frontiers | Frontiers in Energy Research

TYPE Policy Brief
PUBLISHED 23 March 2023
DOI 10.3389/fenrg.2023.1126411

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Sustainable Energy Systems, a section of the journal Frontiers in Energy Research

RECEIVED 01 February 2023
ACCEPTED 13 March 2023
PUBLISHED 23 March 2023

CITATION
Song X and Chen Z (2023), Pathways for an island energy transition under climate change: The case of Chongming Island, China.
Front. Energy Res. 11:1126411.
doi: 10.3389/fenrg.2023.1126411

Pathways for an island energy transition under climate change: The case of Chongming Island, China

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The normal operation of the energy system is related to the security and stability of the region and even the country. Compared with inland areas, islands can become a precedent for building a low-carbon and zero-carbon society due to geographic advantage. However, they also have to deal with more vulnerable energy systems. Taking Chongming Island as a case, this paper discusses the necessity of energy transformation from external, internal, and geographic causes, investigates the possible path of resilient energy transformation for islands, and puts forward a series of policy recommendations together with possible ways toward resilient energy transition.

KEYWORDS

energy transition, island, renewable energy, climate change, energy resilience

1 Introduction

More than 6 years after the adoption of the Paris Agreement, the collective effect of global governments' emissions reduction targets in the short to medium term would still lead to 2.4°C of warming by 2,100, indicating a considerable gap between global climate commitments, goals, and actions (IPCC, 2022). Most studies support that one of the critical measures to accelerate the narrowing of the gap between climate goals is accelerating the energy transformation, especially the rapid decarbonization of the power industry (Wei et al., 2021). However, frequent extreme weather events and the increasing intensity of disasters, including extreme temperatures, heavy rainfall, drought, and complex disaster events, have caused a significant impact on the global energy system (Miara et al., 2017). The pandemic, the steep economic rebound, and the war in Ukraine have successively disrupted energy markets, which is a clear reminder that it is urgent to promote global energy transformation and improve energy resilience (Climate Action Tracker, 2022; Wang et al., 2023).

The regular operation of the energy system is related to the security and stability of the region and even the country. However, the energy system is a complex, large-scale system, inevitably facing the risk of energy supply interruption, price rise, equipment failure, and natural disasters. Compared with inland areas, islands, with their unique geographical location, have become the precedent for building a low-carbon and zero-carbon society in the world. Nevertheless, islands often have disadvantages in constructing transportation and transportation pipelines, and their ability to achieve external energy is limited (Matsumoto and Matsumura, 2022). Their unique geographical location also aggravates the threat of natural disasters, such as typhoons, earthquakes, floods, etc., to local energy security. Based

on this, some scholars discussed strategies to improve the penetration rate of renewable energy and energy independence of islands (Iglesias and Carballo, 2011; Kuang et al., 2016), and some scholars studied the driving factors of island energy vulnerability for specific natural disaster vulnerability, which provided new ideas and methods for global island protection and sustainable development (He et al., 2019; Ahmadi et al., 2021; Dong et al., 2021). Although there are heated topics of energy transition and sustainable island development, the energy transition experiences of specific islands, especially islands in China are not widely discussed. Meanwhile, little work has been devoted to the approach to coordinating the needs of environment and economic development, and creating a compatible high-level ecological island and industrial base.

Located at the estuary of the Yangtze River, Chongming Island is the largest estuarine alluvial island in China. In 2016, it began to promote the construction of a world-class ecological island, and started the construction of a carbon neutrality demonstration area of a world-class ecological island since 2022. Taking Chongming as an case, this paper aims to discuss the possible path of energy transition for islands. Our contributions can be summarized as follows: on the one hand, it analyzes the necessity of accelerating energy transition and coping with climate change from internal and external aspects; on the other hand, based on Chongming's development characteristics and experience, it puts forward the idea of coordinating island ecological environment construction and energy and economic development, so as to provide reference for island energy development and propose policy insights to relevant policymakers and stakeholders.

