A Guideline of China's City-Level Decarbonization Planning
--- With a Case of an Island City in Northern China

by

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EXECUTIVE SUMMARY

Urgent action is needed to reduce greenhouse gas emissions and mitigate global warming, which leads to ecosystem degradation, extreme weather events, and economic and human risks. The Paris Agreement's goals can be achieved by establishing emission reduction targets and decarbonizing the economy. China, the largest emitter of greenhouse gases, aims to reach carbon peaking by 2030 and carbon neutrality by 2060. Urban areas account for 85% of China's emissions, making it crucial for cities to adopt decarbonization measures to fulfill the national targets. Therefore, many city governments have developed decarbonization plans to explore low-carbon development opportunities.

Based on a client project, this policy report focuses on the Chinese context and aims to provide practical knowledge for urban development planners, policymakers, and the public interested in decarbonization issues. The report clarifies the concept of decarbonization planning and provides a comprehensive planning guideline, including greenhouse gas inventory, future emissions forecast, setting decarbonization targets, and developing action plans specific to the region.

To illustrate the practical application of the proposed guidelines, the report also includes a case study of an island city in northern China. The GHG inventory shows that the study area's emissions decreased by approximately 56% from 2016 to 2021, primarily due to the promotion of electrification in various industries. The LEAP model-based emissions forecast for the next 40 years reveals the feasibility of the island city achieving carbon neutrality by 2035 under a stringent low-carbon scenario. Based on this analysis, we design and compile a decarbonization action plan for the island city, presenting information on guiding ideology, principles, cross-cutting strategies, necessary decarbonization initiatives for specific sectors, and capacity-building guarantee systems.

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1. Introduction

1.1 Background and Motivation

Climate change is one of the most pressing issues confronting the world today, with global warming wreaking havoc on natural and human systems (IPCC, 2021). How to achieve net carbon emissions to mitigate the current stressful climate change has become a topic of common concern and effort worldwide. In response to climate change, the Paris Climate Change Conference adopted the Paris Agreement (PA) in 2015, limiting the global average temperature rise to less than 1.5°C above pre-industrial levels (Salvia et al., 2021; Zhao et al., 2022).

A few countries and cities worldwide are already on the way to carbon neutrality, with promising results. Here are some examples and experiences from international cities. Tokyo represents Japan's urban energy mix, and its city-scale carbon reduction policies are meant for the country (Long & Yoshida, 2018). Transportation is Tokyo's largest direct emissions source, so policy interventions can significantly impact this area. For instance, transportation-related policy interventions for the Tokyo Olympics in 2020 reduced CO2 emissions by 40% (Ito et al., 2022). As the capital of Denmark, Copenhagen accounts for a significant portion of the country's carbon emissions. It supports smart city solutions by reducing energy consumption with data to achieve carbon neutrality by 2025. Sensor technologies for real-time decision-making, transportation integration, and energy-efficient building development are all part of the Smart City program. This is a good example of how big data can be used to help the city make energy-saving decisions (Giest, 2017).

Relevant studies show that the ability of cities to act to mitigate climate change is critical to achieving the goals set out in the Paris Agreement. As global centers of communication, commerce, and culture, cities are significant contributors to carbon emissions, estimated to be responsible for more than 70% of global carbon emissions (IEA, 2020). It is worth noting that cities play the same role in China. They significantly contribute to carbon emissions, accounting for 85% of China's total emissions. As the biggest emitter in the world, China bears a significant responsibility for carbon emission reduction. According to statistics, China's carbon intensity decreased by 48.4% in 2020 compared to 2015 (Liu et al., 202), but there is still much opportunity for progress.

Given the situation's urgency, the Chinese government has set clear “double carbon” goals: striving to reach a carbon peaking by 2030 and achieve carbon neutrality by 2060. With that, all levels of government have taken action to reduce local areas’ carbon footprint and work together to achieve net carbon emissions. Despite China's commitment to meeting dual carbon targets, the country faces several challenges. These include a limited time frame for decarbonization, rising carbon emissions, continued reliance on fossil fuels with low utilization efficiency, and the immaturity of low-carbon technologies (Zhao et al., 2022). In response, many Chinese city governments have developed decarbonization plans to investigate opportunities for low-carbon development.

1.2 Conception of Decarbonization Planning

Decarbonization is the process of stopping or reducing the release of greenhouse gas (GHG), particularly carbon dioxide, into the atmosphere as a result of certain processes, for example, the burning of fossil fuels (Cambridge Dictionary, 2022). In China, planning ("Guihua") means making a comprehensive long-term development plan (ZDIC, 2022). City-level decarbonization planning in China is a supporting instrument for local governments to make low-carbon development plans. It involves considering all industries and main city activities that contribute to GHG emissions. Decarbonization planning should reveal the emission status quo, identify existing limitations and potential challenges, and then customize scientific goals and feasible decarbonization strategies in a compatible way with high-quality socio-economic development.

Plans take an important place in Chinese politics. The planning process can be comprehended in China from vertical and horizontal aspects. In a certain sense, China's government takes five years as a round in making socio-economic development plans. The national five-year plan comes out with brief, reasonably general guidelines, sets national priorities, and characterize how they will be met. However, it will then be executed through a network of thousands of sub-plans that developed into detailed execution instructions. These instructions aim at different fields and sectors for different levels of government: center, provincial level, and cities or counties (Heilmann & Melton, 2013).

The Chinese government created the 14th Five-Year Plan for 2021 to 2025, which enables China to link its long-term climate goals with new opportunities in social and economic development, promoting energy transition and more sustainable urban development (Hepburn et al., 2021). Decarbonization planning will be a critical task for all the city governments in China in the 14th Five-Year Plan period. To align with the overarching planning system of China, in vertical aspects, city-level decarbonization planning should be consistent with decarbonization goals, plans, and requirements set by upper layers of government. In the horizontal aspect, it should maintain a consistent, coordinated, and synergetic relationship with other comprehensive plans like urban plans, land use plans, and economic and social development plans (Mao et al., 2015).

Although sometimes, in the language context of Chinese, planning can be taken as the long-term plan itself. However, this report defines decarbonization planning as the practices and procedures when making the long-term plan for guiding a city to stop or reduce greenhouse gases being released into the atmosphere from city activities.

1.3 Purpose, Methodology, and Structure of this Report

Recently, an increasing number of governments released official decarbonization plan documents generated from decarbonization planning, while these documents tend to be conclusion oriented. It is comparatively hard for external people outside the planning group to know the mechanism and procedures involved in the planning process behind these documents.

This report aims to show its mechanism by introducing a guideline of the key decarbonization planning procedures, including GHG inventory, forecasting, goal setting, and making action plans. Most importantly, this report provides a real-world and vivid case study of the decarbonization planning of an island city in Northern China, which will contribute practical knowledge for both professional policymakers as well as the general public interested in city decarbonization topics.

The guideline and the case illustrated in this report are mainly based on a client project for a government of a prefectural island city in China. This project aimed at making a carbon-peaking and carbon-neutral development plan for the island city and was finished with the cooperation of Duke Kunshan University and Tsinghua University. This policy report differs from the final deliverables to our client in several aspects.

To show a more generalized picture, we have filtered out some location-specific considerations from our clients in the case writing. Therefore, a certain amount of analysis on the setting of the decarbonization target and the design of the action plan is different and more generalized from our client project. We also integrate additional literature review and policy review to analyze the report.

In terms of data, this report will process the location information and staple socio-economic data confidentially in the case part.

Regarding the originality of content, the emission forecast part (LEAP model) and carbon sink counting part of the client project were completed by other project team members. In this policy report, we make an analysis based on referring to their output and assumptions.

In terms of structure, this policy report conducts a method of extracting the planning methods used in the client project and further illustrates it with a case study of the island city. Therefore, this report comprises four chapters. The first chapter is the background and introduction of this report. The second chapter characterizes the overall guideline of decarbonization planning. We will concisely illustrate the definition and primary methodologies of the three main sections: GHG inventory, forecasting and goal setting, and making action plans in decarbonization planning. The third chapter is focused on a real-world case of an island city in northern China, in which we will demonstrate the comprehensive procedures and outputs of its decarbonization planning with detailed data. The last chapter is the conclusion and caveat.

