100% WWS. This means that the cost of energy generation for different WWS technologies (onshore wind, offshore wind, utility-scale solar PV, community rooftop PV, and hydroelectric) was gathered, which includes costs in cents per kWh. In addition, the annual costs for each technology type were based on the installation requirements for each generator, which were derived from the necessary capacity. The total annual cost for each technology was calculated by multiplying the number of generators by their respective cost per kWh and the total energy produced annually. The formula I used is: Annual Cost=Number of Generators×Cost per kWh×Annual Energy Produced. So we get Table 2.

In the third step, I estimated the total social costs of energy, including private, health, and climate costs, under both the WWS and BAU models. These costs were based on existing literature or previous studies, providing estimates for health-related costs (due to air pollution) and climate-related costs (due to CO2 emissions). I conclude the total social cost of energy is the sum of private energy costs, health costs, and climate costs, which is shown in Table 3. While the private energy cost data came from Table 2; the health cost is about premature deaths and the associated medical expenses or productivity losses due to air pollution; the climate cost is based on the reduction in greenhouse gas emissions and their corresponding economic impacts. With this information, I could then estimate the costs of the generators, the health cost savings of a transition, the climate cost savings of a transition, and the land required for the new generators.

## 4. Results

Transitioning China’s energy infrastructure to a wind-water-solar (WWS) system could reduce energy consumption, energy cost, and environmental and health externality cost. Specifically, the transition reduces the nation’s energy needs by approximately 33.64%, from 2,804 GW to 1,861 GW, largely due to increased efficiency in energy conversion and distribution. As shown in Table 1, each sector - industry, transport, residential, commercial, and agriculture - would experience significant energy demand reductions under the WWS system compared with the BAU model. Even in the industrial sector, where energy demand is the highest, energy demand under the WWS model is reduced by 17.13%, while in the transportation sector, it plays a huge role, with savings of 74.62% of energy demand. Additionally, this transition would require only 0.21% of China’s total land area, distributed primarily across onshore wind installations, approximately 16,775 km2, and utility PV installations, approximately 2,780 km2. The minimal land use needed for WWS infrastructure suggests that China could achieve environmental and health benefits without substantial disruption of land resources.

**Table 1.** Energy demand in gigawatts GW across various sectors in both the wind-water-solar (WWS) and business-as-usual (BAU) models.

| Sector | Total WWS (GW) | Total BAU (GW) | % Difference (WWS - BAU) |
|---|---|---|---|
| Industry | 1,243 | 1,500 | -17.13% |
| Transport | 117.5 | 462.9 | -74.62% |
| Residential | 260.2 | 507.2 | -48.71% |
| Commercial | 86.98 | 131.3 | -33.73% |
| Agriculture/Forestry | 28 | 59.56 | -53.00% |
| Other | 125.0 | 142.8 | -12.48% |
| Total | 1,861 | 2,804 | -33.64% |

To achieve a full WWS transition, the required infrastructure includes 201,734 new 5-MW onshore wind turbines, 48,330 new 5-MW offshore wind turbines, 18.26 million new 100-kW rooftop PV systems, and 16,133 new 100-MW utility PV systems. We now turn our attention to the issue of energy costs for the technologies in the WWS model. First, in Table 2 we can see the cost of energy per kWh when using the WWS system, differentiated in dollars and cents, applicable to the billing habits of different populations. Moreover, the annual costs are expected to be incurred by different technology types deployed under the WWS system. Each infrastructure within the WWS system has distinct annual costs: 5-MW onshore wind turbines are projected to require $90.76 billion per year, 5-MV offshore wind turbines $141.19 billion per year, utility-scale solar PV systems $75.64 billion per year, community rooftop PV systems $154.42 billion per year, and hydroelectric $0 per year post-transition. It means that the most expensive technology in terms of annual cost is the community rooftop PV system, at $154.42 billion per year, while hydroelectric has no additional cost post-transition. In the last row of the table, which shows total private energy costs, the annual cost of the WWS system is $462 billion, significantly lower than the BAU model's annual energy cost of $696 billion.

**Table 2.** Cost of energy for each technology within the wind-water-solar (WWS) systems compared to the business-as-usual (BAU) model.

| | Wind Onshore | Wind Offshore | Utility-Scale Solar PV | Community Rooftop PV | Hydroelectric | Total WWS | Total BAU |
|---|---|---|---|---|---|---|---|
| Cost of Energy (¢/kWh) | 2.4 | 5.6 | 2.4 | 4.9 | 5.9 | | |
| Cost of Energy ($/kWh) | 0.024 | 0.056 | 0.024 | 0.049 | 0.059 | | |
| Cost of Energy for New WWS Technology ($ billion/year) | 90.76 | 141.2 | 75.64 | 154.4 | 0 | 462 | |
| Private Energy Cost ($ billion/year) | | | | | | 462 | 696 |

Economically, as we have just gotten from Table 2, the transition to the WWS system can reduce China’s private energy costs from $696 billion annually to $462 billion, representing a 33.64% decrease in energy expenditure. More significantly, the total social cost, which includes private, health, and climate costs, is reduced by 96.74%, from $14,187 billion under BAU to just $462 billion under WWS. This dramatic reduction highlights the profound environmental and public health benefits of the transition. While the health costs are greatly reduced due to the decrease in air pollution: the health-related savings amount to $9.741 trillion annually, resulting from fewer deaths and illnesses caused by fossil fuel emissions. In addition, the system also reduces climate-related costs by $3.75 trillion annually, as renewable energy leads to a significant decrease in carbon emissions and mitigates the effects of climate change. Thus, we can sort out the comparison of these data from Table 3, which presents a comparison of private, health, and climate costs under both BAU and WWS systems. In terms of public health, this transition could potentially prevent around 1.1 million air pollution-related deaths each year by reducing harmful emissions from fossil fuel combustion.