The remainder of this study is organized as below. The necessity of accelerating energy transition is discussed from internal and external causes; Energy transition analysis of Chongming's world-class ecological island is presented according to its exploration experience; Policy recommendations suggest how to make the energy systems of islands represented by Chongming more resilient to climate risks.

2 The necessity of accelerating the energy transition

2.1 Internal causes

In the energy field, "resilience" refers to the positive side of the energy system when dealing with disturbances and shocks (Gatto and Drago, 2020; Reyers et al., 2022). As pointed out by UNISDR, resilience reflects the valuable quality shared by human society and nature (Molyneaux et al., 2016). A large number of countries have formed a basic energy supply system. How to build a safe, green, and efficient energy system based on distributed energy, smart energy, etc., has become a significant task for the global energy transition. How to accurately assess its resilience is of great significance to the planning and operation of the local integrated energy system.

Due to the potential inefficiency, redundancy, or green tax, especially in the initial stage of establishing resilience, countries, enterprises, and consumers may have to pay a high price. However, record energy prices have shown that the heavy dependence of traditional energy systems on imported fossil fuels exposes its lack of resilience. In order to maintain the energy supply required for regional economic development and "the uninterrupted availability of energy sources at an affordable price" (IEA, 2019), actions must be taken to promote the diversification of energy mix and imports. The world has transitioned to a more sustainable energy system in the past few years. Wind and solar energy account for 10% of global power generation for the first time. The future energy mix led by low-carbon energy systems will bring greater energy security, affordability, and sustainability (ETC., 2022). At the same time, however, the unstable power generation capacity of clean energy affected by seasons, temperatures, and other factors still deserves attention. Global public and private sectors must take urgent action to improve the resilience of energy systems through multi-energy complementation and new energy storage, and meanwhile, improve the climate resilience of energy infrastructure.

2.2 External causes

Accelerating the transition of energy system is the key way for countries or regions to cope with escalating geopolitical and climate change risks, and to maintain local energy security and sustainable economic and social development. On the one hand, humankind has been facing the most severe energy crisis in the past 50 years (World Economic Forum, 2022a). The energy security problem caused by the Ukrainian war is forcing people to reflect on energy and foreign policy fundamentally (Climate Action Tracker, 2022). Even resource-rich countries have to import energy to some extent, and no country can achieve full energy independence any time soon (World Economic Forum, 2022b). On the other hand, the negative impact of extreme climate events on energy production and transport is rising. Extreme weather such as rainstorm, snowstorm, sandstorm, typhoon and tsunami often cause direct damage to energy infrastructure (Raman et al., 2022). For example, wind power plants and offshore oil and gas platforms in coastal areas are particularly vulnerable to severe weather. Energy transmission systems including power grid and oil and gas pipelines are also affected by earthquakes and blizzards. Therefore, governments must comprehensively optimize the management of energy systems, including leverage off international multilateral platforms to promote energy cooperation and resilience governance. Expanding local energy reserves and strengthening the climate adaptability of energy infrastructure are also worthwhile.

In addition to above causes, islands also face external problems caused by their geographical characteristics. An increasing number of islands around the world have been developed and utilized in recent decades (Harrison and Popke, 2018). Although the fuel on the islands is scarce and expensive, each island, as a matter of fact, owns more than one kind of renewable energy for power utilization (Kuang et al., 2016), which makes countries choose it as an ideal laboratory for the transition to clean energy. For example, El Hierro island, a Spanish island perfectly combining wind and hydro power generation through a power distribution control system, has become the first island in the world to fully harness renewable energy (Tsagkari et al., 2021). However, due to the unique geographical location, islands are more often to encounter extreme natural disasters, and local energy systems are also more vulnerable to damage (To et al., 2021). Most islands around the world, as

FIGURE 1
Chongming and its main photovoltaic projects. Note: Among the five photovoltaic projects, the three completed projects are in Chenjia Town (110 MW), Lvhua Town (44 MW) and Hengsha Township (3.5 MW), respectively, and the two projects under construction are in Gangxi Town (128 MW) and Zhongxing Town (100 MW).

significant local ecological resource clusters, must pay more attention to ecological conservation issues than inland areas. In addition, besides mineral development, islands may face growing energy demand brought by industrial transfer and expanding scale of tourism. Building resilient and comprehensive energy systems in island areas is therefore crucial for reducing energy cost, coordinating economic development and environmental protection, and improving the quality of life for local residents.