2. Methodology of Decarbonization Planning

The overall structure of the guideline for decarbonization planning includes three general sections shown in Figure 1. For the necessary preparation, planners should finish data collection of socioeconomic data and activity data of all the sectors within the city boundary. Then, the first section is completing a GHG inventory to understand the composition of greenhouse gases from different sectors, knowing the foundation and potential for further decarbonization. The second section is forecasting future emissions based on reliable assumptions and scenarios, providing clues to making ambitious but achievable decarbonization goals. The last section is designing and compiling the decarbonization action plan by integrating considerations from current political and socioeconomic information and knowledge from GHG inventory and emissions forecast. In this chapter, we will illustrate each section in detail.

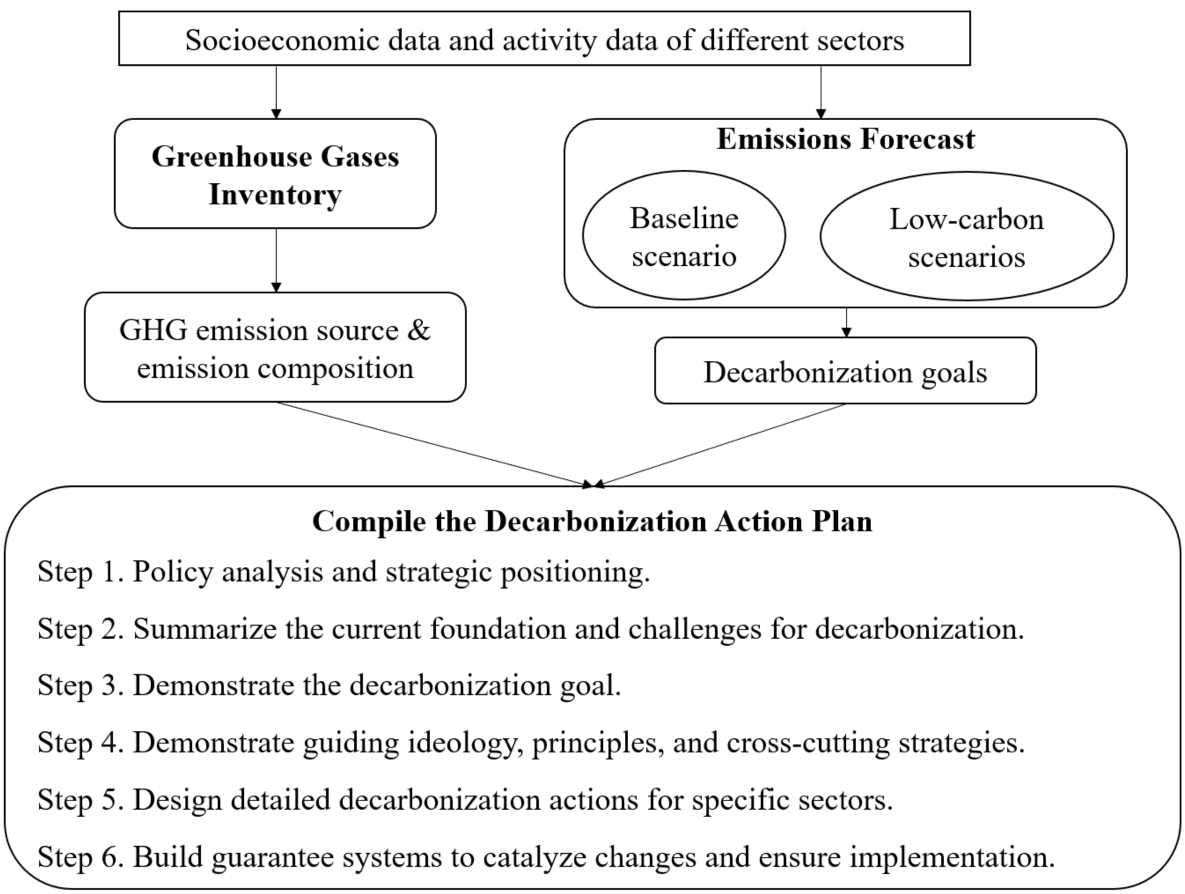


Figure 1. Overall Structure of Decarbonization Planning

2.1 GHG Emission Inventory

A GHG inventory is a detailed record of the amount of greenhouse gases emitted into the atmosphere by a specific entity, such as a country, a city, or a company. The inventory covers a wide range of greenhouse gases, including carbon dioxide, methane, nitrous oxide, and fluorinated gases. It describes emissions from different sectors, such as energy, transportation, industry, agriculture, forestry and other land uses, and waste.

Developing a complete GHG emissions inventory is the first step in developing an effective climate policy for cities (Arioli et al., 2020). This inventory allows for calculating GHG emissions emitted directly or indirectly by governments, businesses, and residents in all aspects of their social and productive activities. Inventorying GHG emissions at the city level is a complex process due to the complexity nature of material and energy flows in urban systems. However, a GHG emissions inventory is essential for understanding the sources and trends of GHG emissions. It can help develop effective strategies to mitigate and adapt to climate change.

As the first step, a city's GHG emissions inventory is particularly valuable for addressing climate change. By identifying industries that are responsible for high levels of emissions and providing factual data to support targeted climate policies (Khanna et al., 2014), a city's inventory can facilitate effective reduction strategies. Accurate and consistent reporting of GHG emissions from cities and urban areas enables policymakers and practitioners to address climate change challenges by meeting mitigation goals and is essential to overall good administration in municipalities. Transparency, validation and replication over time are possible with good reporting. Therefore, it is an essential foundation for effective climate action by cities.

2.1.1 GHG Emission Inventory Protocols

Several international protocols and guidelines have been developed to measure greenhouse gas emissions and identify the potential decarbonization opportunity of a place, including the International Standard for GHG Emissions Inventories and Verification (ISO 14064), IPCC 2006 Guidelines for National Greenhouse Gas Inventories, and The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC). While all three documents aim to provide guidance on measuring and reporting GHG emissions, their scope and focus differ.

ISO 14064 is primarily designed for use by organizations of all types and sizes, which is particularly helpful for those seeking to improve their environmental performance and demonstrate their commitment to sustainability to stakeholders, customers, and investors. Meanwhile, IPCC 2006 Guidelines focus on national-level inventories, providing a standardized methodology for estimating emissions and removals from various sectors to inform national policy development and meet reporting requirements under international climate agreements.

The Global Protocol for Community-Scale Greenhouse Gas Emission Inventories (GPC) is a standardized framework established by the World Resources Institute (WRI) specifically designed for cities and communities to calculate their greenhouse gas emissions from various sources, such as transportation, buildings, and waste management. It helps support local emissions reduction targets, policy development, and sustainability goals.

GPC applies two complementary methods for calculating emissions: the Boundary Method, which is based on activities within the community's boundaries, and the Sectoral Method, which calculates emissions based on local consumption of products and services within the community. The Boundary Method accounts for emissions from stationary energy, transportation, and waste, while the Sectoral Method accounts for emissions from production, transportation, and disposal of goods and services. Using both methods together can help cities or communities gain a more comprehensive understanding of their emissions profile, identify areas where emissions can be reduced, and develop effective emissions reduction strategies (WRI, 2014).

2.1.2 Steps of GHG Emission Inventory

In GPC (2014), GHG inventory is divided into the following three main steps. First, defining system boundary and emission sources, including the geographical area, time span and gas and emission sources covered. GHG emissions from city activities shall be classified into six main sectors: stationary energy, transportation, waste, industrial process and product use (IPPU), agriculture, forestry, and other land use (AFOLU), and any other emissions occurring outside the geographic boundary as a result of city activities (WRI, 2014, p.10). The second step is Categorizing emissions according to where they occurred into three scopes: scope 1 covers the direct emissions from sources located within the city boundary, scope 2 covers the indirect emissions occurring because of the use of grid-supplied electricity, heat, steam and cooling within the city boundary, scope 3 covers all other emissions that occur outside the city boundary as a result of activities taking place within the city boundary (WRI, 2014, p.11). Step 3 is aggregating city inventories. It requires the collection and consolidation of all the data that has been gathered in steps 1 and 2. The aggregated inventory can then be analyzed and reported to stakeholders and used to develop strategies for reducing emissions and improving sustainability in the city.

