Construction of an eco-island: A case study of Chongming Island, China

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ABSTRACT

Chongming Island is the largest alluvial island in the world and is an ecologically sensitive area. It has been planned as a world famous eco-island for future development. Eco-island is a special concept of sustainable development for a small island. This paper explores the applicability of the eco-island concept with respect to six characteristics: integrated ecosystem structure and function, powerful ecological security defense system, sustainable use of natural resources, prosperous and stable eco-economy, comfortable human habitats, and widespread ecological civilization. Combining the concept of eco-island and the vulnerability and disturbance factors the island faced, this paper presents some primary strategies for the eco-island construction. These strategies include wetland protection, control of exotic species, renewable energy programs, integrated water-systems and land-resource management, eco-economic development, and construction of ecological demonstration villages and communities. Implementation of these strategies will improve residents’ quality of life, as well as enhance the resistance of the island’s ecosystem and relieve island ecological pressure from human activities.

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1. Introduction

For more than two decades the sustainable development of island countries and ecosystems has been a subject of international discussion and negotiation. A key moment was the first United Nations Conference on the Sustainable Development of Small Island Developing States held in 1994 [1]. The main outcome of the conference was a framework for planning and implementing sustainable development in small island developing states (SIDS) [2].

One of the challenges SIDS face is to balance economic benefits with environmental pressures arising from their industrial and agricultural endeavors. Island ecosystems are comprised of various subsystems: economic, social, cultural, political, physical, and ecological. The interaction of these subsystems determines the behavior and sustainability of an island in the face of external disturbances. A sustainable equilibrium is achieved when each subsystem performs acceptably, resulting in increased income, health, cultural richness, biological diversity, and security of ecological wildlife. In contrast, disequilibrium results when stresses are so high that one type of society, economy, or set of ecological conditions replace another too rapidly, with inadequate time for all subsystems to adjust [3]. In other words, when pressure on the ecosystem, economy, or society from external sources exceeds the capacity of an island or makes adjustment of subsystems impossible, these subsystems will break down. Disruption of the balance among subsystems makes sustainable development impossible and may lead to the deterioration of the island ecosystem [4].

The United Nations’ Agenda 21 indicates that there are many challenges when planning and implementing sustainable development on small islands. Islands generally possess relatively few natural resources. Their limited natural resources, geographical isolation, undiversified economies, and dependence on a narrow range of products often leads them to be highly dependent on international trade; they are, therefore, vulnerable to external shocks and natural disasters. Consequently, traditional concepts of sustainable development are not applicable to small islands [5,6].

Stephen and Barry consider that the potential for small islands to pursue sustainable development depends upon maintaining the quality and quantity of limited natural resources, because these resources provide essential life-support systems, such as maintaining water supplies and soil fertility, and protecting individual islands from coastal erosion. In general, it is not possible for islands to create new resource frontiers. The challenge for islands is to create policy and technical framework that will sustain natural resource capital and close ecological cycles so that waste is recycled and resources are renewed [3].

Today, many islands are attempting a transition from export economies, dependent upon agriculture and natural resource exploitation, towards tourism and light industry. However, these new economies also depend upon environmental resources such as coastlines, landscapes, watersheds, and diverse biology [7,8]. New economies also create other problems such as solid waste, pollution, landscape change, erosion of cultural traditions, large
consumption of water and energy resources, and excessive appropriation of natural habitat, all of which contribute to environmental degradation [9,10]. As with the historical syndrome of deforestation, such impacts can be irreversible and limit the performance and resilience of island subsystems [3].

In other cases, although restricted by their vulnerability, many small islands are performing well economically. Smallness does not necessarily imply weak economic development [11]. The potential comparative advantage of small islands suggests that their growth success is likely to be founded upon particular patterns of sectoral activity. Island economies tend to be highly specialized and based around a small number of export markets [12]. Usually, primary and tertiary industries dominate in island economies, and manufacturing is seldom a major sector.

In 2002, The State Environmental Protection Administration of China (SEPAC) confirmed Chongming Island as a national ecological demonstration zone. In 2005, the concept of “eco-island” was adopted in the Master Development Plan for Chongming Island (MDPCI). Now, the construction of an eco-island has become a main goal for the island’s future development.

Although a considerable amount of research has discussed the problems of sustainable development in small islands, there does not exist a model suitable for all small islands [1–3,6,13]. The framework of sustainable development strategies should fit a variety of conditions in a wide range of small islands. Eco-islands can be seen as one sustainable development possibility for small islands. However, there is little information available in literature about what constitutes an eco-island or how eco-islands should be constructed. This paper attempts to define what constitutes an eco-island and, based on specific conditions on Chongming Island, offer concrete development strategies for eco-island construction.

2. Definition of eco-island

An island ecosystem can be understood in terms of a nature–economy–society complex. According to complex ecosystem theory, an eco-island should possess the six characteristics detailed below.

2.1. Integrated ecosystem structure and function

The theory of dissipative structure shows that the development of ecosystem maturity via natural succession is the result of a system organized to dissipate more incoming energy with each stage of succession. Schneider thought that successional processes in ecosystems, under the theory of dissipative structure, would result in systems with: (1) more captured energy; (2) more energy flow activity within the system; (3) more cycling of energy and material; (4) higher average trophic structure; (5) higher respiration and transpiration; (6) larger ecosystem biomass; and (7) more biodiversity [14]. Without human activity disturbances and natural disasters, an island ecosystem will possibly show these characteristics through long-term self-organization. With these disturbances, an island ecosystem should have an integrated ecosystem structure and function to buffer and dissipate external energies from disturbances, so that stability is maintained. An eco-island should have a natural ecosystem structure with a rational landscape layout, complex food web, sophisticated hierarchy structure, and high biodiversity. An island cannot depend on a large degree on ecosystem services from other regions because of its isolation. It should be autarkic by improving ecosystem services, including both natural ecosystems’ self-maintaining functions (head water conservation, water/soil self-purification, soil fertility maintenance, biodiversity conservation, etc.) and the function of providing welfare to residents (food production, resource supply, etc).

2.2. Powerful ecological security defense system

An island ecosystem is vulnerable to disturbances from human activities and natural disasters because of its isolation, small size, and limited natural resources [15]. The resistance of an island ecosystem should be enhanced to reduce its vulnerability and prevent ecological deterioration caused by external disturbances. The construction of an ecological security defense system (ESDS) can enhance the resistance of an island ecosystem. A powerful ESDS in a human-inhabited eco-island should have the following characteristics: (1) maintenance of a large area of natural ecosystems (such as wetland, coral reef) along the coast for buffering the invasion of salt, storm tide, and protecting the coast from erosion; (2) a rational forest shelterbelt network for preventing destruction from typhoons; (3) maintenance of high biodiversity for natural ecosystem stability; (4) a strict quarantine system to prevent exotic species invasion; (5) integrated ecological and environmental monitoring system for predicting and preventing ecological and environmental deterioration; and (6) a fast response mechanism to deal with natural disasters and serious environmental pollution accidents. With these characteristics, island ecosystems can maintain their cycle of self-regulating functions and ecological security.

2.3. Sustainable use of natural resources

An island is increasingly confronted with environmental consequences through their consumption of limited natural resources for economic development. An irrational use of resources usually leads to resource depletion and serious environmental issues. The import of natural resources will result in significant transportation costs and create the risk of external shock and is, therefore, not considered sustainable. An eco-island should ensure self-support of scarce resources through sustainable use of these resources, so that an equilibrium between environment and economy can be achieved. The sustainable use of natural resources requires: (1) self-support of high-consumptive resources to avoid high import costs (such as energy resources); (2) use of renewable resources (such as renewable architectural material) substituting nonrenewable resources to support economic development; (3) maintenance of regenerating capacity of natural resources (such as freshwater, ocean fishing resources) through comprehensive planning and management; (4) improvement of resource use efficiency through economical consumption and recycling; (5) decreased waste generation through reuse or concentrated treatment; and (6) strict control of the import of environmental-risk resources and export of scarce resources by legislation.

