

Research on Institutional Mechanisms and Policy Systems for Green Smart Energy Transformation on Islands Under Zero-Carbon Goals: A Case Study of Dachen Island, Taizhou

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Abstract: *Against the backdrop of global carbon neutrality and carbon peaking goals, islands as unique geographical units face systemic challenges in their energy transition. This study aims to construct a systematic theoretical framework and design specific transition pathways using the “Zero-Carbon Smart Island” initiative on Dachen Island, Taizhou, Zhejiang Province as an empirical case. This approach seeks to overcome institutional and systemic bottlenecks in its energy transition and provide insights for similar islands. The study employs a combined approach of case analysis and theoretical construction. First, it thoroughly examines the practical challenges facing Dachen Island’s energy transition across three dimensions: the power system, clean energy development and utilization, and policy support. Building on this analysis, it proposes and argues for a “trinity” synergistic theoretical framework: “Power System Reform – Innovation in Clean Energy Development and Utilization Mechanisms – Construction of an Energy Policy Support System.” The study reveals that Dachen Island’s transition challenges stem from the failure of “technology-market-policy” coordination. Consequently, three core pathways are designed: In power system reform, establish a market system featuring “high-efficiency island-wide circulation + flexible external integration,” including cultivating third-party electricity sales markets, innovating cross-sea green electricity trading, and implementing island-specific electricity pricing. For clean energy development and utilization, establishing a “distributed-as-the-mainstay, centralized-as-the-supplement” development model, and constructing an integrated smart consumption mechanism for “generation-grid-load-storage” alongside multi-scenario collaborative utilization. Regarding policy support, proposing a targeted policy toolkit centered on differentiated subsidies, energy storage industry support, renewable energy consumption responsibility quotas, and regional coordination mechanisms.*

Keywords: Zero carbon target, Island energy transition, Trinity framework, Institutional mechanism, Policy system, Dachen Island.

1. Introduction

With the deepening advancement of the “dual carbon” strategy, the green and smart transformation of energy systems has become a global consensus. As isolated geographical units distant from the mainland, islands have long relied on external energy inputs or high-carbon diesel power generation for their energy supply. Constrained by natural conditions such as typhoons and salt fog, they face multiple pressures including fragile energy security, high costs, and environmental pollution [1,2]. Therefore, advancing the green and smart energy transition on islands is not only an imperative for achieving nationwide carbon neutrality but also a critical measure for ensuring the sustainable socioeconomic development and ecological security of these regions. However, existing research on energy transition has predominantly focused on contiguous mainland areas. The mature grid structures, large market scales, and relatively homogeneous geographical environments of these regions often render relevant theories and policies ill-suited for application on islands [3,4]. The inherent characteristics of island energy systems—including isolation, volatility, small scale, and ecological sensitivity—demand fundamental innovation and adaptation in

institutional mechanisms and technological policies for their transition pathways [5].

Current domestic and international research indicates that studies on island energy transition have developed two primary pathways: technology pilot projects and policy benchmarking. However, systematic integrated research remains insufficient. Internationally, the EU’s “Clean Energy for EU Islands Initiative” promoted wind-solar-storage microgrids on Greece’s Sifnos Island, emphasizing community engagement and technological integration, yet it paid insufficient attention to designing market-based trading mechanisms [6]. Japan piloted wind-powered hydrogen production and energy storage on northern Hokkaido islands, demonstrating technological foresight, but high costs hindered its replication [7]. These cases reveal an international research tendency to prioritize technology over market mechanisms. Domestic studies, meanwhile, have focused more on power market structures and multi-energy complementary system optimization. Examples include Li Chen et al.’s [3] flexible DC transmission proposal for the Zhoushan Archipelago and Xiao Lincheng’s [8] exploration of integrated wind-solar-storage systems on Pingtan Island. However, existing research generally fails to deeply analyze

the institutional barriers arising from the independence of island grids and the unique challenges of cross-sea transmission. There is a particular lack of systematic design for market mechanisms tailored to accommodate renewable energy consumption on islands.