2.2 Emissions Forecast and Decarbonization Goals Design

Making an emission forecast is beneficial for understanding the direction and potential of future decarbonization. It enables planners to design more accurate and scientific decarbonization goals because the forecast should integrate the consideration of current socioeconomic data. In addition, it can simulate the trend of emissions change based on specific assumptions or scenarios, ensuring there are feasible pathways to realize the goals. Therefore, it is also helpful for making the decarbonization goals more comprehensible and acceptable for different stakeholders.

2.2.1 Methodologies of Emissions Forecast

Various methodologies have been employed to forecast carbon emissions, such as Integrated Assessment Model (Weyant, 2017), Long-range Energy Alternatives Planning System (LEAP), artificial neural network (ANN), support vector machine (SVM), autoregressive moving average (ARIMA) models, and other statistically supervised machine learning algorithms (Qader et al., 2013).

In the case part of this report, we use the methodology of LEAP to make the forecast. The Long-range Energy Alternatives Planning System (LEAP) is a software tool extensively employed for energy policy analysis and climate change mitigation assessment.

LEAP is designed around the concept of scenario analysis, which involves creating coherent narratives about the potential evolution of an energy system. LEAP empowers policy analysts to generate and evaluate alternative scenarios by comparing their energy requirements, social costs and benefits, and environmental impacts. The LEAP Scenario Manager can be used to assess individual and combined policy measures, knowing their impact and interactions. The model will generate the future emission trajectory corresponding to different scenarios of policy combination (Stockholm Environment Institute, 2005).

2.2.2 Design Decarbonization Goals

City-level decarbonization planning necessitates setting a mitigation goal and a list of intermediate goals in different sectors. Principles of goal-setting processes can follow either a top-down or a bottom-up way or consider both, as shown in Figure 2. (Mao et al., 2015).

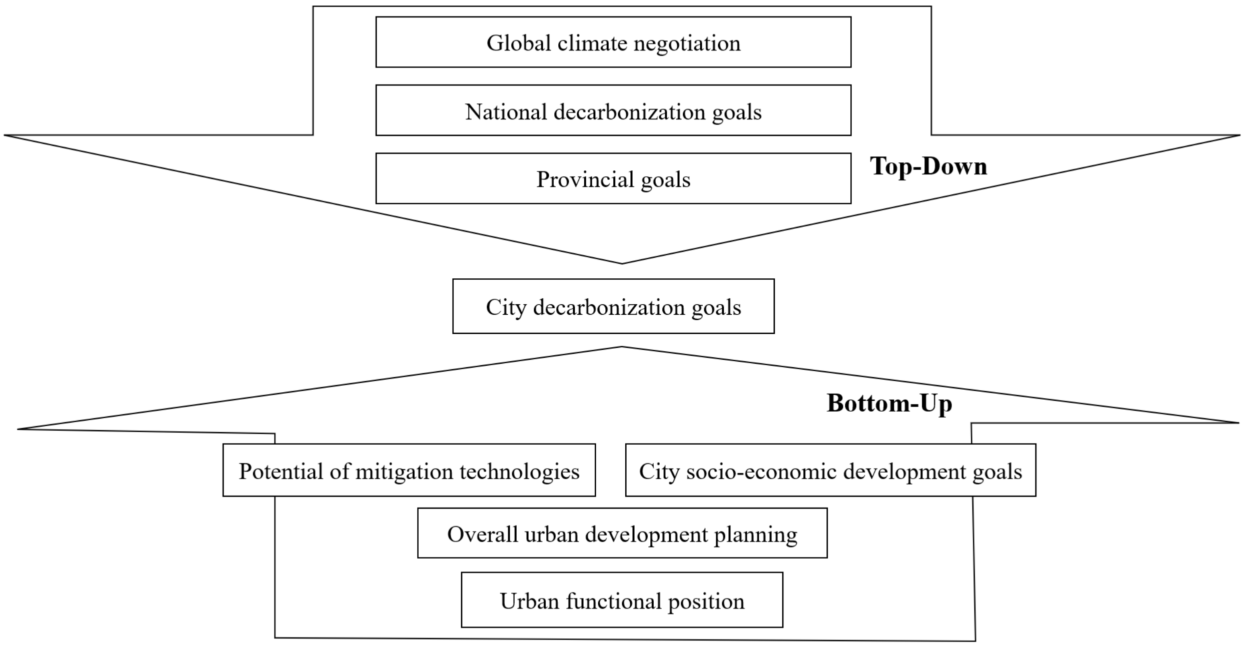


Figure 2. Principles of Goal-setting Processes

A mitigation goal is a commitment to reduce or constrain the increase of GHG emissions or emissions intensity by a specified level by a designated date. Many types of mitigation goals can be designed based on various criteria. Table 1 shows the steps of making a mitigation goal.

Table 1. Steps of Designing a Mitigation Goal

Define goal boundary	Geographic area
	Sectors
	Greenhouse gases covered by the goal
Choose goal type	Base year emissions goal
	Fixed-level goal
	Base year intensity goal
	Baseline scenario goal
Define the goal time frame	Multi-year / single year Short-term / long-term
Decide on the use of transferable emissions units	It is important to verify that any transferable emissions units applied to fulfill a target

	adhere to the highest quality standards and are generated during the target period or year.
Define goal level	The number of emission reductions within the goal boundary in the target year or period that the jurisdiction commits to achieving.

(World Resources Institute, 2015)

Intermediate goals are about delineating the milestones and ambitions in specific sectors within a designated period to realize the final mitigation goal. The intermediate goals for specific sectors may include reducing energy consumption in buildings, promoting low-carbon transportation, increasing the consumption ratio of renewable energy, improving industrial energy efficiency, and enhancing waste management (Mao et al., 2015). Setting intermediate goals can be very case by case in different cities. Intermediate goals contribute to mapping specific initiatives in designing action plans, which identify feasible and precise pathways to achieve the final mitigation goal.

2.3 Compile and Design the Decarbonization Action Plan

With the completion of GHG inventory and emissions forecast in potential policy scenarios, planners can move into designing decarbonization goals and detailed action plans. We suggest going through the following steps to compile the action plan.

Step one is a current policy analysis and strategic positioning. Introduce the current domestic and international situation of decarbonization development and clarify the positioning and role of decarbonization in the city's development strategy. It is recommended to mention relevant national and provincial policies to analyze the opportunities the city faces and how to connect the city's plan with plans and requirements of upper-level administrative divisions.

Step two is to summarize the current foundation and challenges for decarbonization. Based on information on the city's social, economic, and industrial foundation, population, urbanization, spatial layout, land, and ecological environment, as well as the GHG inventory result, the planner can summarize historical decarbonization achievements and outline the foundation for future decarbonization. In addition, planners are supposed to identify the existing challenges, including deficiencies and potential constraints that the city may face in pushing for future decarbonization, highlighting the key issues that the city should solve.

Demonstrating the decarbonization goals is step 3. As mentioned in the section about goal setting and emission forecast, the goals are divided into a mitigation goal and a series of intermediate goals for each sector.

Step four is demonstrating guiding ideology, principles, and cross-cutting strategies. The guiding ideology and fundamental principles are ordinary and necessary elements in Chinese planning documents. The guiding ideology emphasizes the overall implementation direction and reflects the work priorities. The basic principles emphasize bottom-line issues that should be considered for practical work. Cross-cutting strategies tease out crucial decarbonization strategies which need combined efforts from many sectors.

Existing decarbonization planning literature (Mao et al., 2015; Rica, 2019; Barker, 2022) reveals that the plan should highlight two layers of design regarding detailed actions and implementation. The first layer is specific initiatives for different sectors, and the second layer is deploying capacity-building guarantees to ensure implementation. They correspond to step five and step six.