2.4. Prosperous and stable eco-economy

A sustainable scenario should be founded upon community-based initiatives that combine ecologically sound alternatives that also are economically viable [6]. From Lester’s point of view, market forces have shaped today’s global economy, not by the principles of ecology. Unfortunately, by failing to reflect the full costs of goods and services, the market provides misleading information to economic decision makers at all levels. This has created a distorted economy that is out of sync with the island ecosystem—an economy that is destroying its natural support systems [16]. To protect fragile natural support systems, an eco-economy may be the one and only suitable economic development mode for small islands. An eco-economy respects the sustainable yields of the ecosystems on which it depends. It is the basis of the eco-island to grow economically while at the same time promoting environmental protection of critical habitats. It requires that: (1) instead of being run on fossil fuels, the island be powered by renewable energy......
sources, such as sunlight and wind; (2) the materials loop be closed through emulating nature, yielding no waste and nothing for landfills (small islands do not have sufficient land resources to deal with waste); and ecological industries largely replace extraction industries; (3) eco-agriculture replace traditional agriculture on the island with less harmful chemicals being introduced into the soil and foods; (4) ecotourism development be encouraged to increase the income of residents while minimizing the adverse effects of traditional tourism on the island ecosystem; (5) the information industry and other high-tech industries, which typically have low resource consumption and high value added, play an important role in the new economy; and (6) sustainable financing strategies are needed to manage the island’s economy.

2.5. **Comfortable human habitats**

The ecologically sustainable development of islands requires a thorough understanding of the underlying demands of human habitats. The science of human habitats refers to the re-interpretation and application of natural and social science findings regarding the creation of human environments [17]. A good natural environment is the basis for comfortable human habitats, and requires a suitable climate, high environmental quality, secure food supply, high quality of natural ecosystem services, low risk of natural disasters, and pleasant landscape. Good social and economic environments are also absolutely necessary because they are related to residents’ welfare. Good social environments refer to secure living, fair social welfare, good and convenient social services, and effective and disinterested government of the island. Good economic environments require that residents have a rich life and that the business environment be active and attractive enough to absorb external investment and support economic growth. The building environment is another key factor that has an important influence on the comfort of human habitats because it provides the residents with the most direct, frequent, and unavoidable images and experiences of everyday life [18]. Green building and ecological design can provide comfortable and healthy living spaces for residents.

2.6. **Widespread ecology civilization**

An ecological view of the world, freed from biological determinism and enriched by the relationship of man towards the natural and social conditions of his living environment, contributes to the formation of an ecological civilization. An ecological civilization that considers the ecology, environment, and decision making at all levels and sectors will promote ecological protection on an island. It is built on the basis of a well-sensitized and educated population. Adequate education and training opportunities provided to the general population by local government and organizations will promote the spread of ecological awareness on an island. When ecological civilization is widespread, it will promote changes of the mode of government decision-making and the lifestyles of residents. Sustainable-development decision-making will alter the economic growth mode and determine the sustainability of the eco-island. Residents, with a new perspective, would pay more attention to ecological and environmental problems, promote green and economical consumption, and try to discharge the least amount of waste materials into the environment. Ecological pressure from economic development and the daily residents’ production and living activities on the island will be largely reduced for the new mode of government decision-making and the new lifestyles of residents resulting from widespread ecological civilization.

3. **A case study of Chongming Island**

3.1. **Location**

Chongming Island is located at longitude 121°09'30"–121°54'00" East and latitude 31°27'00"–31°51'15" North. Lying on the estuary of the Yangtze River and the western coast of the Pacific Ocean, it resides at the midpoint of China’s north–south coastal line. The Yangtze River is divided into a south branch and a north branch; which surrounds the island along with the East China Sea. The island is isolated from Shanghai City by the south branch of the Yangtze River (Fig. 1). It is the world’s largest alluvial island. The total area of the island is 1225 km²; 80 km long from east to west and 13 – 18 km wide from south to north. There are no mountains or hills on the island. The middle and northeast of the island are higher than the southwest and the east. Over 90% of the altitude is between 3.2 m and 4.2 m. The island is of subtropical, oceanic climate, which provides a comfortably warm and humid climate with sufficient rainfall and distinct changes of seasons. Mean annual temperature is 15.2 °C and the average annual rainfall is 1025 mm.

The island has a history spanning more than 1300 years. In 618 AD (the year of the reign of Wu-deo in the Tang Dynasty) two islands, Xisha and Dongsha, emerged in the estuary of the Yangtze

![Fig. 1. The study area, Chongming Island, in the Yangtze estuary.](image-url)
River. Later, small islands around the area emerged until the end of the Ming Dynasty and the beginning of the Qing Dynasty when these small islands connected and became one large island. According to historical recordations, in 696 AD (Tang Dynasty), there were people living on the island. In 1958, the island became one of the administrative regions of Shanghai’s Municipal Government.

### 3.2. General ecology

The major ecosystem types on Chongming Island are agro-ecosystems and natural wetland ecosystems. Agro-ecosystems dominate most of the land use and provide most of the food supply. Natural wetland ecosystems are widely distributing along the coastline and provide important habitats for many wildlife species. There are 2–3 million migratory winter birds living there in spring and autumn. The large area of wetlands feeds a large number of benthos species living there. Vegetation cover on the island has been highly modified by human activity: little native forest remains, and approximately 16.8% of the land is covered in man-made forest. There are some north subtropical evergreen broadleaf forests and evergreen-deciduous broadleaf mixed forests distributed on the island [19].

In some sense, the island is an ecologically sensitive area on the global scale. The east wetland is considered a biodiversity “hotspot.” It is in the midpoint of the route of Asia–Australia bird migration, a habitat where migratory fish species of the Yangtze River complete their life cycles, and a place rich in species of aquatic animals of economic importance.

### 3.3. Socio-economic and environmental background

In 2004, the total population on Chongming Island was about 600,000, among which the floating population from outside the island was about 830,000. Being isolated from the mainland and far from Shanghai, population flow, material flow, and information flow of the island was suffocated due to traffic inconvenience, so it benefited little from the economic boom of Shanghai, and the scale and benefit of secondary and tertiary industry was uncompetitive with other areas in the Yangtze Delta Region [20]. In 2004, the value added to the island reached US $10.3 hundred million, among which 18.9% came from prime industry, 43.8% came from secondary industry, and 37.3% came from the tertiary sector. Agriculture is a significant sector. The 2004 population census recorded that greater than 75% of employed people are engaged in agriculture for both subsistence and commercial purposes. Real GDP per capita is currently around US $1400 per person per annum. However, great disparities and inequalities in income exist between city and countryside. The average annual income of urban residents was about US $698, while the income of countryside residents was only US $698. Income from the tourist industry has become increasingly important. The number of visitors between 2003 and 2005 ranged from 627,000 to 792,000 per year, and total income from tourism had reached US $2.239 million in 2005. Housing was affordable for most residents, and the per capita housing area was 19.7 m² in urban areas and 66.9 m² in the countryside. There were four waterworks and 110 km of water pipe, and the yearly water supply capacity was about 17.5 million tons. Most of freshwater supply was from the Yangtze River, which adequately met the water demand. Electricity production was mainly from a fire power plant in Baozhen with an installed capacity of 165 MW. In 2004, total electricity production was 1364 GWH, and total electricity consumption was 1550 GWH. Other electricity demands were supplied from neighboring Jiangsu Province. Electricity supply could not meet the continually increasing electricity demand.

The island is rarely affected by disturbance from industrialization in the Yangtze Delta Region. It is famous for clear water, clean soil, and fresh air in East China. However, the high population density has put great pressure on the natural and economic resources. A number of substantial environmental pressures and symptoms of environmental degradation have been identified in recent years. Eco-agriculture and ecotourism have been determined by the local government as the two main industries of the island that will contribute not only to the development of the rural economy and an increase in the income of the rural households, but also to maintaining the overall environmental quality on the island.

### 3.4. Main problems faced

#### 3.4.1. Vulnerability of the island

Small islands are increasingly confronted with the classic contradiction between economic progress and environmental degradation. Since the Barbados conference on SIDS, the international community has become more aware that traditional concepts of sustainable development are not applicable to small islands [6]. Almost all small islands share similar characteristics that constrain their path to sustainable development. Over the last decade, these characteristics have been increasingly associated with the concept of “vulnerability” of small islands. China defined vulnerability as the extent to which the environment, economy, or social system is prone to damage or degradation by external factors [2]. Many local and external pressures combine with global environmental change to place additional pressure on local ecologies of small islands. However, these islands generally have a limited capacity to buffer against these environmental hazards and pressures due to their isolated geography, small sizes of their economies, and limited natural resources. They usually show environmental, economic, and social vulnerability in the process of sustainable development.