At the policy level, both domestic and international efforts have actively explored innovative approaches. Germany incentivizes renewable energy investment on islands through fixed feed-in tariffs [9], while the UK launched the “Rural and Island Infrastructure Fund” to support energy storage projects [10]. China also places high importance on marine energy development and zero-carbon island construction. The National Energy Administration explicitly proposed “exploring the development of renewable energy on islands” in the “14th Five-Year Plan for Renewable Energy Development.” In early 2025, it jointly released the “Guiding Opinions on Promoting the Large-Scale Utilization of Marine Energy” with multiple departments, advocating for the construction of multi-energy complementary marine power stations on islands [11]. However, existing policies still lack systematic solutions for addressing the unique challenges of island ecosystems—such as ecological sensitivity and high construction costs—and for tackling critical issues like the extended investment return cycles of energy storage projects and insufficient participation from private capital.

As a pioneer demonstration zone for China’s “Zero-Carbon Smart Island” initiative, Dacheng Island in Taizhou possesses abundant resources for clean energy such as wind and solar power. Its 34 wind turbines generate 60 million kilowatt-hours annually, not only meeting the island’s electricity demand but also achieving carbon reduction of 45,000 tons per year. Concurrently, Dacheng Island has launched China’s first island-based “green hydrogen” demonstration project and implemented the world’s first island low-frequency interconnection technology [12]. Furthermore, the island has pioneered innovations in ecological value conversion, completing Zhejiang Province’s inaugural marine blue carbon transaction. However, its transition remains constrained by deep-seated challenges including inflexible electricity market mechanisms, inadequate clean energy consumption, and insufficiently targeted policy support [8]. Using Dacheng Island as a case study, this paper explores how islands can build resilient, economically viable, and sustainable green smart energy systems under zero-carbon constraints. This involves synergistic institutional innovation coupled with integrated technological and policy frameworks.

To this end, this paper constructs a “trinity” systemic analytical framework. By examining three dimensions—the power system, development and utilization mechanisms, and policy systems—it delves into the transformation pathways for Dacheng Island. This approach aims to provide theoretical guidance and a practical blueprint for the energy revolution on this island and similar offshore islands.

2. Challenges in Taizhou’s Dacheng Island Energy Transition and the Construction of a “Three-in-One” Framework

Island as a “Zero-Carbon Smart Island” has laid a preliminary

foundation through a series of engineering practices. However, its transformation process still faces systemic challenges stemming from the unique characteristics of an island. This section aims to deeply analyze the core challenges confronting Dacheng Island’s energy transition and thereby demonstrate the necessity of constructing a systematic theoretical framework. Building upon this foundation, it elucidates the inherent logic and suitability of the “Trinity Framework” for resolving Dacheng Island’s practical problems, providing a theoretical basis for designing subsequent transition pathways.

2.1 Core Challenges Facing Dacheng Island’s Energy Transition

Despite significant progress in energy infrastructure on Dacheng Island, advanced hardware facilities have not fully resolved the inherent contradictions within the island’s energy system. Its transition process now confronts a series of intertwined, deep-seated challenges primarily manifesting across three dimensions: technological synergy, market mechanisms, and policy environment. These challenges collectively form a typical cluster of systemic issues.

2.1.1 Rigid power sector structure, insufficient market vitality and regulatory capacity

Electricity Sales Entity Structure

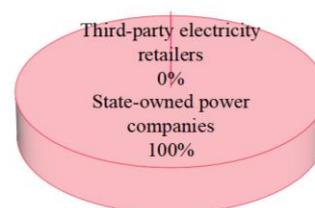


Figure 1: Pie Chart of Main Electricity Sales Entities on Dacheng Island

Figure 1 provides a visual representation of the current electricity sales market status on Dacheng Island. At present, no third-party electricity suppliers have been introduced to the island, with power sales exclusively handled by State Grid Taizhou Power Supply Company [14]. Although physical connectivity has been enhanced through technologies such as flexible low-frequency transmission, the corresponding electricity trading and market mechanisms remain lagging.