3 Energy transition analysis of Chongming's world-class ecological island

3.1 Current situation of energy development in Chongming

So far the installed capacity of renewable energy in Chongming has exceeded 570 MW, and the proportion of renewable energy power generation in the total social electricity sales has exceeded 30% (Shanghai Chongming District People's Government, 2022a). In Chongming, nearly one-third of the electricity consumption is "green power" without carbon emission, ranking first in Shanghai. Among them, the most important renewable power in Chongming are photovoltaic and wind power (Figure 1).

In terms of solar photovoltaic, Chongming has an average annual sunshine time of more than 2,600 h, making it an ideal place to develop photovoltaic projects. By combining fishery farming with photovoltaic power generation, Chongming greatly improved the utilization efficiency and the economic value of land. On 29 November 2020, an integrated smart energy power station was successfully connected to the grid for power generation. This "fish-light complementary" project adopts AI, "Internet + " and big data technologies to achieve intelligent operation and maintenance management of the power station. It has an average annual power generation of 120 million kWh, which can save 36,500 tons of standard coal compared with thermal power stations with the same generation capacity. In terms of wind power, located in the East Asian monsoon prevailing area, Chongming has open area with few obstructions. It provides the island with rich wind energy resources especially in the offshore area. Up to now, there are now five wind farms with a total installed capacity of about 223 MW in Chongming, and some of them are equipped with lithium iron phosphate batteries and own an energy storage system of about 2 MW.

From 2016 to 2021, despite the significant development of renewable energy, Chongming's power generation increased by only 6%, while its electricity consumption increased by about 28% (Bureau of Statistics of Chongming District, 2017). Among them, the electricity consumption of the tertiary industry has increased by about 73% under the influence of the "ecological + tourism" development strategy (Figure 2). As Chongming continues to be hot in summer these years, the security of urban and rural electricity and gas is facing greater challenges. At the same time, the Chongming energy system also faces a systematic challenge. It has to adapt to climate change and achieve the goal of carbon peak and carbon neutrality. As an essential bearing space for the construction of "Ecological City" in Shanghai, Chongming has a relatively small industrial scale, and its carbon emission scale is the smallest among all districts in Shanghai. However, its carbon emission intensity is relatively high, especially in critical fields such as shipping and energy users (Cai et al., 2020). How to make full use of the local resource endowment to accelerate the transition of the energy system and adequately handle the triangular relationship among

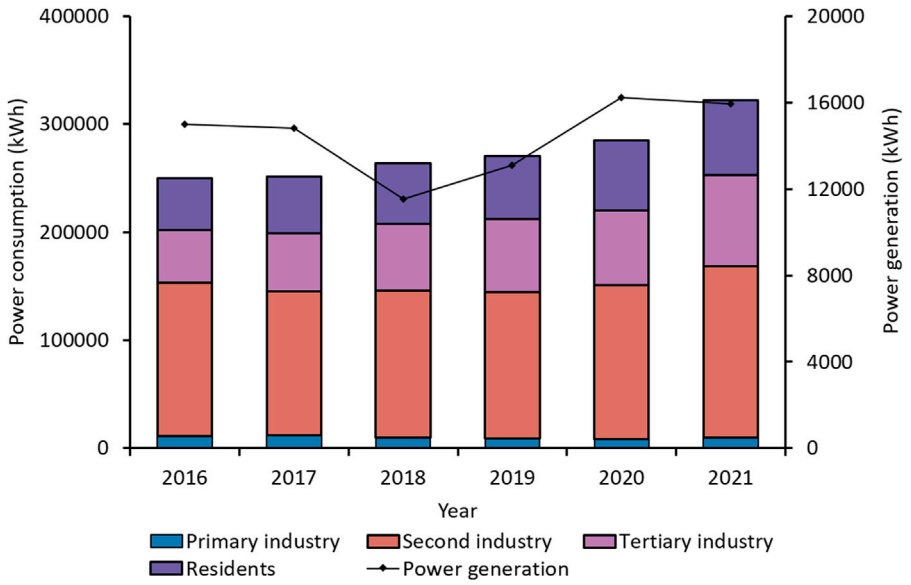

FIGURE 2
Power generation and consumption in Chongming from 2016 to 2021. Note: The power consumption is divided according to the primary industry, secondary industry, tertiary industry and urban and rural residents'living. Source: Chongming statistical yearbooks 2017–2022.