Like many other small islands, Chongming Island also faces these limitations. To highlight China’s summarization on the vulnerability of small islands [2], Table 1 presents the natural characteristics that are thought to contribute to the enhanced vulnerability of an island. Natural characteristics such as small physical size, ecological uniqueness and fragility, limited terrestrial

### Table 1 Factors leading to the ecological vulnerability of Chongming Island

<table>
<thead>
<tr>
<th>Characters</th>
<th>Description</th>
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<tbody>
<tr>
<td>1. Geographical isolation</td>
<td>It is 40 min from Shanghai ports to Chongming Island by passenger ship, and road traffic is in the planning stage</td>
</tr>
<tr>
<td>2. Small physical size</td>
<td>Eighty kilometer in length and 11–18 km in width with a total land area of 1267 km²</td>
</tr>
<tr>
<td>3. Ecological uniqueness and fragility</td>
<td>Agroecosystems dominate the island, and natural wetlands play an important role in maintaining ecological security but suffers many disturbances such as reclamation, tourism, and exotic species invasion</td>
</tr>
<tr>
<td>4. Limited terrestrial natural resource endowments and high import content</td>
<td>Limited biology, land and mine resources cannot meet economic development demands</td>
</tr>
<tr>
<td>5. Susceptibility to climate change and sea-level rise</td>
<td>The island has 195 km of coastline and over 90% is between 3.2and 4.2 m elevation</td>
</tr>
<tr>
<td>6. Sensitivity and exposure to extremely damaging natural disasters</td>
<td>There are on an average of 7–8 powerful typhoons per year and 1 super storm per 18 years</td>
</tr>
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</table>
Saltwater intrusion is the most significant natural calamity on Chongming Island. In the dry seasons, rainfall in the upper reaches of the Yangtze River decreases which significantly decreases runoff in the lower reaches. The push of tidewater and surface circulation results in upstream movement of the salt tide in both the south and north branches of the Yangtze River. In addition, the salt tide in the north branch usually infuses back into the south branch; thus, the salt tide surrounds the island. In addition, water projects such as dams, pumping stations, and reservoirs along the Yangtze River in the upper regions largely reduce the runoff at the lower reaches and thus increase saltwater intrusion. Most of the runoff of the Yangtze River passes through the south branch. In the humid seasons, freshwater from the upper river is abundant, and the multi-yearly average runoff of the south branch in July and August reaches 47,000 m³/s at the Datong water station. Freshwater diffuses to the North China Sea, and the salinity in the estuary is very low. But in the dry season, especially from January to March, the runoff of the Yangtze River obviously decreases, and the average runoff is only 10,800 m³/s. At this time, the salt tide surrounds the island. The maximal salinity in the estuary of the Yangtze River occurs during these dry seasons each year. According to monitoring data of the south branch from 1992 to 2001 at the monitoring stations of Baizhen, Nanmen, and Xinjian, the highest concentration of chloride at Baizhen station reached 5130 mg/L (salinity was 9.3 thousandths) on January 18, 1992, Nanmen reached 2730 mg/L (salinity was 5.0 thousandths) on March 25, 1999, and Xinjian reached 1780 mg/L (salinity was 3.2 thousandths) on March 21, 1999. Multi-yearly average concentration of chloride at Baizhen station from January to March was 491 mg/L, Nanmen average was 244 mg/L, and Xinjian average was 144 mg/L. According to the monitoring data at the north branch from 1982 to 2001 in Baizha, the highest concentration of chloride reached 14,900 mg/L (salinity was 26.9 thousandths) and the multi-yearly average concentration of chloride was 3749 mg/L (salinity was 6.8 thousandths). The average content of chloride in the north branch was far higher than the south branch. The north branch was surrounded by salt tide almost the entire year, and water in the river showed some properties of inshore seawater. It has already lost its function as the freshwater source for the island.

In addition, rising sea levels in the future will decrease the thickness of the freshwater lens and, therefore, the availability of freshwater and an increase in frequency and intensity of storms will lead to increased incidences of soil and freshwater contamination by storm over-wash. Saltwater intrusion results in soil salinization and a crisis of freshwater on the island. Soil salinization has a significantly negative effect on the agriculture of the island. The Yangtze River is the most important freshwater source for the island. In dry seasons, some water dams on the island cannot effectively pump freshwater because of salt tide intrusion. In some cases, saltwater intrusion results in a crisis of freshwater and will hold back the social and economic development of the island.

Exotic species invasion

Natural ecosystems on small islands are especially sensitive to exotic species invasion because they are ecologically unique. Most exotic species spread very quickly on small islands because their natural foes and competitors do not exist in the new habitat. Exotic species affect the way a variety of native species, communities, and ecosystems interact. The most populous exotic species on Chongming Island are Spartina alterniflora and Solidago canadensis. S. alterniflora originated on the US Atlantic coast. As a highly effective pioneering emergent halophyte, its dense roots and stems can gradually raise the substrate elevation and convert unvegetated, low intertidal estuarine flats to low marsh habitats at a rate much faster than the endemic marsh community. For ecological engineering purposes in coastal areas, the species was introduced to many coastal and estuarine regions of the world, and has become a serious plant invader in those ecosystems [21]. It was introduced onto the island in 1979 for coastal protection. Now, S. alterniflora on the east wetland covers an estimated 33.1% (2751.2 hm²) of tidal flat vegetations and the cover rate of the north wetland is 12.4% (2644.4 hm²) [22]. Although its rapid growth has greatly helped stabilize the tidal flats, the negative impacts on native habitats have also been significant. Without natural foes, S. alterniflora rapidly invaded and occupied the land originally covered by native plants that provide habitats for many species of wildlife. When S. alterniflora invades native communities and mudflats, the corncobs and seeds of native communities are considerably reduced for wildlife species and lead to large numbers of deaths of those species. At the same time, the rigid, densely packed stems may prevent water birds from feeding on fish and bottom-dwelling invertebrates, which causes many water birds to leave these habitats [23]. After the invasion of S. alterniflora, the biologic chain of the wetlands was broken, biodiversity decreased, and native ecological balance of wetland habitats was destroyed. Unfortunately, once wetland ecosystems are infested with S. alterniflora, it is very difficult to eradicate it [21].

S. canadensis originated in North America. Based on the only official record, it was introduced to Shanghai as an ornamental plant in 1935 [24] and widely spread on the island in the 1980s. Now, S. canadensis has invaded about 9300 hm² (7.8%) of land on the island. It can be found in abandoned fields or disturbed and successional habitats. In such habitats, the established fields increase in size rapidly when new ramets are produced via rhizomes. Thus, the species can rapidly become a dominant member in many established fields and can persist in the fields for 50–75 years [25]. S. canadensis also competes for nutrients, water, and living space with native species, resulting in large number of deaths of native species. At the same time, it invades and occupies large amounts of farmland planted with cotton, maize, and soja and affects the yield and quality of these crops, which can directly or indirectly result in economic loss.

Disturbance from human activities

The population's daily activities involve the consumption of great amounts of natural resources and the discharge of great amounts of waste into the environment. According to statistical data, in 2004, daily primary resource consumption on the island was, on average, about 3730 MWH of electric power, 47,600 tons of tap water, and 896,400 tons of coal, and daily primary waste generation was, on average, about 16,900 tons of industrial wastewater, and 9.5 tons of SO₂. Today, modern intensive agriculture has brought about soil pollution, erosion, and degradation on the island. In the past few decades, wetland reclamation, modification, riparian-wetland grazing, fish culture, and wildlife tourism have destroyed natural wetland ecosystems to some extent and occupied a significant amount of important wildlife habitats. New construction land use has been occupying an increasing amount of land resources, especially farmland. The development of township-village enterprise has brought about unsustainable economic development, and has lead to some environmental problems. All of
these influences are putting great ecological pressure on the island ecosystem.

3.5. Primary strategies for the ecological development of Chongming Island

The following sections will present some development strategies for Chongming Island in accordance with the eco-island concept and the main problems the island faces. Natural ecosystem protection and the sustainable use of natural resources combined with eco-economic development, human habitat construction, and ecological civilization should be used as the primary strategies to promote the ecological development of the island.

3.5.1. Natural ecosystems protection

It has been recognized that there are two factors that determine the vulnerability of island ecosystems: the susceptibility of natural and human systems to environmental changes, and their resilience. Successful adaptation will take place by reducing the susceptibility of these systems and enhancing their resiliency [26]. Two main measures—wetlands protection and control of exotic species—are critical to reduce susceptibility and enhance resiliency of the island.