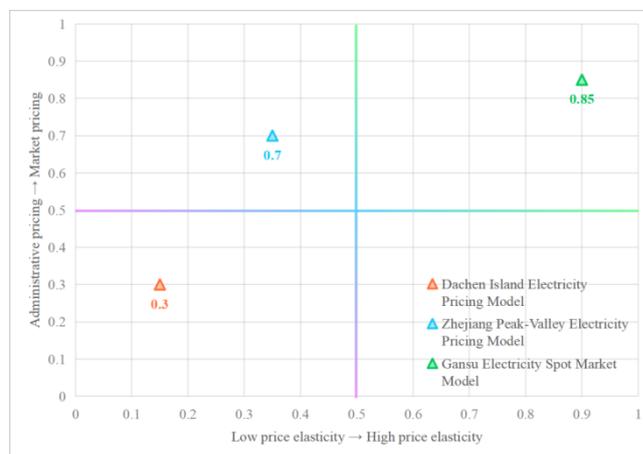


Figure 2: Schematic Diagram of Market Mechanism Comparison

Figure 2 presents a two-dimensional analytical matrix (i.e., a four-quadrant analysis model) constructed using publicly available policy and market data. It positions the three electricity pricing mechanisms in areas like Dacheng Island within a coordinate system defined by the dimensions of “administrative-market” pricing and “low-high” price elasticity, visually illustrating their core differences and evolutionary trajectories. The Dacheng Island pricing model resides in the “predominantly administrative pricing” and “low price elasticity” quadrant. This indicates that the island’s current pricing mechanism heavily relies on administrative regulations, implementing a province-wide uniform fixed time-of-use tariff with only three fixed price tiers (e.g., peak, off-peak, and valley) throughout the day. This structure fails to reflect minute-to-hourly real-time fluctuations such as wind power variability and surges in tourism-related loads. Faced with a fixed tariff schedule, users have little incentive or flexibility to adjust consumption, making it difficult to effectively guide demand response. Zhejiang’s peak-valley pricing model represents a transitional step toward marketization. While policy defines peak/valley periods and

fluctuation ranges, its time-of-use price differentials (e.g., 98% upward adjustment) introduce price elasticity to guide consumption behavior, marking progress beyond Dacheng Island’s mechanism. However, the price differential magnitude and time periods are still predetermined by policy one year in advance, limiting its ability to respond to intraday supply-demand fluctuations. This constitutes a transitional, “semi-market-based” arrangement with constrained flexibility. Gansu’s electricity spot model occupies the quadrant characterized by “market-based pricing” and “high price elasticity,” representing the highest level of marketization. Its prices are entirely formed by real-time supply-demand competition (e.g., Gansu prices fluctuate significantly between 0.08 yuan and 0.388 yuan), instantly reflecting supply-demand tensions. Consequently, it most effectively signals costs and incentivizes “price-chasing consumption.” In summary, the absence of electricity price signals reflecting true costs and supply-demand dynamics, coupled with the lack of diversified electricity suppliers, makes it difficult to effectively guide user-side participation in demand response on Dacheng Island.