Step five is to design specific and practical decarbonization initiatives and actions for local sectors. Planners should make a precise and nonoverlapping categorization for identifying decarbonization initiatives for these sectors. It is recommended that the sectors categorization in initiative designs align with the sectors in the GHG inventory. United Nations Framework Convention on Climate Change reporting guidelines on annual inventories require parties to provide annual GHG inventory from five sectors: energy, industrial processes and product use, agriculture, land use, land-use change, and forestry and waste (2021). Based on this, we suggest a sector list for city-level initiatives design, as shown in Table 2.

Table 2. Sectors List for City-Level Decarbonization Initiatives

<table>
<tr><td rowspan="2">Energy supply</td><td>Electricity generation</td></tr>
<tr><td>Heat supply</td></tr>
<tr><td rowspan="4">Energy consumption</td><td>Commercial and service sector</td></tr>
<tr><td>Industrial sector</td></tr>
<tr><td>Residential sector</td></tr>
<tr><td>Building and infrastructure construction</td></tr>
<tr><td colspan="2">Transportation</td></tr>
<tr><td colspan="2">Agriculture</td></tr>
<tr><td colspan="2">Waste</td></tr>
<tr><td colspan="2">Land use and carbon offset</td></tr>
</table>

Step six is to construct stable guarantee systems to ensure the implementation of the initiatives designed for particular sectors, catalyze changes, and achieve the expected results. Planners should consider the following aspects to strengthen the city's capacity building in implementing decarbonization actions. Such as policy, legal, regulatory, organizational, and management institution guarantees, low-carbon development financing mechanisms and funding guarantees, technology guarantees, talent guarantees, enhancing public awareness, just transition, and strengthening domestic and international communication and cooperation.

3. Case Study

3.1 Background Information

The case study area is an island city located at the junction of the Yellow and Bohai Seas in northern China. It is strategically located in the Bohai Sea Economic Zone's connecting belt, with significant location, ecology, and resource advantages. The region has an ideal natural environment, abundant tourism, fishery, biodiversity, wind energy, and shipping resources, which all contribute to the region's substantial potential for developing a blue economy. Additionally, the local government is highly committed to ecological protection and sustainable development in response to the national dual carbon goals and guiding policies. Efforts are being made to establish a green, low-carbon, and circular economic system and build a "net-zero carbon emissions pilot zone" in the future, making it a national leader in carbon neutrality.

3.2 GHG Emission Inventory

The specific accounting is based on the emission factor approach according to The Provincial Guidelines for GHG Inventory (Trial) (2011 Edition) compiled by the National Development and Reform Commission of China. Its accuracy depends on the accounting system chosen and the precision of emission factors estimated for specific regions and source categories (Shan et al., 2017).

3.2.1 System Boundary and Dataset

The accounting is based on the administrative boundary of the study area, and the time boundary is from 2016 to 2021, which covers the 13th Five-Year period. It provides a better picture of greenhouse gas emissions and changes in the study area. The inventory covers the six GHGs specified in the Kyoto Protocol: carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF6). However, due to the limitation of GHG emission activities, this accounting only included carbon dioxide (CO2), methane (CH4), and nitrous oxide (N2O). The accounting data set of the case study area includes secondary data from urban statistics files, data directly obtained from local government officials, and published reports and literature.

3.2.2 Scopes and Emission Sources

Based on the international standards for urban greenhouse gas accounting published by organizations such as the World Resources Institute (WRI), the greenhouse gas emissions of the case study area are divided into scope 1 (direct emissions) and scope 2 (indirect emissions). Direct emissions refer to greenhouse gases generated within the region, such as emissions from coal-fired boilers, biomass combustion furnaces and gas stoves used by residents, vehicles driving on the island, and ships sailing between islands and on land. Indirect emissions refer to the greenhouse gas emissions generated by consuming externally purchased electricity in the region. As there is no external demand for thermal or steam energy in the area, only electricity consumption from the entire society is considered in this report.

From the perspective of emission sources, the emissions in the region are identified as four major sectors: stationary energy, transportation, agriculture, and waste. Stationary energy is one of the largest sources of urban greenhouse gas emissions. The main consumption sectors include the thermal supply sector, the industrial and commercial sectors, and the residential sector. The energy production sector refers to the thermal production activities of the three industries: centralized heating, winter heating for residents, and hot water supply for public baths. The transportation sector includes road and waterway transportation, with road transportation referring to greenhouse gas emissions from registered vehicles on the island, while water transportation covers emissions from vessels for passengers and freight. The agricultural sector comprises fishery, livestock, and crop farming, with emissions from fishery vessels, energy consumption in production processes, and non-carbon dioxide greenhouse gases from livestock and crop farming. The waste sector only includes emissions from domestic wastewater treatment, while solid waste disposal is outsourced and not included in the analysis. The relationship between Emission sources and scopes will be illustrated in Table 3.

Table 3. Scopes and Emission Sources of GHG Emission Inventory

Emission Sources		Scope 1	Scope 2
Stationary energy	Heating supply	√	√
	Industrial and commercial sector		√
	Residential sector	√	√

Transportation	Water transportation	√	
	Land transportation	√	
Agriculture	Fishery	√	√
	Animal husbandry	√	√
	Crop farming	√	√
Waste	Domestic wastewater	√	

3.2.3 Main Findings of GHG Inventory

In 2018, an integrated experimental zone for marine ecological civilization was established in the region, and the transformation of the energy structure with bought-in electricity as the main alternative to coal dependence for energy production and heating was initiated. This change led to a significant reduction in greenhouse gas emissions. From 2016 to 2021, the greenhouse gas emissions in the study area decreased by approximately 56%.

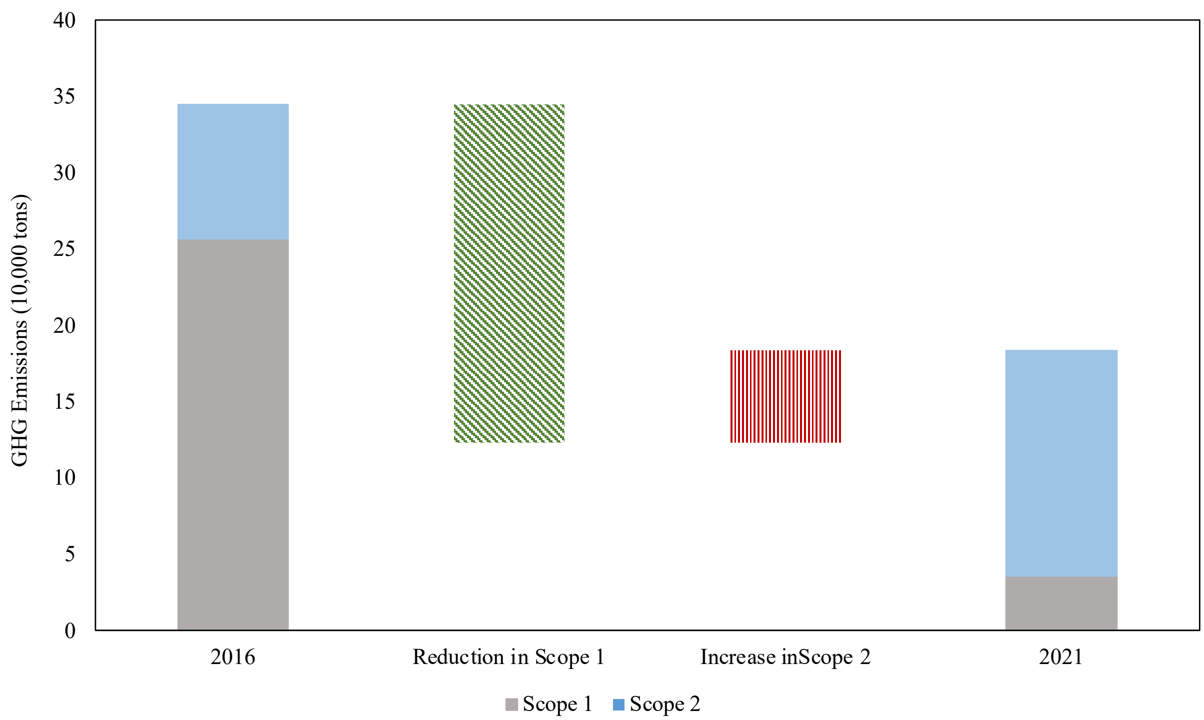


Figure 3. GHG Emission Inventory of the Different Scopes

As shown in Figure 3 above, emissions in Scope 1 have significantly decreased over the past six years, by approximately 86%, mainly due to centralized heating and electricity substitution projects, which reduced coal consumption for heating and lowered the direct greenhouse gas emissions from the heating sector to 16.03% of the original level. However, since 2018, emissions in Scope 2 have rapidly increased by approximately 68%, accounting for 75% of the total emissions in 2021, which is 19% in 2016, mainly due to increased electricity consumption.