3.5.1.1. Protect wetlands from human disturbance. There are approximately 84,750 hm² of wetlands distributed around Chongming Island, and about 21,179 hm² of these wetlands are above sea level. According to their distribution, these wetlands can be divided into north, south, east, and west. The east and north wetlands are saltwater, and the south and west wetlands are freshwater. These wetland ecosystems play an important role in maintaining both ecosystem health and ecological security of the island. First, they provide a huge natural buffer that protects the island from the hazardous forces of saltwater tides, typhoons, and storm tides. Second, they provide important habitats for wildlife such as invertebrates, fish, and waterfowl, and are home to hundreds of species of migratory birds that spend winters on the island. Third, they purify the coastal environment by promoting sedimentation, absorption, and degradation of pollutants. Fourth, they provide a significant amount of aquatic products for residents. Finally, their beautiful landscapes are important tourism resources. Therefore, the wetlands should be protected during eco-island construction. Reclamation and forestation of the tidal marsh should be forbidden because of their extremely negative effect on native wetland ecosystems.

In the past, wetland cultivation was a serious human disturbance on wetland ecosystems around the island. From the 1950s to the 1990s, about 42,800 hm² of native wetland around the island was cultivated for agricultural production. Along with the increasing requirement of land resources for economic development, the area of wetland cultivation has been increasing from year to year. From 1991 to 2001, about 13,500 hm² of native wetland was cultivated, and the average annual area reclaimed was 280 hm² more than during the previous phase. Almost all of the high tidal marshes and even some of middle and low tidal marshes have been reclaimed in the past few decades. Cultivation has lead to serious degradation of wetland ecosystems. Some important processes and functions of wetland ecosystems, as mentioned above, have been lost and some negative effects have been shown.

Forestation of tidal marshes was another serious human disturbance on the native wetland ecosystems due to the mistaken viewpoint that forestation of the marshes could improve coastal resistance to typhoons and storm tides. Practice proved this viewpoint incorrect. From an ecological viewpoint, forestation of tidal marshes is incongruent with their natural laws; it destroys the native ecology of wetland ecosystems, invades and occupies the habitats of many species, and leads to a decrease of biodiversity. From an economic standpoint, the cost of forestation on tidal marshes is very high and the survival rate of newly planted trees is low. Furthermore, forestation of marshes reduces the production of aquatic products and reduces the economic benefit of wetlands.

In recent years, the importance of the wetland on the island has been more highly regarded. The construction of natural protected areas is viewed as an effective route to protect wetland resources. On the World Wetlands Day in 2002, the east wetland was officially included on the Ramsar List of Wetlands of International Importance. The total protected area is 24,155 hm². In 2005, SEPAC deemed the east wetland a national natural protected area in order to protect some rare and endangered bird species. However, irrational or illegal human activities such as wildlife tourism, fishing, cattle grazing, and poaching still disturb the wetland because of weak institutional capacity to protect these areas. The south, west, and north wetlands are still not under the protection system, and since their conservation was largely neglected, adverse effects have appeared in some areas. Therefore, further measures and activities should be undertaken for wetland conservation: (1) establish an integrated wetland management bureau to enhance institutional capacity for integrated wetland management on the island; (2) establish wetland conservation funds to support the monitoring, evaluating, study, and planning of wetland conservation and identify best management practices for wetland conservation; (3) consider all development possibilities available and weigh the balance between industrial development and wetland conservation, and focus the island’s economy on ecological development; (4) promote wise use of wetlands to meet the economic needs of local people while protecting wetlands, such as creating wetland parks in unprotected areas to develop ecotourism; (5) create a buffer or transition area in the vicinity of the wetlands to control human activities such as garbage discharge and intensive agriculture to minimize the potential negative impact of development on wetlands; (6) create vegetated zones immediately adjacent to a developed area such as an intensive agriculture area to buffer wetlands from the directly negative impacts of development; (7) mimic the functions of natural wetlands to design and construct artificial wetlands in rural communities to protect downstream areas, including natural wetlands; and (8) prohibit cattle grazing, reed harvesting, fishing, and cutting or burning grass in ecologically sensitive areas such as habitats for migratory birds and fish.

3.5.1.2. Control exotic species. As previously discussed, there are two main exotic species on Chongming Island: S. alterniflora and S. canadensis. These two species have negative effects on the island ecosystem structure and function, and pose a potential threat to the ecological security of the island. Effective control of these two exotic species is in accordance with the requirements of eco-island construction.

Chongming Island’s ecosystem is extremely fragile and especially sensitive to the disturbance of invasive species because it is unique ecologically and has a low resistance to foreign species; therefore, prevention and rapid response to pioneer invasion is critical. In addition, the size of any infestation by invasive species is inversely correlated with the probability that it can be successfully eradicated and directly correlated with the resources required for eradication. Therefore, early detection of small, pioneer invasive species is critical to an effective control strategy. Of special concern are pioneer infestations that could produce propagules and be a potential source of further infestation. Detecting and eradicating any pioneer infestations, preferably while they are still small, is considered a good choice for effective control. It is particularly urgent to act quickly if an infestation is flowering or setting seed so that dispersal can be limited. The development of a list of managed areas susceptible to S. alterniflora and S. canadensis and the ability to rapidly contact the appropriate management entity is very
important to control them. A better understanding of the areas most suitable for growth and reproduction of the two species would be helpful in focusing the control efforts. If these were mapped, using GIS technology for example, control could be more focused and efficient. For locations where large areas have already been invaded, successful control requires the availability of a variety of control techniques that are applied in a manner most appropriate for the site and the size and stage of the infestation. An integrated response will be the most effective in eradicating these invasive species from the island. The development of efficient control strategies is necessitated by both the urgency to protect habitats before harm has been caused and the integrative management of large infestations. In an island ecosystem, biological control of invasive species may not be feasible because their natural enemies usually cannot be found in the limited number of species native to the island, and introduced foes from outside the island may lead to new invasions and as a result put the island ecosystem at higher risk. Chemical control using glyphosate-containing herbicides is usually thought to be a good choice for invasive weeds due to its high effectiveness, low toxicity to native animals, lack of bioaccumulation in organisms, and ease of degradation in the environment [27,28]. However, the herbicides’ deleterious effects on some native herbage will probably result in an ecological imbalance in some native areas. Therefore, integrated physical control should be the first choice to control the diffusion of invasive species.

For *S. alterniflora*, the suite of traditional physical control methods includes mowing, crushing, tilling, hand digging, and pulling. Success with these methods has been limited due to the great quantity of *S. alterniflora* on the island. Tilling, digging, and pulling inevitably result in the escape of small pieces of stems, roots, and rhizomes of *S. alterniflora* into sediments and tidal currents that could spread the infestation. Treatments often need to be reapplied to keep the *S. alterniflora* from rebounding [29]. As a result, the rate of increase of *S. alterniflora* has usually outpaced the rate of control. Daehler suggests that a simple and effective method should first be put in place to detect and ensure whether invasion has appeared in areas susceptible to *S. alterniflora*, and then rapid response should be undertaken to eradicate it. However, eradication of large infestations through traditional physical control methods may be impractical. Containment (controlling an established *S. alterniflora* infestation so that it does not increase in area or spread propagules to other areas) may be a more appropriate goal for large infestations. Covering with specialized cloth has been effective on small patches of *S. alterniflora* and can be used to contain and slowly eradicate large patches.

For *S. canadensis*, when the invasive infestation is small and scattered, physical eradication and incineration of immature and mature individuals can effectively prevent its spread to other areas. In addition, education and encouragement for the general public to continue eradication efforts directed at the scattered infestations would also be useful. For large infestations on abandoned farmland, due to its small seeds and limited germination ability in deep soil, deep mechanical tillage can be used to alter the habitat and control further diffusion.

### 3.5.2. Sustainable use of natural resources

Resource management on the island should mimic and/or act in concert with natural energy buffers and ecological processes, especially to increase resilience in the face of external economic and environmental forces. Energy, water, and land are essential resources for economic development. Sustainable use of these resources would contribute to the sustainability of the ecosystem. Concrete measures include: maximum use of renewable energy through renewable energy programs; rational use of freshwater from the Yangtze River through integrated water system management; and effective use of land resource through integrated land resource management.