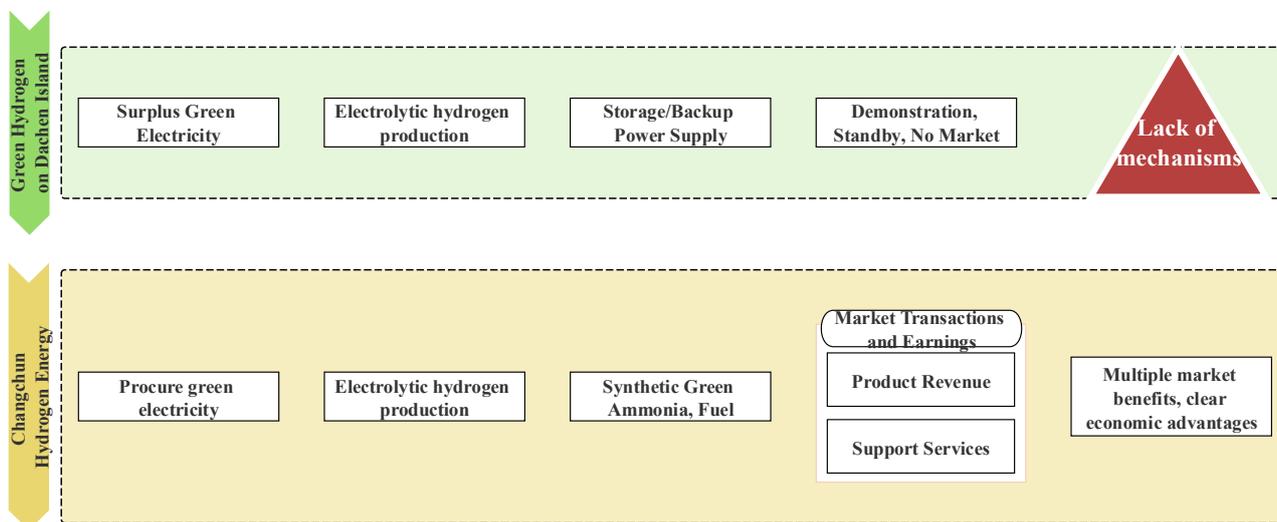


Figure 3: Comparison of Value Realization Pathways for Green Hydrogen Projects

As shown in Figure 3, the green hydrogen demonstration project on Dacheng Island features a short and closed value chain, with its value culminating in “demonstration operation” and “backup power supply.” Compared to mature commercialization pathways, its core flaw lies in the absence of key trading mechanisms connecting the electricity market with the hydrogen commodity market. Unlike established commercial models, the shortcomings of Dacheng Island’s green hydrogen project stem not from technical issues but from systemic market mechanism deficiencies. First, the project lacks conversion and export pathways to transform hydrogen into high-value commodities like green ammonia and secure clear market pricing (e.g., international green ammonia at approximately €1,000/ton). Second, and more critically, the project fails to design pathways for participating in the electricity ancillary services market. Unlike the Changchun project, it cannot generate incremental annual revenues exceeding 80 million yuan by providing peak-shaving services, thereby preventing the realization of its core value as a flexible resource. The absence of multiple market interfaces prevents projects from establishing clear economic projections comparable to the over 12% internal rate of return achieved by integrated wind-to-hydrogen

projects in Inner Mongolia. This severely hampers the willingness of social capital to evaluate and invest in such initiatives.

2.1.2 Systemic bottlenecks in clean energy development and utilization are prominent.

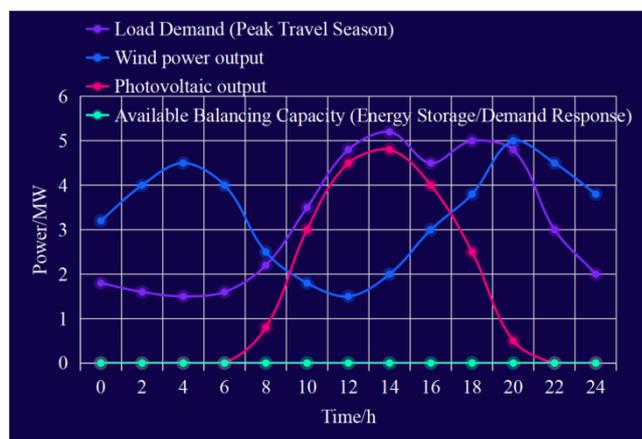


Figure 4: Source-Load Comparison and Regulation Capacity Analysis Diagram

Currently, Dachen Island’s energy development model remains heavily reliant on centralized wind power generation at 25.5 MW, while the potential for integrated utilization of distributed photovoltaic and ocean energy resources has yet to be fully tapped, resulting in a monolithic energy supply structure. Simultaneously, the harsh marine environment imposes stringent demands on equipment durability and reliability, leading to escalating maintenance costs and technical applicability challenges. From a system operation perspective, the “source-load spatiotemporal mismatch” analysis diagram (Figure 4) clearly reveals the core contradiction: the inherent variability of renewable energy output is poorly matched with the island’s steep load curve driven by tourism (daily peak demand around 6 MW). Specifically, during midday peak loads in the tourist season, wind power output often hits its daily trough while solar supplementation falls short, creating supply shortages. Conversely, during nighttime off-peak hours, abundant wind power cannot be fully absorbed, posing curtailment risks. More critically, the capacity of existing energy storage facilities falls far short of the necessary proportion (10%-15% of installed capacity) required for system stabilization. The dispatch capabilities of the smart energy management platform remain rudimentary, as illustrated by the “existing regulation capacity” curve in the figure, indicating the system