TABLE 1 Key policies and guidelines on the transition of Chongming to the world-class ecological island.

Issued time	Name	Key and new formulation related to energy
2010-01	Outline of Chongming's Eco-island Construction (2010–2020)	Optimize energy structure and build green energy system, promote energy efficient use and energy saving, green buildings and building energy saving
2016-01	The 13th Five-Year Plan for the development of Chongming world-class ecological island	Develop natural gas, wind power, photovoltaic and other clean energy sources, and build a green and low-carbon energy development and utilization system
2021-01	The 14th Five-Year Plan for the development of Chongming world-class ecological island	Advance the energy revolution, reform the way energy is produced and used, and build a clean, low-carbon, safe and efficient modern energy system
2022-01	Outline of Chongming world-class Ecological Island Development Plan (2021–2035)	Accelerate the development of renewable energy, build an efficient and low-carbon energy system, and promote refined management of carbon emissions
2022-11	Implementation of Chongming world-class ecological island and carbon neutral demonstration zone	Accelerate the construction of new electric power systems, promote the construction of zero-coal cities, comprehensively improve energy efficiency, and strengthen new infrastructure to save energy and reduce carbon

energy security, energy equity, and environmental sustainability is of great significance.

3.2 New requirements for Chongming's energy development

Since Shanghai proposed the concept of Chongming ecological island in 2001, relying on its unique geographical location and resources, Chongming has unswervingly followed the path of ecological priority and green development (Li et al., 2020). Table 1 shows the essential documents released during Chongming's process of constructing the world-class ecological island, as well as the key and new formulation related to energy. In 2010, around the positioning of the ecological island, Chongming proposed to pay attention to energy utilization, energy conservation and emission reduction, and more scientific management. In 2016, the 13th Five-Year Plan for developing Chongming's world-class ecological island was released (Shanghai Municipal People's Shanghai Municipal People's Government, 2016). As an upgrade from the plan to make it a modern ecological island, it puts forward higher requirements for developing natural gas, wind power, photovoltaic, and other clean energy and the construction of green and low-carbon energy development and utilization system. Up to 2020, Chongming has formed a preliminary framework for constructing a modern ecological island. The following year, the Ministry of Ecology and Environment signed a strategic cooperation framework agreement with the Shanghai Government to jointly promote the construction of

Chongming's world-class ecological island and carbon-neutral demonstration area, and meanwhile brought Chongming into the list of zero-waste cities. According to the newly released implementation in 2022 (Shanghai Chongming District People's Government, 2022b), the construction of new power system and zero coal city will become the critical direction of energy production in the ecological construction of Chongming. Comprehensively improving energy utilization efficiency and constructing infrastructure for energy conservation and emission reduction will contribute to its energy reduction. While there are multiple pathways for limiting warming and realizing carbon neutrality, all share standard features—for example, decarbonizing electricity, reducing and reversing forest and coastal wetland loss, electrifying buildings and industry, improving energy efficiency, and adopting active policy responding to CO_2 emission reduction, e.g., CCUS and CCRS (Climate Analytics, 2022). Fortunately, these approaches have been continuously implemented and innovated in Chongming.