#### 3.5.2.1. Renewable energy programs

In 2004, the total electricity production on Chongming Island was 1364.0 GWH, and the total electricity consumption was 1550.0 GWH. It is estimated that if the average annual growth rate of electricity demand on the island reaches 8%, as anticipated by the economic growth rate, the total electricity demand will gradually increase to 4552.0 GWH by 2020. In meeting rapidly growing electricity demands, there are concerns of how the local government will actually boost power generation in coming decades. Geographic isolation from Shanghai means that the island has limited physical options for grid connection with the Shanghai power system. Aside from limited electricity import from neighboring Jiangsu Province, the island is highly dependent on fossil fuel import for electricity generation. However, the combined effect of high transportation costs for fossil fuel imports and the diseconomy of small-scale power production make electricity generation not only extremely expensive, but also financially risky in the long term. In addition, traditional use of fossil fuels is increasingly recognized as a prime threat to human health, one of the most environmentally disruptive human activities on the island, and one of the main causes of global warming which leads to changes in agricultural production and other catastrophic events [30]. Especially on the island, the most significant problem concerning the supply of conventional power lies in its dependence on limited exhaustible resources, as opposed to the unlimited supply of solar, wind, and other renewable power sources. From an ecological and economic viewpoint, the current nonrenewable energy sources are inadequate to solve long-term energy problems and are not in accordance with the sustainable development goal.

The broad application of renewable energy technologies is widely regarded as being able to improve what is known as the “three principal pillars” of local energy policy: (1) economic efficiency, (2) environmental performance, and (3) security and diversity of supply, in comparison to fossil-fuel-based energy systems [31–33]. However, present renewable energy utilization represents only a small fraction of total energy utilization on the island. In these contexts, the need to provide the island with a framework for future development in renewable energy has already been highlighted in the master plan.

1. **Solar energy**

Average annual solar radiation on Chongming Island is about 4700 MJ/m². According to the primary estimate, the entire island has a total solar radiation of about 1.567 million GWH per year, which provides good conditions for photothermal and photovoltaic use of solar energy. Currently, solar energy water heaters are among the most advanced and economically feasible piece of equipment in the world. The development of modern technology, such as solar photovoltaic (SPV) cells, has enabled the possible use of solar energy both in terms of scale and geographic distribution linked to end-use needs. The use of power generated through an SPV plant has already been recognized as a possible alternative, from a technological point of view [30]. The restricting factor of solar energy use is the high cost of its electricity generation. According to estimates, the cost of electric power from a SPV plant is 3–4 times higher than traditional electric generation. Exhilaratingly, it is estimated that the cost of electric generation from SPV plants will fall to the level of traditional electric generation within the next 15 years. This will make the per-unit energy cost of SPV plants comparable to centralized systems at all levels.

2. **Wind energy**

Chongming Island is among the regions with the most abundant wind power resources in China. At an altitude of 70 m, the average wind speed reaches 7 m/s, and the energy density is 329 W/m².
Although annual time of powerful wind approaches 7300 h, there are only three small wind turbines on the east wetland. Each electric turbine has an installed capacity of 1500 kW. The scale of the wind-power electric generation system is still too small in relation to the abundant wind-power resources. If 250 km² of wind-electric plants were constructed in the east and north wetlands, the installed capacity could reach 150 million kW, and the total yearly power production could reach 3000 GWH [34]. In reality, the potential sites that can be exploited are highly dependent on a series of meteorological, orographic, environmental, technical, and financial factors. To avoid having a negative impact on tourism and migrating birds [35], the landscape of the different sites, the distance from the nearest observer, the type and size of plants to be installed, and the possibility of integrating them with their surroundings must all be considered when evaluating the various alternatives proposed.

(3) Biomass energy

There is 51,651 ha² of farmland on Chongming Island. Table 2 shows the energy potentials of these agricultural residues. The heating values of residues, irrespective of the biomass species, were assumed to be 18.6 MJ/kg higher than heating values on a moisture- and ash-free basis [36]. Total energy potentials of agriculture residues is estimated to be approximately 4,566,625.5 × 10⁶ MJ/year, or about 156 thousand tons of coal equivalent (The Statistical Yearbook, 2005). Considering that about half of these agricultural residues are used or disposed of in other ways, roughly half could be used to fuel a biomass power plant. If the power efficiency of the biomass power plant reached 40%, an estimated 253 GWH of electric power would be generated per year. Biomass gasification power generation systems are a cleaner method of electric power generation and energy availability is assumed to be 18.6 MJ/kg higher than heating values on a moisture- and ash-free basis [36]. Total energy potentials of agriculture residues are estimated to be about 2600 million m³, and average daily current of fresh-water area. The mean tide range is about 3.04 m, and the largest tide is about 2600 million m³, and average daily current of fresh-water area. The mean tide range is about 3.04 m, and the largest tide is about 5.95 m. Average daily throughput of water is about 2600 million m³, and average daily current of fresh-water from the Yangtze River is about 164 million m³. According to surveys by the Shanghai Institute of Energy, some sites are suitable for the construction of tidal power plants; the potential installed capacity is about 700 MW and yearly power production potential is about 6000 GWH [34]. However, the north wetland is a productive and sensitive wetland ecosystem; therefore, barrage-based tidal power is not considered a truly sustainable mode because of its substantial disruptions to the natural processes of wetlands. The utilization of the fast-flowing marine currents caused by tidal action is considered a more sustainable system due to its limited negative impact. Yushan Island, Yinchen Island, and Dajishan Island in the estuary of the Yangtze River near Chongming Island are three suitable sites on which to build wave electric plants [34]. High utilization can be obtained through engineering solutions that match generators [37,38]. Particular advantages of wave energy are limited environmental impact and negligible demand on land use [39]. The main reasons tidal and wave power are not yet commercially exploited are cumbersome installations and large associated investments. The still pre-commercial status of most devices is associated with high up-front costs due to technology development, limited project size, and the difficulty of finding investors for these high-risk ventures. However, the amount of power available from tidal and wave power is substantial if it can be harnessed in an effective way, and electricity price is predicted to decrease with the development of the technology [38].

According to the potential of each of the renewable energy programs assessed above and their anticipated exploitation rate and energy transition rate (Table 3), it is estimated that the total electricity from renewable energy could reach 3170 GWH per year, which would meet about 70% of the anticipated electricity demand in 2020 on the island. Wind energy and biomass energy should be the first choices at the present stage because of their relatively low generation cost. Solar, tidal, and wave energy can be gradually implemented as their generation costs decrease in future decades.

Table 2

<table>
<thead>
<tr>
<th>Crop type</th>
<th>Production (t/year)</th>
<th>Residual ratio (100%)</th>
<th>Residue production (t/year)</th>
<th>Moisture content (100%)</th>
<th>Ash content (100%)</th>
<th>Energy potential (10⁶ MJ/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rice</td>
<td>192,300</td>
<td>1.43</td>
<td>274,990</td>
<td>0.20</td>
<td>0.22</td>
<td>2,966,592.1</td>
</tr>
<tr>
<td>Wheat</td>
<td>38,900</td>
<td>2.53</td>
<td>98,420</td>
<td>0.28</td>
<td>0.14</td>
<td>1,061,735.0</td>
</tr>
<tr>
<td>Barley</td>
<td>6100</td>
<td>2.50</td>
<td>15,250</td>
<td>0.09</td>
<td>0.15</td>
<td>21,537.4</td>
</tr>
<tr>
<td>Soybean</td>
<td>11,300</td>
<td>2.14</td>
<td>24,180</td>
<td>0.6</td>
<td>0.15</td>
<td>11,243.0</td>
</tr>
<tr>
<td>Corn</td>
<td>23,900</td>
<td>1.10</td>
<td>26,290</td>
<td>0.47</td>
<td>0.10</td>
<td>2,10,267.4</td>
</tr>
</tbody>
</table>