possesses virtually no real-time peak shaving or valley filling capability. Consequently, achieving real-time dynamic balance across the entire “generation-grid-load-storage” chain proves challenging, posing dual threats to system operational efficiency and power supply reliability. This underscores the urgency of transitioning from “single-source development” to a systemic solution integrating “multi-energy complementarity + smart dispatch + large-scale storage.”

2.1.3 Insufficient precision and coordination in the policy support system

As shown in Table 1, a significant “policy gap” exists between the unique challenges facing Dachen Island’s energy transition and current policies. First, policies lack sufficient precision. When confronting cost increases (approximately 20%-30%) stemming from the island environment, existing policies fail to provide any targeted “boosting” subsidies or tax incentives. This directly worsens the financial models of projects like energy storage and prolongs investment payback periods. For emerging sectors like green hydrogen and ocean energy, grid connection pricing and market access rules remain entirely absent. This absence of clear commercial expectations has stalled cutting-edge technologies at the demonstration phase.

Table 1: Policy Tool Comparison Matrix

Policy Requirements	Specific challenges	National Green Electricity Special Policy	Policy Gap in Dachen Island	Evaluation Results
Investment and Costs	Environmental factors lead to increased equipment investment and maintenance costs.	Energy storage projects and renewable energy receive dedicated subsidies.	Lack of investment subsidies or depreciation policies for “island environmental adaptation”	✗ Insufficient precision
Technical Standards	Lack of technical standards and safety regulations for energy storage and hydrogen energy equipment suitable for the harsh environmental conditions of Dachen Island	There are corresponding access standards.	The absence of mandatory standards or certification systems tailored for island environments poses significant market entry risks.	✗ Insufficient precision
Price mechanism	The product lacks a clearly defined feed-in tariff or pricing mechanism.	Wind power and photovoltaic power have benchmark electricity prices/guidance prices.	Green hydrogen grid integration and ocean energy power generation lack clear electricity pricing policies; unable to participate in the power ancillary services market to generate revenue.	✗ Insufficient precision
Absorption responsibility	No clear designation of the responsible entity for local consumption of onshore wind power or mandatory consumption quotas.	Renewable Energy Power Consumption Responsibility Weight Assessment	The responsibility for power absorption has not been effectively allocated among power generation companies, power grids, and large-scale users on the island, and the assessment pressure has not been effectively transmitted.	Lack of coordination
Regional Coordination	The absence of regional trading mechanisms makes it difficult to transmit surplus green electricity/green hydrogen to the mainland to realize its value.	A cross-provincial green electricity trading mechanism exists.	Lack of dedicated rules and preferential transmission pricing within the Taizhou region to support point-to-point directed trading of green electricity/green hydrogen from offshore islands.	Lack of coordination

Second, there are significant shortcomings in policy coordination. Although the national level has established a renewable energy consumption responsibility assessment, this metric has not been effectively broken down across the “generation-transmission-consumption” stages within Dachen Island, resulting in unclear accountability. Particularly glaring is the absence of clear, effective policy tools at the regional coordination level. Unlike national-level green power transmission corridors such as Qinghai-Henan or Zhangbei-Xiong’an, which feature three key mechanisms — point-to-point dedicated trading, independent transmission pricing, and green certificate/revenue sharing—Dachen Island lacks any comparable policy framework. In contrast, although Da Chen Island is physically interconnected with

mainland Taizhou, its institutional framework remains entirely vacant: lacking dedicated trading rules, independent price adjustment mechanisms, and revenue-sharing designs. This prevents the implementation of responsibility-sharing mechanisms, hinders the seamless integration of surplus green electricity and green hydrogen into broader markets, and constrains regional energy complementarity potential through institutional barriers.