4 Policy recommendations

Chongming and other island areas often face similar problems in energy system construction. Due to the location at the end of the power grid, the power quality of Shanghai's purchased power arriving in Chongming is relatively poor. Apart from the main island, the natural gas of Hengsha and Changxing islands needs to be transported to the gas station by ships and tankers. Besides, the relatively backward economic level and industrial structure on the islands have led to a relatively low level of electrification and a relative lack of energy-supporting infrastructure. Hence, in order to realize the ecological protection and emission reduction goals while promoting the resilient transformation of islands' energy systems, this paper proposes the following policy recommendations:

Firstly, on the basis of ensuring the security of the energy system, a hybrid renewable energy system in an orderly manner is necessary. On the one hand, priority must be given to a new system which can carry and absorb a large-scale and high proportion of wind power and photovoltaic power generation. It is also cruical to promote the transition of thermal power from the main power supply to the fundamental guarantee and system regulation power supply, so as to form emergency standby and peak shaving power supply. On the other hand, the government, as a regulator, must predict the potential impact of intermittent energy on the system and ensure a stable energy supply through strategic planning and gradual integration (Latorre et al., 2019). In the face of multiple energy demands of end users, the government should encourage multi-energy complementary projects, and build an integrated energy supply infrastructure. In particular, the government should play the target role of public finance to accelerate the expansion of new low-carbon technologies, and the development of new energy sources such as biomass energy. Accelerating the facilitation of payment and credit systems is also welcomed, since it can stimulate orderly participation of social capital through the whole process of investment, construction and management in the energy field (Ren et al., 2023a).

Secondly, distributed power generation and grid integration technology using island renewable energy is essential to ensure a sustainable and stable power supply. Distributed generation uses distributed available energy to generate electricity, which can be directly connected to the distribution network or the user side. Compared with the traditional centralized power, distributed power generation is more flexible and reliable for the island environment (To et al., 2021), which is remote and with a small population. On this basis, the government should optimize the distribution network structure and improve the construction of a smart microgrid according to local resources. An off-grid micro-grid system integrating wind, light, storage, and load, and a grid-connected micro-grid system integrating light, storage and load are both necessary. The off-grid microgrid system adopts the self-use mode, while the grid-connected microgrid system can adopt the self-use and residual power grid connection mode. In addition, supporting energy storage systems can also help smooth the power curve and achieve peak and valley clipping.

Thirdly, to realize the energy-green transition of the island, governments need to not only increase the power generation from zero carbon sources, but also to control the energy demand (Climate Analytics, 2022). Local residents tend to consume more energy when they think that the energy produced by water and wind power is free. Thus, deepening the application of digital technologies in promoting the energy system transition based on the existing energy Internet is meaningful. Such approach to realizing refined energy management may help the government strengthen the guidance of residents and enterprises on energy conservation and carbon reduction. Relying on advanced communication and information infrastructure, demand side management can be used to coordinate residential energy consumption and power generation from renewable energy changes (Pfeifer et al., 2018). In addition, vigorously developing ecotourism may aggravate the burden of local energy use and even break the island's relatively stable energy supply. Local governments must strictly regulate eco-friendly hotels, ecological facilities, and agricultural tourism projects to control the scale of tourists and strengthen the supervision of the efficiency and types of energy use in tourism (Ren et al., 2023b).

5 Conclusion

On the whole, islands are important places for in-depth global exploration of balancing economic development with ecological protection and climate governance. However, in the context of the volatile global situations and frequent climate disasters, all countries and regions must weigh energy affordability, security and sustainability, and seriously consider launching a flexible energy transition that can achieve long-term climate goals. As a significant ecological barrier of Shanghai, Chongming put forward the concept of ecological island in 2001. Since then, it has unswervingly followed the path of ecological priority and green development, relying on its unique geographical location and resource advantages. Like most island areas, however, Chongming's energy system is facing systematic challenges brought by adapting to climate change and achieving the goal of carbon peak and carbon neutrality. In this context, this study aims to draw inspiration for global island protection and sustainable development. A series of policy recommendations are concluded, including orderly construction of hybrid renewable energy systems,

promotion of distributed power generation and microgrid technology, exploration of low-carbon power generation and energy conservation.

Author contributions

XS designed the idea, while ZC jointly wrote this paper.

Funding

This study is supported by the Key Topics of Shanghai Municipal People's Government Decision-making Consulting Research (2022-A-013-B).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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