3.5.2.2. Integrated water system management. One advantage of Chongming Island is the available freshwater resources from the south branch of the Yangtze River. Rational utilization of these freshwater resources would improve the water quality and protect these sources from saltwater intrusion. The water system on the island is mainly a man-made system. There are two trunk canals, the south diversion canal (77 km) and the north diversion canal (34 km) which run west to east, 31 subtrunk canals with a total length of 371 km which run south to north, 420 township-level canals that connect trunk canals and subtrunk canals with a total length of 1118 km, and 19,280 village-level canals with a total length of 9338 km. The average canal net density is about 9.4 km/km², and the water surface rate is about 9.4%. There are 24 water supply or drainage dams around the island, which have a total water supply capacity of 3210 m³/s, and a water drainage capacity of 250 m³/s. Dams are the controlling infrastructures that connect the man-made water system on the island with the Yangtze River. Though these dams and canals have played important roles in ensuring the safety of the water supply on the island, there has not been an integrated trunk canal around the island which has caused slow water renewal and deteriorating water quality and these canals have filled with silt, sediment, and waste. Two measures should be taken to increase the water renewal rate and improve water quality on the island. The first measure is to repair and update the canal system. In order to connect the south canal with the north canal, an integrated trunk canal around the island should be rebuilt to carry freshwater from dams along the south branch of the Yangtze River to the inner canals. The south and west segments of the trunk canal would serve as a freshwater input segment, and the north segment of the trunk canal would serve as a drainage segment. Some control dams and man-made lakes should be built as buffers between the trunk canal and other small canals.
input from the Yangtze River passing through each canal would also increase the water renewal rate of these canals and improve water quality. In addition, freshwater input to the canals would largely replenish groundwater, and would, therefore, prevent soil salinization. Scientific management of the canal system would contribute to the maintenance of water and soil quality. The second measure is to establish natural riparian buffer zones along canals to prevent soil erosion and agricultural nonpoint pollution. Ecological engineering (such as artificial wetlands and bank protection work) in the buffer zones would improve buffer zones’ efficacy to protect the water system [40]. In summary, the integrated management of the water system should ensure both freshwater supply and ecological security of water bodies.

3.5.2.3. Integrated land resource management. Land is a limited and precious resource on the island. Efficient use must be made of all available land to meet the needs of the people for water, food, energy, building materials, and to maintain functioning, natural systems on which all of these depend. Along with economic development, there exist increasingly conflicting demands for access to and use of land resources. The demands require integrated ecosystem approaches to conservation and sustainable use of these land resources. Comprehensive planning and careful allocation of land for the most appropriate use or combination of uses is an essential step. A land susceptibility study on the land systems was carried out to ascertain how susceptible the land systems are to deterioration if disturbed by catastrophic events or various types of land-based human activities. A suitability assessment, building on the resource inventory and capability assessment, incorporates ecological susceptibility and social priorities to determine which land uses are suitable for a given area. From an ecological point of view, land management should protect fragile land systems from degradation. From an economic point of view, land management should aim to sustain high income on relatively small land units. Finally, scenario assessments were incorporated into the suitability assessment to promote comprehensive planning based on possible future land-use patterns. According to the comprehensive susceptibility, suitability, and scenario assessment, the MDPCI divided the island into five function divisions (Fig. 2). Each function division with different dominant function and management strategies is shown in Table 4.

In recent years, land degradation has become a serious problem on the island. Saltwater intrusion, intensive agriculture, and other negative land-use activities were the main driving forces of land degradation. Sustainable land stabilization and soil conservation programs considering these driving forces should be undertaken to protect the fragile land system. Permanent preservation areas should be set up to protect susceptible and important ecosystems (such as wildlife habitats and agriculture) from exploitation. New residential, recreational, commercial, and industrial development should be supported in appropriate locations where these uses do not conflict with permanent preservation areas or other beneficial uses, and should ensure that appropriate buffer areas are provided to protect the surrounding environment from being negatively impacted.

3.5.3. Eco-economic development

Balancing the continued growth of an island’s economy to environmental conservation is a great challenge for many small islands. Many researchers have described the disadvantages that small size imposes on economic development and environmental protection [41,42]. However, there is also some evidence which suggests that some small islands are wealthier, and have a better environment than large states which shows there exists opportunities for small islands to gain economic prosperity as well as environmental security [43,44]. Growth success is usually associated with particular patterns of sectoral specialization (such as a strong service sector) and the effective use of an appropriate growth strategy [45]. An eco-economy is a feasible way to reach this goal. It can restructure the island economy, replacing a fossil-based, waste generating economy with a new one that is environmentally sustainable and economically efficient. According to resource endowment and comparative advantage, eco-agriculture and ecotourism should dominate and be advocated since research indicates that island-based manufacturing is rarely successful [46], and the propensity to develop advanced technology is restricted at present for a poor endowment of human capital. Meanwhile, sustainable financing strategies should be developed to attract long-term capital investments in eco-agriculture, ecotourism, environmental and infrastructure improvement from various sources, and introduce ecological compensation principle in economic system.

3.5.3.1. Eco-agriculture. Agriculture is the basic livelihood for more than 70% of the island residents. It is also an important agricultural base for Shanghai, which has a high market demand for high quality of agricultural products. It is a good opportunity for the island to develop agriculture. However, island ecosystems are particularly vulnerable to damage by intensive modern agriculture because of their low resistance capacity. Due to intensive modern agricultural practices, serious local consequences have emerged in recent years. Intensive agricultural practices have simplified the biodiversity, physical structure and dimension, and chemical

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**Table 3**

Potential renewable energy and anticipated production on Chongming Island in 2020

<table>
<thead>
<tr>
<th>Energy types</th>
<th>Potential (GWH/year)</th>
<th>Exploitation rate (%)</th>
<th>Energy transition rate (%)</th>
<th>Anticipated production (GWH/year)</th>
<th>Generation cost ($/kWh)*</th>
<th>Anticipated proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar energy</td>
<td>1.567 x 10⁶</td>
<td>0.5</td>
<td>18</td>
<td>1410</td>
<td>0.178–0.542</td>
<td>31</td>
</tr>
<tr>
<td>Wind energy</td>
<td>3000</td>
<td>60</td>
<td>80</td>
<td>960</td>
<td>0.042–0.221</td>
<td>21.1</td>
</tr>
<tr>
<td>Biomass energy</td>
<td>1270</td>
<td>50</td>
<td>40</td>
<td>250</td>
<td>0.031–0.103</td>
<td>5.5</td>
</tr>
<tr>
<td>Tide and wave energy</td>
<td>7400</td>
<td>15</td>
<td></td>
<td>550</td>
<td>0.122</td>
<td>12.1</td>
</tr>
<tr>
<td>Total</td>
<td>157.3 x 10⁴</td>
<td>/</td>
<td>/</td>
<td>3170</td>
<td>/</td>
<td>69.7</td>
</tr>
</tbody>
</table>

circulation of the landscape. Traditional deep plowing and widespread over-irrigation, with monocropped soil surfaces unprotected by vegetative cover, are contributing to serious soil erosion and salinization at some sites on the island. High chemical input is increasing the risk of soil and water pollution and affecting soil biota in ways that make plants more vulnerable to pests and diseases [47]. High input cost and the negative impact of intensive agriculture on crop yields can outweigh any positive effect of additional input (fossil energy and chemicals) on crop production. Quality of farm produce is decreasing due to the absorption of accumulated chemical pollutants in the soil, which is threatening human health.

The adverse environmental and social consequences of intensive agricultural activity have resulted in the call for more sustainable systems of agricultural production on the island. The main question is: under which conditions it is possible to favor high biological diversity in a high-yielding system that assures quality production while safeguarding the environment? Eco-agriculture is a good choice since it is both a conservation strategy and a rural development strategy. It requires an integrated ecosystem approach to the sustainable management of the agricultural system on the island. The development of more ecologically designed agricultural systems which reintegrate features of traditional agricultural knowledge and add new ecological knowledge into the intensification process can contribute to an integrated ecosystem approach. Considering interactions among the different elements within agricultural systems and between agricultural and non-agricultural systems, eco-agriculture is expected to achieve three broad goals on the island: (1) enhance rural livelihoods; (2) protect and enhance biodiversity and ecosystems services; and (3) develop more sustainable and productive agricultural systems (crops, livestock, fish) with low inputs.