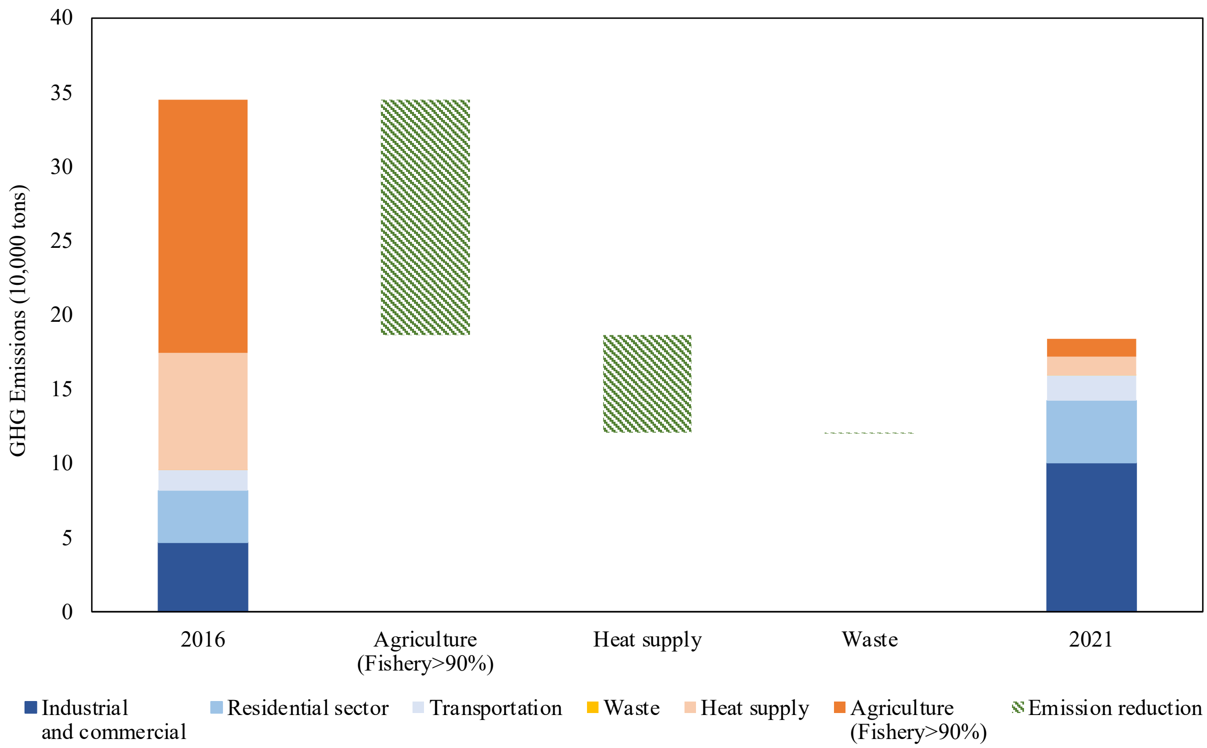


Figure 4. GHG Inventory of Different Emission Sources and the Changes Over Time

Figure 4 presents the emission changes in the study area from the perspective of different energy consumption sectors in recent years. Over the past six years, the greenhouse gas emissions in the study area mainly came from the fishery and industrial and commercial sectors, accounting for 37.42% and 23.65%, respectively. However, as the coal reduction measures progress, such as the gradual elimination of coal-fired boilers in fishery breeding grounds, emissions from the fishery sector have rapidly decreased from 52.36% in 2016 to 6.76% in 2021.

In addition, the promotion of electrification in various industries has gradually replaced fossil fuels with electricity in the energy supply system, reducing emissions from the heating sector from 24.56% in 2016 to 8.39% in 2021. The foreign-purchased electricity in the region is mainly used by large industries and general industrial and commercial sectors, which account for 50.96% of the total electricity consumption. This has also increased emissions from the industrial and commercial sectors from 10.55% in 2016 to 50.96% in 2021, making them the region's main greenhouse gas emission source and primary electricity consumption sector. Emissions from the residential sector ranked second, increasing from 8.04% in 2016 to 21.51% in 2021.

In summary, energy conservation and emissions reduction in the electricity sector have become the key to achieving carbon peaking and neutrality in this city. There are still a lot of potential opportunities in promoting the low-carbon transformation of the electricity sector, tapping into the potential of clean ocean energy, and forming a low-carbon energy structure dominated by clean energy to achieve a zero-carbon economic model as soon as possible.

3.3 Emission Forecast and Goal setting

The LEAP software is used to forecast long-term carbon dioxide emissions based on local industrial characteristics and economic structure. The configuration of the model is divided into two modules: terminal energy consumption and energy transformation, as the framework shown in Figure 5.

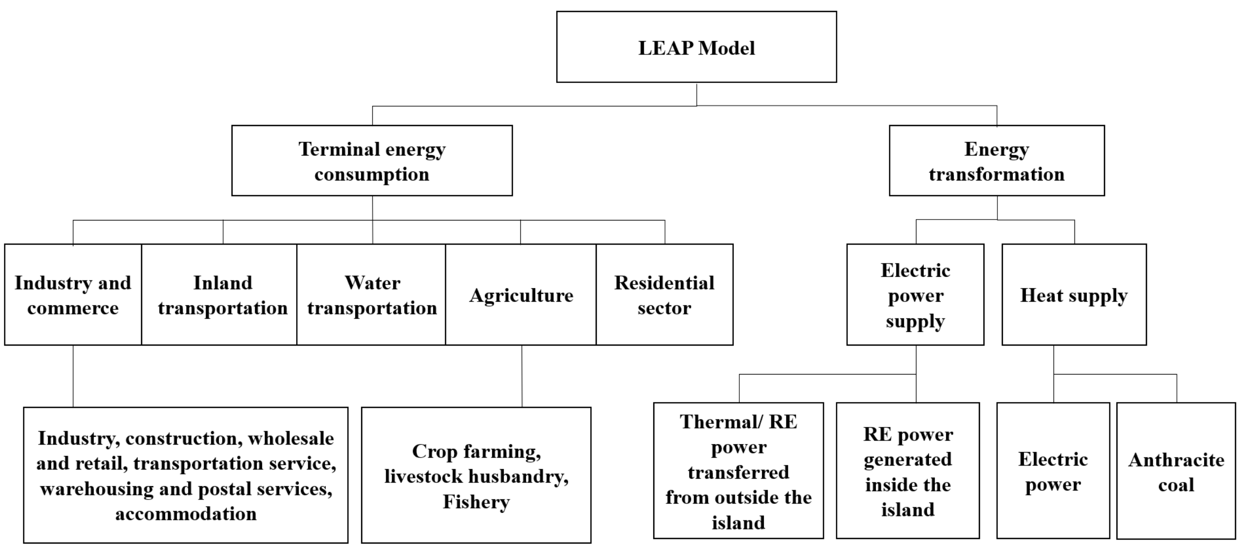


Figure 5. Configuration of LEAP Model

3.3.1 Data and Scenario Assumption

The designated base year is 2020. Input data covers the Energy Balance Table (Energy Balance Tables, 2022) and the activity level data of different sectors of 2020, such as population, agricultural output, the added value of industry and commerce, and car ownership amount, based on which energy intensities of various departments can be estimated. The forecast period is from 2021 to 2060, with a calculation frequency of one year.