2.2 Construction and Adaptability Analysis of the “Trinity” Theoretical Framework

The challenges facing Dachen Island clearly reveal that the essence of its energy transition dilemma lies in the lack of

coordination among the three subsystems: technology, market, and policy. Linear reforms confined to any single dimension are unlikely to achieve comprehensive breakthroughs. Based on this systems perspective, this paper constructs a “trinity” theoretical framework designed to address such complex challenges. The core of this framework emphasizes that three dimensions—power sector reform, innovation in clean energy development and utilization mechanisms, and the establishment of an energy policy support system—must be designed synergistically and advanced in tandem.

The framework’s construction and specific adaptability to Dacheng Island are reflected in its precise response to core challenges:

2.2.1 Revitalize the core engine of the system through “power sector reform” to directly address market failures.

The framework positions electricity market development as a core driver, mandating the design of a market model tailored to the small-scale, highly volatile characteristics of island grids. This directly addresses the core issue of insufficient market vitality on Dacheng Island, providing the theoretical basis for introducing peak-off-peak electricity pricing, cultivating electricity retailers, and establishing a green electricity-green hydrogen trading market. It is the key to unlocking the energy value conversion chain.

2.2.2 Strengthen the material foundation through a “clean energy development and utilization mechanism” to overcome technical bottlenecks.

The framework advocates for mechanism innovations centered on “distributed and centralized collaborative development” and “integrated operation of generation, grid, load, and storage.” This approach provides a clear direction for systematically addressing the current challenges on Dacheng Island, namely its single-track development model and insufficient system resilience. It guides the island away from pursuing breakthroughs in isolated technical metrics toward building an efficient, resilient, and adaptive integrated energy system.

2.2.3 Establish institutional pillars through an “energy policy support system” to address policy shortcomings.

The framework emphasizes that policy tools must be precise, coordinated, and actionable. This directly addresses the current lack of targeted policies on Dacheng Island, providing design principles and integrated approaches for formulating differentiated policies such as environmental adaptive energy storage subsidies, hydrogen industry support guidelines, and regional consumption responsibility allocation mechanisms.

In summary, the proposal of the “Trinity Framework” is not a theoretical abstraction, but rather stems from a profound understanding of the complexity and systemic nature of Dacheng Island’s energy transition. This framework clearly elucidates the intrinsic coupling relationships and synergistic mechanisms among institutional innovation, technological pathway selection, and policy safeguards, providing an integrated analytical tool and action guide for addressing Dacheng Island’s practical challenges. This establishes a solid

theoretical foundation for the subsequent detailed, actionable pathway design across the three dimensions.

3. Pathway Design for Green and Smart Energy Transformation on Dacheng Island

Based on the preceding analysis of the challenges facing Taizhou’s Dacheng Island in its energy transition and the “three-in-one” theoretical framework, this section will systematically propose specific implementation pathways for Dacheng Island’s green and smart energy transition. These pathways will be explored from three dimensions: power sector reform, innovation in mechanisms for clean energy development and utilization, and the establishment of a policy support system.

3.1 Power Sector Reform

The power grid of Dacheng Island combines both independence and limited interconnection. Its power sector reform must break free from the constraints of the mainland’s unified power market model and establish a differentiated approach tailored to the unique characteristics of island environments.

3.1.1 Fostering an Effective Competitive Electricity Market Structure Within the Island

Given the small user base and dispersed distribution on Dacheng Island, efforts should focus on introducing diverse market entities to stimulate market vitality. Specifically, market access conditions could be moderately relaxed to attract third-party electricity retailers. These entities would provide customized retail electricity packages and value-added services to differentiated user groups such as residents, homestay clusters, and aquaculture enterprises. Simultaneously, prudently explore incremental distribution network business reforms by encouraging qualified private capital to participate in the investment, construction, and operation of the island’s distribution grid through mixed-ownership models. This approach will enhance distribution network operational efficiency and improve its capacity to integrate distributed renewable energy sources through market-based mechanisms.