McNeely and Scherr identify six main strategies for eco-agriculture that can be applied on Chongming Island: (1) create biodiversity reserves that benefit local farming communities; (2) develop habitat networks in non-agriculture areas; (3) reduce land conversion to agriculture by increasing farm productivity; (4) minimize agricultural pollution; (5) modify soil, water, and vegetation resource management; and (6) modify farm systems to mimic natural ecosystems [48]. Some integrated approaches such as agroforestry, crop diversification (intercropping, rotation), conservation tillage, and traditional production systems in China (such as grain–livestock–mulberry [Morus L.–fish]) are strategies for eco-agriculture. Agroforestry can provide the means to increase biomass and, in turn, improve food crops and livestock productivity while simultaneously upgrading the productivity of degraded soils and improving agricultural systems’ resilience to natural disasters. Intercropping, rotation, and conservation tillage is not only more productive than monocropping, but also maintains agricultural biodiversity and provides important habitats for wildlife. The traditional production system is actually a closed circulation system for nutrients that can greatly reduce the use of fertilizer and production costs. Today, some eco-agriculture and organic agriculture patterns, such as, duck or crab raising combined with organic paddy cultivation, or the pattern of “grain–livestock–biogas digester–fish” etc., have been applied in some areas and successful patterns should be popularized. Integrated nutrient and pest management approaches are considered operable pathways to sustainable, high-production agriculture and the reduction of off-site problems. Integrated nutrient management considers that one key to nutrient use efficiency lies in the spatial and temporal match of nutrient resources and plant demands. Integrated pest management is a flexible and holistic approach that utilizes a variety of biological, cultural, genetic, physical, and chemical techniques, as required, to hold pests below economically damaging levels with a minimum amount of disruption to the cropping ecosystem [49].

3.5.3.2. Ecotourism. Chongming Island is located close to three large tourist markets: 21.4 million people in Shanghai, 74.3 million people in Jiangsu Province, and 48.9 million people in Zhejiang Province. Chongming Island has great development potential for ecotourism due to its environmental conditions and abundant tourism resources. Tourism is an important vehicle to overcome size constraints on the economic development of small islands [45]. Several tourist sites such as Dongping National Forest Park, Qianwei Agro–Ecological Village, Yingdong Fishery Village, and Dongtan Wetland Park have been developed to attract ecotourists. In 2005, the number of visitors visiting the island reached 792,000, and net profit reached US $2.239 million. However, tourism constitutes both an opportunity and a challenge to the island: an opportunity to diversify limited economic activities and employment, and a challenge since tourism has a considerable impact on island systems that are extremely vulnerable [1]. Traditional tourism consumes large amounts of natural resources and produces large amounts of waste, similar to other unsustainable industries. According to the indicator framework and indicator sustainability threshold of environmental vulnerability index developed by SOPAC, UNEP, and their partners, annual number of tourists per km² land on the island is too large for a fragile island ecosystem [50]. Without controls, tourism development can exceed the social and environmental capacity of the island and result in the ecological deterioration of island systems.

As a solution to the present ecological deterioration of exploitive tourism, a sustainable tourism development model, called ecotourism, is required to maintain environmental quality on which both the host community and the visitor depends, improve the quality of life for island residents, and provide a high-quality experience for visitors [51]. The tourism capacity of the island should be analyzed and long-term strategies for an integrated regional development plan must be introduced as a preventive measure to make tourism compatible with the conservation of the main ecosystems Tourism infrastructure should be improved, but
attempts to increase capacity by simply expanding current infrastructures will only lead to high-density, mass-market tourism that will speed degradation processes. The creation of new coastal facilities (such as sports centers and marinas) that are at risk to changing coastal dynamics should be suitably regulated, and natural wetland wildlife tourism activities (such as bird watching and shrimp and crab hunting) that could have a negative effect on habitat preservation and island coast biodiversity should be controlled. The creation of parks (such as a wetland, forest, and agro-tourism parks, etc.) and protected areas (such as the east wetland wild bird protection area) is a suitable and compatible measure that serves to protect wildlife habitats, as well as increase the value and attraction of tourism. Tourism income should be enhanced by maximizing visitor expenditures rather than numbers, and the season could be lengthened to the extent that ecological and infrastructure recovery is allowed. Sightseeing and agro-tourism should be modestly developed to attract urbanites from surrounding cities and enhance local farm income.

3.5.4. Human habitats

According to the definition of an eco-island, human habitats on the island should meet two basic goals: minimize impact of human activity, and maximize resident welfare.

To reach the first goal, green building (or sustainable building) should be advocated to minimize environmental impact. Green building based on low-impact development will use less water, energy, and natural resources, avoid toxic chemical pollution, reduce waste, and decrease ecosystem pressure [52]. Green building projects on the island can be implemented with the following principles: (1) locate buildings far from natural wetlands; (2) minimize impervious surfaces and increase rainwater infiltration to help decrease storm water runoff and prevent erosion that can destroy the canal system; (3) install SPV cells, solar energy water heaters, and small wind-turbine systems on the rooftops of buildings; (4) install water conservation and reuse systems, energy-efficient heating/cooling systems, appliances, lighting, and building envelopes; (5) select recyclable, durable, and low-cost building materials; (6) consider waste reduction, reuse, and recycling during construction and throughout the life of the home; (7) improve indoor environmental quality by choosing low- or non-toxic building materials and by maximizing natural ventilation and sunlight; and (8) enhance disaster resistance.

To reach the second goal, the local government should promote the creation of places where people can live comfortably and conduct business with minimum difficulty in agreeable surroundings in harmony with their cultural values and lifestyle. A comfortable community should have few environmental problems and health risks, convenient traffic flow patterns, adequate provisions for hospitals, sanitation, schools, parks, and recreation facilities. It is also necessary to provide spaces for social, cultural, and traditional activities. However, housing prices, which is a key factor determining the happiness of the residents, are easily influenced by Shanghai and, should be controlled at the proper level, so that it is affordable to residents.

3.5.5. Ecological civilization

3.5.5.1. Ecological education

Environmental education is needed to help people make sound decisions for the environment and their living conditions. Primary and secondary schools should play an important role in ecological education because, at this age, ecological awareness is easily learned. The issues of limited natural resources, ecosystem vulnerability, land degradation, environmental pollution, exotic species invasion, and wildlife protection can be taught in science and social science-based subjects from primary school through senior high school. This enables students to have an adequate understanding of relevant issues upon graduation. Mass media sources such as newspapers, radio, and television are also valuable tools, as are posters, leaflets, community meetings, environmental protection activities, and wildlife protection activities, which also contribute to public awareness.

3.5.5.2. Ecological demonstration village

Until now, most of the population of the island has lived in the countryside, so sustainable development in the countryside is a key issue for eco-island construction. Some ecological demonstration villages should be set up to explore sustainable development models suitable at the village level. Some positive measures (such as the certification of villages as ecological-civilization villages) can be implemented to encourage villages with positive sustainable development. Successful models can be gradually popularized across the entire island. The construction of ecological demonstration villages can increase the ecological awareness of residents while simultaneously improving their living conditions and promoting ecological progress of the entire island.

3.6. A case-study of ecological development in a rural community: Qianwei Agro-Ecological Village

Qianwei Agro-Ecological Village (QAEV) in the north central part of Chongming Island has created a "socially harmonious, economically prosperous, and ecologically sustainable" settlement that can serve as a model of ecological development.

The village was formed from a section of tidal flat in 1969. It covers a total area of 2.5 km² and has 279 homes and a population of 753. Although the agricultural production environment is affected by salinization, barren soil, and frequent typhoon and rainstorm events in the summer, applying the principles of ecology and ecological economics in the village has created unprecedented economic growth and environmental recovery. In 1996, it was nominated as UNEP's "Global 500 Award for Environmental Achievement". While improving air, water, and soil quality, the village has achieved economic progress. In 2005, Qianwei's net income per farmer was US $929, which was greater than the national average (US $403) and the island average (US $766). Farm household income was mainly from eco-agriculture (i.e., organic crop production, greenhouse fruit, vegetable and flower production, animal husbandry, and aquaculture) and two non-agricultural income opportunities (i.e., agro-tourism and employment at the local lactic acid production facility).