There are two broad categories of scenarios for emission prediction in the LEAP model, named baseline scenario and low-carbon scenario. The setting of the Baseline scenario takes the secular decarbonization trend with social development into account and attempts to reasonably assume future energy consumption's structure and efficiency without additional low-carbon intervention. Low-carbon scenarios are classified into three subcategories: energy efficiency improvement, electrification, and renewable energy. A series of decarbonization measures, which are more ambitious than the baseline, are expected to be taken in these scenarios.

Energy efficiency improvement embodies energy saving with higher productivity for each unit of energy consumption. Electrification means substituting fossil fuel with electric power in terminal sectors. Renewable energy refers to a transformation in power generation using renewable energy instead of fossil fuel. By progressively combining different low-carbon subcategories, eight kinds of final scenarios are generated (Table 4). Appendix A summarizes the parameter settings of all scenarios over time from 2020 to 2060.

Table 4. Scenarios for Forecast in LEAP Model

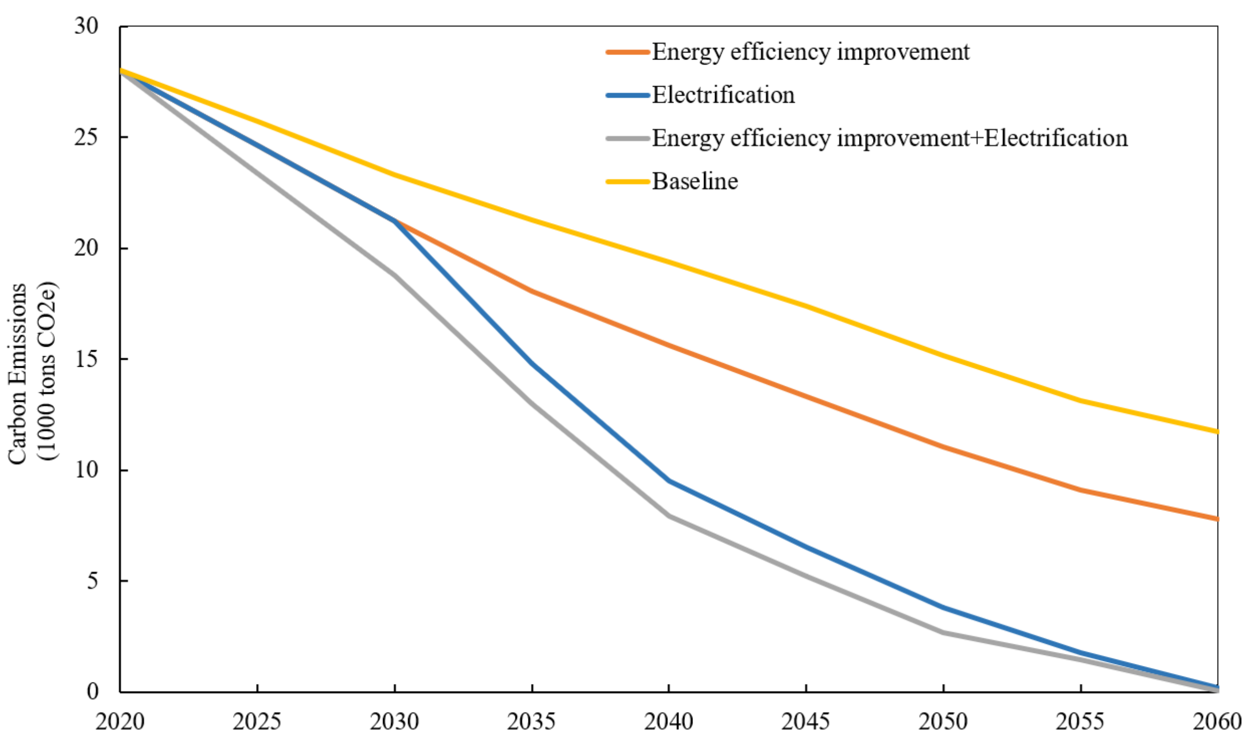
Scenario	1	2	3	4	5	6	7	8
Baseline	√							
Energy efficiency improvement		√			√	√		√
Electrification			√		√		√	√
Renewable energy				√		√	√	√

3.3.2 Forecast Result

We will only discuss the results from the scope level in this section, including scope 1 and scope 2. Nevertheless, each scope is also internally composed with detailed results for more fine-sorted sectors[1].

Scope 1

Scope 1 is direct emissions from terminal energy consumption within the inventory boundary. Renewable energy and its combination scenarios are not analyzed for scope 1 because renewable energy does not impact direct emissions. Figure 6 shows the emissions forecast result for scope 1. In 2020, the scope 1 emission was around 28 kilotons. In all four scenarios, the city emissions show a downward trend. In 2060, the emission of the baseline scenario is 40% of the 2020 level, and the emission of the energy efficiency improvement scenario is 27% of the 2020 level. In the electrification scenario, zero emissions will be achieved in scope 1 by 2060. The combined scenario of energy efficiency improvement and electrification enables significantly lower cumulative emissions in 40 years.



[1]There are four sectors in scope 1, including land transportation, waterway transportation, fishery, and residential sector. For scope 2, the electric power demand of 6 sectors is calculated. These sectors include industry and commerce, transportation, fishery, crop farming, livestock husbandry, and the residential sector

Figure 6. Terminal Energy Consumption Forecast in Different Scenarios

Scope 2

Figure 7 shows the long-term changes in electric power demand in different scenarios. Under the single scenario of electrification, accelerating electrification without improving energy efficiency, the demand growth for electric power is the fastest, with an increase of nearly 2 times from 2020 to 2060. In contrast, the energy efficiency improvement scenario embodies the smallest electric power demand growth, which will be reduced to around 85% of the 2020 level. Demand growth in the scenarios combination of electrification and energy efficiency improvement is moderate.