3.1.2 Innovation in Cross-Sea Power Trading and Coordination Mechanisms

Leverage advanced interconnection technologies such as flexible low-frequency transmission to establish a flexible and efficient cross-sea power trading model while ensuring the security of the island’s power supply. The core lies in establishing a targeted green power trading mechanism with Taizhou. When Dacheng Island has surplus renewable energy generation, it can transmit green electricity to the mainland grid via cross-sea channels to capture environmental premiums. Conversely, during periods of insufficient wind or solar output or peak tourism season electricity demand, clean power can be procured from external markets. This approach achieves dynamic energy supply-demand balance on the island and facilitates regional power mutual support.

3.1.3 Implementing an Islanded Electricity Pricing

Mechanism

Electricity pricing mechanisms are key to guiding behavior on both the supply and demand sides. It is recommended to implement a significant peak-to-off-peak electricity price differential policy on Dachen Island, using price signals to guide tourists and residents to consume electricity during off-peak hours, thereby effectively shaving peaks and filling troughs. The residential tiered electricity pricing system should be adjusted for island conditions, with scientifically set and appropriately increased consumption thresholds for each tier to accommodate basic residential electricity needs. Furthermore, users adopting the “self-generation for self-consumption, surplus fed into the grid” model for distributed photovoltaic systems should receive preferential feed-in tariffs for their grid-connected electricity, thereby incentivizing the widespread adoption of distributed energy.

3.2 Clean Energy Development and Utilization Mechanism

The development of clean energy on Dachen Island must move beyond the mere accumulation of individual technologies and shift toward a systematic approach that integrates the entire chain and coordinates across multiple scenarios.

3.2.1 Implement a development model that prioritizes distributed systems while supplementing with centralized systems.

Optimize the layout of energy development, prioritizing the potential of distributed resources. Systematically promote distributed rooftop photovoltaic systems on buildings, covering residential homes, public institutions, and tourism facilities. In areas with stable wind resources that have undergone rigorous ecological assessments, prudently plan the expansion of centralized wind power projects. For smaller islands such as Jilongtou and Zhuyu, focus should be placed on demonstrating marine energy technologies like wave and tidal power. This will ultimately establish a diversified supply system tailored to each island’s resource endowment and ecological carrying capacity—a “one island, one strategy” approach.

3.2.2 Building an Integrated Source-Grid-Load-Storage System for Consumption and Storage

To address the intermittency of renewable energy, establish a diversified and integrated energy storage and smart dispatch system. While vigorously developing electrochemical storage, explore the construction of small pumped-storage hydroelectric plants utilizing the island’s mountainous terrain based on local conditions. Continuously advance green hydrogen demonstration projects, converting surplus wind power into green hydrogen for tourism transportation, fishing vessel propulsion, and backup power generation, thereby establishing a closed-loop “wind-solar-storage-hydrogen” system. The core initiative involves establishing a smart energy management platform. This data-driven system enables real-time monitoring and coordinated optimization of power generation, grid operations, load management, and energy storage, maximizing local clean energy consumption.

3.2.3 Establish a Cross-Island Multi-Scenario Collaborative Utilization Mechanism

Break down barriers between energy and industry to promote deep integration between energy systems and distinctive local industries. First, plan and construct flexible inter-island DC microgrids connecting the main island with key subsidiary islands, enabling mutual support for energy surpluses and deficits while ensuring backup supply across islands. Second, innovate the “clean energy + industry” integration model. For example: construct photovoltaic charging walkways at fishing boat docks to power electric fishing vessels; equip modern aquaculture workboats and land-based farms with wind or solar-powered aeration, temperature control, and desalination systems. This deeply embeds green energy into industrial chains, enhancing overall value.

3.3 Policy Support System Tailored for Islands

To address the high costs and risks associated with island development, it is necessary to design a precise and robust policy support system that covers the entire chain.

3.3.1 Refine Targeted Electricity Pricing and Subsidy Policies

Develop more attractive support policies distinct from those on the mainland. For distributed photovoltaic and decentralized wind power projects invested in on the island, implement feed-in tariff subsidies higher than the provincial benchmark or appropriately extend the subsidy period. Establish a special fund for the application of new energy storage technologies on islands, providing a certain percentage of initial investment subsidies or low-interest loans for projects procuring and using energy storage equipment certified for typhoon and salt spray resistance.