Agricultural production in the QAEV seeks to mimic the efficiency of the natural ecosystems to promote a sustainable production and consumption system and as a result they have reduced waste (materials and emissions) and converted by-products into reusable resources. Fig. 3 presents the waste material and energy flow in the recycling system. In 1994, a lactic acid production facility (LAPF), capable of producing 2000 tons of l-lactic acid per year through the fermentation of enzymatic hydrolyzates from corn starch, was established in the village. While creating profit and employment opportunities for the village, the LAPF also brought a large amount of waste residues, organic wastewater, and waste heat requiring further disposal. Improper disposal of these wastes would pollute the wetland and pose a threat to wildlife living there. At the QAEV, this waste is reused as raw material and energy. Downstream from the LAPF, organic waste residue is processed and transported to a swine production facility (SPF) and converted to feed; organic wastewater is degraded by photosynthetic bacterium in a wastewater treatment station and is then transported to greenhouses through a water pipe network as a source of organic fertilizer; waste heat is transported to turtle and crab ponds in greenhouses to accelerate the growth of turtles and crabs and shorten hibernation periods.
The SPF produces 10,000 slaughter pigs, 4860 tons of fresh manure, and 6300 tons of liquid manure annually, which is a source of air pollution and a threat to aquifers and wetlands. Four biogas digesters which have a total capacity of 600 m$^3$ were established to treat swine manure and human biosolids. About 150 m$^3$ of biogas is produced daily from the four biogas digesters for cooking, lighting, and other power applications in houses and hotels in the QAEV. About 3600 tons of biogas slurry per year is transported to greenhouses and fields as organic fertilizer, which not only supplies essential nutrients, but enhances water holding capacity and soil aeration, accelerates root growth, and inhibits weed seed germination. Production of biogas not only provides clean energy and reduces air pollution, but also increases the application of highly efficient organic fertilizer, improves soil fertility, and reduces the spread of pathogens from swine manure.

Some residue from the LAPF, the SPF and the biogas digester are processed into pellet feed for fish. Over time, excessive accumulation of organic matter in pond sediment not only reduces the depth and space available for fish, but also makes the water environment unfavorable for fish growth. Therefore, when fish are harvested, the sediment in the pond is removed for use as organic fertilizer which is enriched with organic matter, nitrogen, and phosphorus. The LAPF, SPF, biogas digester facility, fish production facility, organic farm, and greenhouse facility jointly form a sustainable agriculture system which not only improves the livelihood of farmers, but also maintains a healthy natural environment.

Agro-tourism is another important income source for the QAEV. In 2000, the QAEV developed an agro-tourism program called “agricultural vacation” which allows tourists to sample organic farm produce, live in a farmhouse, do farm work and experience traditional farm life. From 1999 to 2005, the total number of visitors reached 600,000, and total net income was US $2.476 million. While gaining profit from tourism, the QAEV takes many measures to avoid the negative impact of tourism activities on the environment. In 2004, ecological planning for the village was completed by the Shanghai Tongji Urban Planning & Design Institute. The protection and conservation of environmental resources were prime considerations in the planning process. Great care was taken to protect natural vegetation and wildlife habitats in and around the village. A natural wetland park which covers about 7.0 km$^2$ to the north of the village has been constructed to protect the wetland from human disturbances. Sustainable lifestyle is encouraged among residents and tourists to minimize resource consumption and waste generation. Bamboo baskets and cloth bags are offered to tourists to reduce the use of plastic bags in the area. Throwaway dishware is prohibited in hotels and roads are paved with asphalt-rubber grain mixtures which absorb traffic noise. Sightseeing buses are powered by electricity and solar energy. Streetlights along the landscape road are powered by a wind–solar hybrid energy system which transforms solar energy into electricity in the daytime and saves wind energy for night use.

As a result of past economic gains and financial support from Shanghai, the village is committed to improving human habitats through advanced energy and environmental technologies. Houses are constructed using green building technologies. In 2007, an SPV System, which has a total area of 6000 m$^2$ and total installed capacity of 600 KW, was mounted on the roof of each house. It is estimated that the system can generate 1.2 GWH of electricity, reduce coal consumption by 450 tons and prevent over 960 tons of CO$_2$ from entering the atmosphere per year. Today, the village is totally powered with clean energy generated by the SPV system, the solar energy water heating system, and the biogas digesters. Rainwater harvesting techniques are employed to collect rainwater from the roof of houses to be used for farmland irrigation and landscape water. All domestic sewage is collected and transferred via a wastewater pipe to an artificial wetland treatment system which covers 4000 m$^2$ and has a wastewater treatment capacity of 600 m$^3$/day. The system produces clean effluent through plant, media, and microorganism interaction, while forming a functional landscape and providing a valuable ecological habitat for wildlife at the same time. Several experimental and demonstration bases have been constructed by universities and research institutes from Shanghai to research and develop environmental, energy, and ecological agricultural technology for sustainable village development. Five ecological demonstration residential buildings which have 3400 m$^2$ of total floor space are being built to research, develop, and demonstrate sustainable building technologies by synthetically applying 23 types of intelligent, ecological technologies. It is estimated that 65–75% of energy consumption will be reduced, and more than 60% of rainwater and wastewater will be recovered in these houses. A natural ventilation system is designed to provide fresh air and maintain a healthy and comfortable indoor environment. In the future, these demonstration projects will be extended to other buildings throughout the island. These experimental demonstration bases also offer residents and tourists the opportunity to learn about natural systems, eco-agriculture technology, and the best practices of low-waste lifestyles.

![Diagram of waste material and energy resources in the QAEV.](image)
4. Conclusions

An eco-island is an integrated conception of sustainable development which orientes the local government and public toward smart decision-making and action in island development. Usually, the establishment of sustainable development strategies for a given island should combine the concept of eco-island and the main problems faced on the island. The concept of an eco-island can be summarized by the following six themes: integrated ecosystem structure and function, powerful ESDS, sustainable use of natural resources, prosperous and stable eco-economy, comfortable human habitats, and widespread ecological awareness. Eco-island development should focus on protecting natural resources and virgin ecosystems from the disturbance of human activities since these natural resources and virgin ecosystems are essential for any island.

As with many other small islands, the development of Chongming Island is limited by its ecological vulnerability, such as its unique ecological nature, limited terrestrial natural resources, susceptibility to climate change and sea-level rise, and sensitivity and exposure to typhoons and storm tides. Besides these vulnerabilities, the island also faces other disturbances, such as saltwater intrusion, exotic species invasion, and uncontrolled human activities. The combined effects of these vulnerabilities and disturbance factors are pushing the island toward high ecological risk.

To avoid these adverse effects, some sustainable development strategies were advocated in the process of eco-island construction. Integrated development strategies include five important components: natural ecosystem protection, sustainable use of natural resources, eco-economic development, human habitat construction, and ecological civilization construction. Measures of natural ecosystem protection on the island include wetland protection and the control of exotic species. Wetland forestation and conversion should be forbidden due to their significant negative effects on wildlife habitats and on the defensive capacity of the island against typhoons or storm tides. Invasive species, such as S. alterniflora and S. canadensis, should be controlled through integrated physical methods such as covering with specialized cloth and eradication when the invasive area is small. Sustainable use of natural resources, such as renewable energy programs, integrated water management systems, and integrated land resource management can promote the natural renewal of these resources for economic development and relieve ecological pressure from exploitation. It is estimated that renewable energy programs will meet about 70% of the electric demand on the island in 2020 through strategic planning, and will significantly reduce environmental impacts from coal-fired electricity plants. Integrated water system management on the island should consider using freshwater from the Yangtze River by repairing and updating the man-made canal system to an integrated water system, and by establishing natural riparian buffer zones along these canals to prevent soil erosion and agricultural nonpoint pollution. Integrated land resource management requires comprehensive planning and careful allocation of land to the most appropriate use or combination of uses. MDPCI has divided the island into five function divisions with different land-use strategies through land suitability assessment.

For developing a prosperous and stable eco-economy, two types of eco-industry are advocated for the island: eco-agriculture and ecotourism. Eco-agriculture, which reintegrates features of traditional agricultural knowledge and adds new ecological knowledge into the intensification process, would be a dominant agricultural model on the island as part of both a biodiversity conservation strategy and a rural development strategy. Ecotourism as a solution to present ecological deterioration of exploitative tourism would adopt preventive measure to make tourism compatible with the conservation of the main ecosystems, biodiversity, and natural resources on the island. In addition, sustainable financing strategies such as attracting investment in eco-economy from various sources and introducing ecological compensation principle in economic system are important for prosperous and stable eco-economy. Creating habitats comfortable for residents is the final goal of eco-island construction. On the basis of natural ecosystem protection, sustainable use of natural resources, and a prosperous and stable eco-economy, human habitat construction should implement green building and comfortable-community construction. Green building based on low-impact development would use less water, energy, and natural resources, avoid toxic chemical pollution, reduce waste, and decrease the negative effect on the island ecosystem and residents’ health. Finally, ecological awareness through education and demonstration villages can reduce the ecological pressure on the ecosystem that comes from residents’ daily activities.

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