**Table 3.** Comparison of social costs under wind-water-solar (WWS) and business-as-usual (BAU) energy models

| | Total WWS ($ billion/year) | Total BAU ($ billion/year) | Per cent Difference |
|---|---|---|---|
| Private Cost of Energy | 462 | 696 | -33.64% |
| Health Cost of Energy | | 9,741 | |
| Climate Cost of Energy | | 3,750 | |
| Total Social Cost of Energy | 462 | 14,187 | -96.74% |

## 5. Discussion

The findings from this study indicate significant potential benefits for China in transitioning to a WWS energy system, both for economic savings and environmental conservation. For policymakers, this transition aligns with China’s carbon neutrality by 2060 and would contribute to global climate objectives such as the Paris Agreement.

Economically, while the initial setup costs for fossil fuel plants are often lower than those for renewable systems, the long-term costs are significantly higher. Over time, this leads to an escalation in costs as extraction becomes more difficult and expensive, further driving up operational costs. Furthermore, the social costs of fossil fuels, including the environmental damage caused by extraction, transportation, and combustion, are substantial. For instance, oil spills, mining waste, and habitat destruction all contribute to external costs that are not typically included in the direct pricing of fossil fuel energy. In contrast, renewable energy systems, especially those based on wind, solar, and hydro sources have lower and more predictable long-term operational costs. Additionally, they benefit from the fact that they are not dependent on fuel sources that are subject to market fluctuations.

In the case of scale and land use requirements, fossil fuel energy production often requires large amounts of land for mining operations, refineries, pipelines, and power plants. On the other hand, their infrastructure such as power plants and transportation networks occupy large amounts of land, and their installation often results in negative environmental consequences. However, WWS systems generally have much lower land use per unit of energy produced are often less ecologically sensitive and can be integrated into existing landscapes.

One of the most significant environmental drawbacks of fossil fuel-based energy production is its high level of pollution. They are the major sources of air pollution, releasing PM2.5, SO2, and CO2 into the atmosphere. These pollutants not only contribute to global warming but also cause serious environmental damage, such as acid rain, smog formation, and habitat destruction. These injuries to nature are mirrored in humans, leading causes of respiratory diseases, cardiovascular problems, and premature deaths worldwide. On the other hand, renewable energy sources like wind, solar, and hydroelectric power generate little to no pollution during energy production.

Fossil fuel combustion has direct and significant negative impacts on human health due to the byproducts. Air pollution from coal-fired power plants and vehicle emissions is a major cause of respiratory diseases such as asthma, bronchitis, and lung cancer. In addition to respiratory illnesses, which increases the risk of cardiovascular diseases, strokes, and premature death, too. Transitioning to WWS energy would result in significant improvements in public health. As renewable energy sources produce little to no harmful emissions, they would reduce the incidence of pollution-related diseases, preventing millions of premature deaths and significantly improving overall life expectancy. Furthermore, the shift would reduce various health issues in local communities.

However, some limitations in this study should be considered. The analysis relied on 2021 IEA data, which may not fully reflect recent changes in China’s energy consumption trends or advances in renewable technologies in 2024. Additionally, regarding methodology, the assumptions made regarding fixed capacity factors and energy reduction estimates could impact the accuracy of certain projections, as these factors can differ based on region, season, and ongoing technological innovations, suggesting that actual savings or land requirements may vary in practice. For data analysis, the lack of consideration for long-term climate change trends or localized energy demand fluctuations may have affected the accuracy of energy savings and land use projections. Future research could refine these estimates by incorporating more recent data and technological advancements, providing a better understanding of the economic and environmental impacts.

Based on the research findings, the recommended actions for policymakers, industry stakeholders, and researchers would also be imperative. Policymakers could support the WWS transition through incentives for renewable energy investments, updated environmental regulations, and strategic planning that prioritizes sustainable energy infrastructure. For industry stakeholders, the transition presents opportunities for the adoption of WWS technologies and the development of training programs to support regional feasibility studies for WWS deployment, and more comprehensive modelling of air quality improvements, all of which could further strengthen the case for China’s transition to 100% renewable energy.

## 6. Conclusion

Transitioning China’s energy infrastructure from a fossil fuel-based one to a clean, renewable energy one will do the following: reduce energy needs by 34%, require about 0.21% of China’s land area, reduce private energy costs by about 34%, reduce the social cost of energy (private energy cost + climate cost + health cost) by 97%, and reduce air pollution deaths by about 1.1 million each year. This will require about 202,000 new 5-MW wind turbines, 48,000 new 5-MW off-shore wind turbines, 18 million new 100-kW rooftop PV systems, and 16,000 new 100-MW utility PV systems. The land needed for new utility PV (2,780 km2) and new on-shore wind (16,800 km2). The private energy cost reduction is from $696 billion to $462 billion per year. WWS reduces health costs by $9.7 trillion per year and climate costs by $3.8 trillion per year. It highlights a significant reduction in energy demand, lower costs for energy consumers, and a dramatic decrease in social costs, including health and climate impacts. The transition would also prevent a large number of air pollution-related deaths annually, while requiring minimal land use, showcasing that clean energy can drive sustainable growth with positive long-term outcomes for both society and the environment. All in all, this study demonstrates that transitioning China to a clean, renewable energy system offers substantial benefits in terms of economic savings, environmental protection, and public health.

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