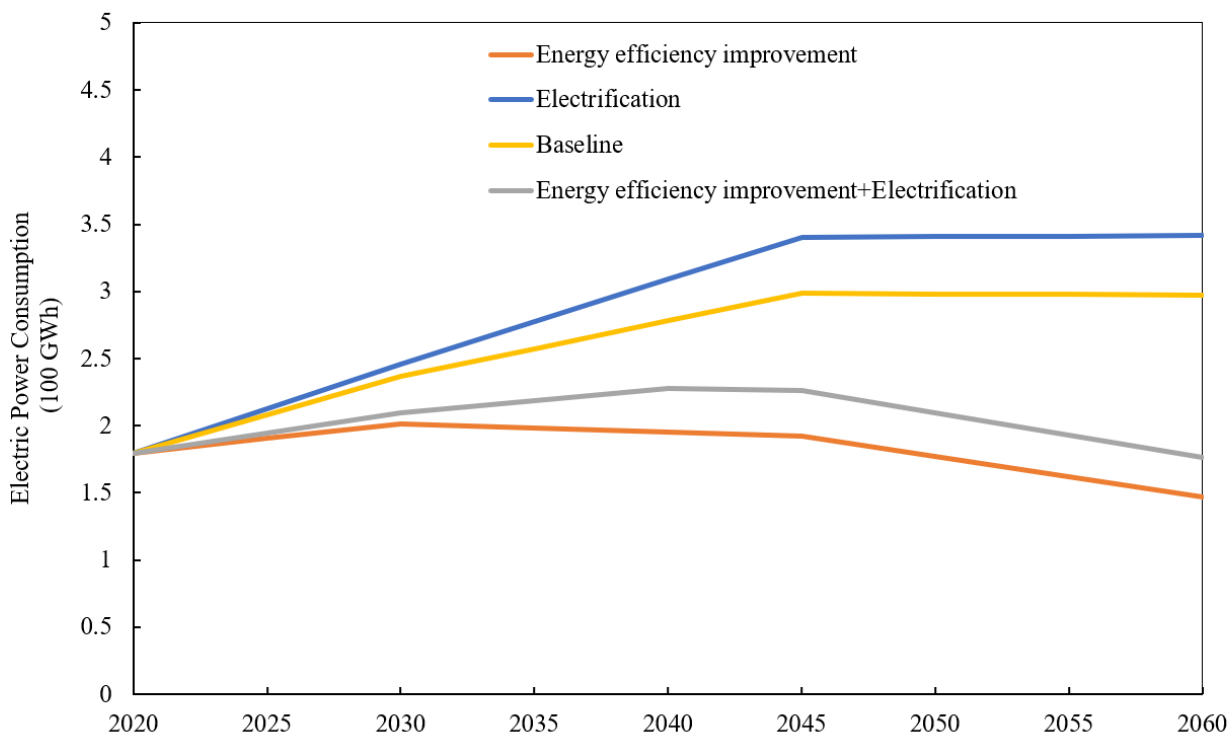


Figure 7. Electric Power Consumption Forecast in Different Scenarios

Figure 8 shows the long-term trend of carbon emissions from electric power consumed by the city (scope 2). Nearly all the electric power consumed in the city is transferred from outside the island. The baseline scenario shows that if only passively relying on the long-term downward adjustment of the emission factor of the external power grid, the Scope 2 emissions will experience a process of increasing, peaking, and slowly decreasing. Therefore, merely accelerating electrification without efficiency improvement will lead to even higher emissions than the baseline scenario in scope 2. After integrating energy efficiency improvement, the carbon emissions in scope 2 reveal a pure decline tendency and reach near-zero emissions by 2060. Furthermore, under the scenario combining renewable energy, the scope 2 carbon emissions will show a rapid downward trend and reach net zero emission in 2035.

It is evident that the island city will keep producing a large number of carbon emissions in terms of electric power consumption if it will not actively reduce the emission factor of its power supply activities. Therefore, the combined effort in electrification and increasing the proportion of green electricity is crucial and urgent.

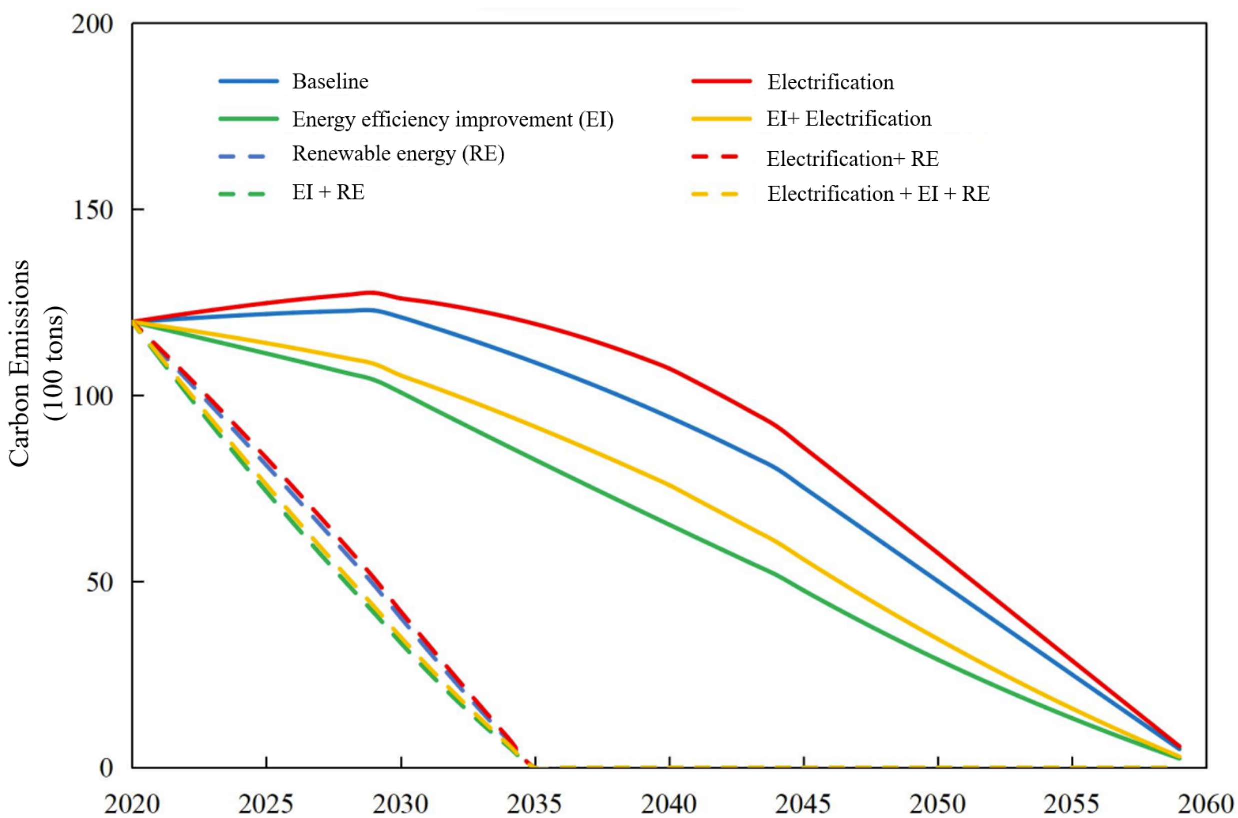


Figure 8. Carbon Emissions Forecast in the Power Generation Sector in Different Scenarios

3.3.3 Overall Forecast

Figure 9 shows the overall carbon emissions of the island city from 2020 to 2060 under the most stringent combined scenario of energy efficiency improvement, electrification, and renewable energy, in which the solid bar indicates the carbon emissions generated locally within the island boundary (scope 1), the blue hollow part indicates the carbon emissions in scope 2 (mainly from power production outside the boundary), and the concave part below the abscissa indicates the offset volume of carbon sinks, which are divided into carbon credits (high standard carbon offsets) and other carbon sinks.

Thanks to a series of ambitious actions, the city will experience a rapid decarbonization process before 2035. If all carbon sinks are calculated, this region would realize carbon neutrality around 2031. However, if we only calculate high-standard carbon sinks (carbon credits) of around 5 kilotons CO2e, the result will reach net zero emission around 2045. However, carbon emissions would have been reduced to less than 10,000 tons in 2035, reaching a near-zero emission state. Therefore, it is feasible to set a mitigation goal of building a zero-carbon island in 2035.

The forecast highlights the key points for future decarbonization efforts. First, it is taking the initiative to increase the proportion of green electricity in power consumption. Secondly, after 2030, the scope 1 emission will occupy the major proportion of the gross emission volume. It is recommended to accelerate the electrification and low-carbon technology deployment in these direct emission sources such as stoves, gasoline cars, and vessels for transportation and fishery.