3.3.2 Improve Market-Oriented Incentives and Industrial Development Policies

Enforce and incentivize green electricity consumption through institutional design. Clearly define the renewable energy consumption responsibility quotas for grid operators and major energy-consuming enterprises on Dachen Island, establishing a rigorous assessment mechanism. Actively pursue policy support to integrate Dachen Island into the provincial green electricity trading market, while supporting pilot projects for marine blue carbon (e.g., shellfish and algae carbon sinks) trading. Explore market-based pathways to realize the multifaceted value of the “green electricity-green hydrogen-blue carbon” value chain.

3.3.3 Strengthening Technology R&D and Regional Coordination Support Policies

Addressing technical bottlenecks and regional barriers, provide innovation and collaborative support. Promote the establishment of an Island Green Energy Technology Innovation Alliance involving enterprises, Taizhou University, and research institutions to jointly tackle key technologies such as corrosion-resistant materials and efficient marine energy conversion. At the municipal level, establish the Taizhou Island Energy Transition Coordination Office to centrally address coordination issues for Dachen

Island concerning cross-regional energy planning, mutual recognition of technical standards, and infrastructure funding allocation, thereby creating a long-term support mechanism.

4. Conclusions and Implications

This study takes Taizhou's Dachen Island as its empirical research subject, systematically constructing and demonstrating a "three-in-one" theoretical framework for island green smart energy transformation serving the "zero-carbon" goal. Through analyzing Dachen Island's current status and designing its transformation pathway, the study draws the following key conclusions and distills implications for similar regions.

4.1 Conclusions

(1) Systemic coordination is the fundamental prerequisite for driving island energy transformation. This study demonstrates that the complexity of island energy systems dictates that their transformation cannot be achieved through the linear accumulation of individual technologies or policies. The case of Dachen Island confirms a profound coupling relationship among three elements: power sector reform, innovation in clean energy development and utilization mechanisms, and the establishment of an energy policy support system. A positive cycle of transformation can only emerge when market mechanisms create value space for technology application, technological pathways provide the material foundation for market operations, and targeted policies remove institutional barriers for both. Weaknesses in any dimension will result in losses of system efficiency.

(2) Differentiated design is the core principle ensuring the viability of the transition pathway. The path design for Dachen Island fully demonstrates that transition plans detached from the island's unique characteristics are difficult to implement. Its electricity market model of "high-efficiency, internal circulation coupled with flexible external integration," its development strategy of "primarily distributed generation supplemented by centralized power," and its targeted subsidy policies for equipment resistant to high salt fog and typhoons—all represent precise responses to the island's practical constraints: geographical isolation, ecological sensitivity, industrial characteristics, and high construction costs. This differentiated approach is key to overcoming the "cultural incompatibility" issues in island energy transitions.

(3) The "trinity" framework proposed in this paper possesses strong theoretical explanatory power and practical guidance value. This framework not only systematically reveals the intrinsic logic of Dachen Island's energy transition, but its core elements and synergistic mechanisms are equally applicable to analyzing coastal islands facing similar challenges, such as the Zhoushan Archipelago and Pingtan in Fujian. Despite variations in resource endowments, industrial structures, and policy environments across islands, the framework's emphasis on the market-technology-policy synergy provides a transferable analytical paradigm and practical reference for identifying core issues and designing integrated solutions in comparable regions.

4.2 Outlook

Based on the findings and limitations of this study, future research can be further deepened in the following areas: On one hand, future studies can conduct full-lifecycle techno-economic assessments and quantitative simulations for key technologies in this pathway design, such as flexible low-frequency power transmission, salt-fog-resistant energy storage, and island hydrogen production. Through methods like cost-benefit analysis and sensitivity analysis, these efforts will provide more precise data support for investment decisions and policy formulation.

On the other hand, the success of energy transition ultimately hinges on broad societal acceptance and active participation. Subsequent research should extend into the social sciences dimension, delving into the acceptance levels, participation willingness, and influencing factors among island residents, tourism practitioners, and businesses regarding energy transition. It should also explore the design of effective community co-creation and benefit-sharing mechanisms, thereby further ensuring the social sustainability of the transition process on the basis of technical feasibility.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

All data, models, and code generated or used during the study appear in the submitted article.

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