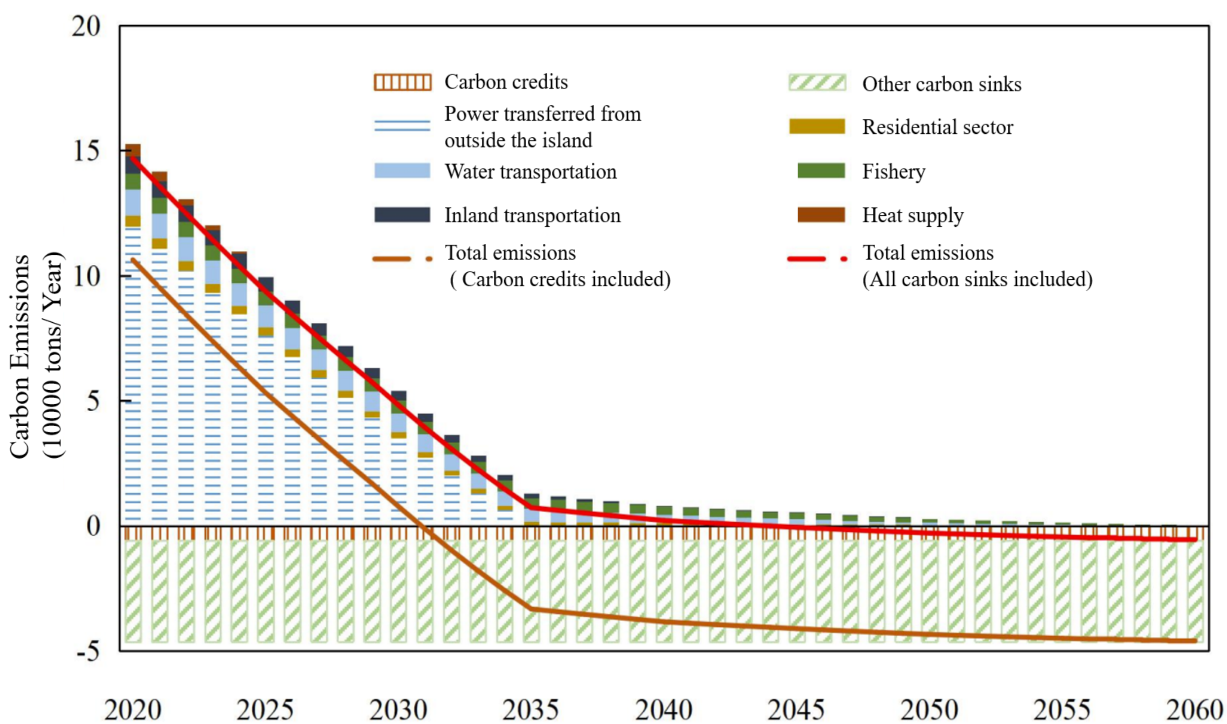


Figure 9. Carbon Emissions Forecast in the Most Stringent Low-carbon Scenario

3.3.4 Decarbonization Goals

Based on the emissions forecast, it is more tangible to set scientific and practical decarbonization goals, which might be composed of an overall mitigation goal and a series of aligned intermediate goals. We design a Multi-year Decarbonization goal for this island city. For a more detailed characterization, please refer to Table 5.

By 2025, build a first-class marine low-carbon island. Realize the decoupling of industrial and commercial economic growth and carbon emissions, and fully electrify heat supply.

By 2030, build an exemplary international electrification island free of coal. Eliminate the use of fossil energy from all stationary sources.100% realize the replacement of electric vehicles for official vehicles on the island.

By 2035, build a high-standard international carbon-neutral island with outstanding socio-economic performance. Realize a 100% green electric power supply by connecting wind power projects outside the island, ocean energy, and geothermal energy within the island region. Achieve substantial breakthroughs in zero-carbon transportation.

Table 5. Decarbonization Goals for the Island City

Year	Mitigation goal	Intermediate goal	
		Power supply	Other main sectors
2025	First-class marine low-carbon island (< 120 kiloton CO_2e)	30% of electric power consumption is green electricity	Stop coal consumption and 100% electrification in the heat supply
			Electric vehicle Stockpile reaches 25%
			Electrify 30% of fishery vessel
2030	Electrification exemplary island (< 60 kiloton CO_2e)	60% of electric power consumption is green electricity	100% get rid of fossil fuel in stationary source
			Electric vehicle Stockpile reaches 50% (100% of official cars should be EVs)
			Electrify 40% of fishery vessel
2035	Carbon neutral island (< 5 kiloton CO_2e)	100% of electric power consumption is green electricity	Zero emission in the land transportation system
			Electrify 50% of fishery vessel
			Carbon emissions from water transportation will decrease by 50% compared to 2020

3.4 Design and Compile a Decarbonization Action Plan for the Island City

3.4.1 Policy Analysis and Strategic Positioning

To achieve the targets of carbon peaking by 2030 and carbon neutrality by 2060, the Chinese government has implemented a series of measures and policies. These policies have been constructed under a "1+N" system for carbon emissions peaking and neutrality. To further advance these efforts, the Chinese government issued the "Opinions on Comprehensively Implementing the New Development Concept to Do a Good Job of Carbon Peaking and Carbon Neutrality" in October 2021. This document sets out five working principles and five main objectives to guide the country's efforts toward carbon peaking and carbon neutrality. Moreover, the State Council officially released the Action Plan for Carbon Peaking by 2030 on October 26, 2021.

In response to the national policy, provincial governments have also taken steps to improve the quality of the ecological environment and accelerate the promotion of green and low-carbon development. For instance, the province's 14th Five-Year Plan for Ecological and Environmental Protection defines the guiding ideology of reducing pollution and carbon emissions as the overall focus. The plan outlines the four aspects of accelerating the carbon peaking process and controlling greenhouse gas emissions, including carrying out carbon peaking actions, strengthening greenhouse gas emission control, actively adapting to climate change, and strengthening climate change response management.

To implement these policies, administrative cities in the case study areas have released their local "14th Five-Year Plan for Ecological and Environmental Protection". This plan proposes specific control targets and measures for CO2 emissions in industry, transportation, and construction. The plan also covers greenhouse gas emission control, climate change adaptation, green building, low-carbon city construction, integrated greening and wetland protection, and basic research on ocean carbon sinks. The aim is to make significant progress in environmental protection and carbon emission reduction.

3.4.2 Foundation and Challenges for Future Decarbonization

Considering the emission foundation in 2021, there are four challenges necessitating concerns. Firstly, in 2021, the proportion of electric power emissions (scope 2) in the overall emissions on the island is about 75%. However, the current electricity relies on external inputs, which entails a passive position regarding Scope 2 emissions reduction. Waiting for the emission factor of purchased electricity to decrease may make it difficult to achieve the city's carbon-neutral goal by 2035. Secondly, the island is a key ecological conservation area and must consider constraints from conserving ecology when it deploys its decarbonization strategy. For example, the construction of wind farms and photovoltaic power plants may affect the regular migration, habitat, and reproduction of birds and other animals and plants through radiation and light pollution, disrupting the local ecological balance. Thirdly, approximately 8% of overall emission comes from the fuel combustion of vessels in the water transportation and fishery sectors. These vessels are hard to substitute due to technology and financial limitations. Finally, there are few carbon sinks that can meet the standard of a high-quality carbon offset credit. Although rich in marine resources, it lacks internationally recognized marine carbon sink systems such as mangroves and salt marshes. Developing or purchasing high-quality carbon credits to offset the inevitable remaining carbon emissions is a key issue that needs to be addressed to achieve carbon neutrality.

3.4.3 Decarbonization Goal

A Multi-year Decarbonization goal is applied to this island city with an expectation to achieve carbon neutrality by 2035. Details about the goal can be referred to the part 3.3.4.

3.4.4 Guiding Ideology, Principles, and Cross-cutting Strategies

The overarching guiding ideology is to create a comprehensive framework for green and low-carbon development, reshape a high-quality socio-economic development system, and achieve a win-win situation for the environment, the economy, and society.

The government should insist on the principle of constructing ecological civilization in the process of building a comprehensive framework for green and low-carbon development. Under regional characteristics, it is essential to promote marine ecological civilization and strengthen the construction of ecological systems, clarify the responsibilities of various subjects, improve the emergency response system for ecological protection, and strengthen marine ecological security. At the same time, it is necessary to enhance regional ecological environment protection, improve the ecological environment quality, and increase the capacity for efficient use of natural resources.

In addition, the government should insist on the principle of sustaining social welfare. Attention should also be paid to ensuring energy security and improving people's livelihoods by integrating social development with the decarbonization action and accelerating the development of education, medical care, social security, public safety, and other fields to enhance the living standards of the people effectively.

Therefore, we suggest a cross-cutting strategy of building a high-quality blue economy to achieve a win-win situation for the environment, economy, and society. The blue economy should integrate abundant local marine natural resources into a more sustainable economic structure. Should actively promote the ecological development of fisheries, accelerate the construction of modernized and intelligent low-carbon marine pastures and cultivate an internationally influential brand of aquatic products. Make an effort to develop a low-carbon tourism island, combining regional characteristics and local culture to promote an innovative and sustainable ecological tourism industry.

3.4.5 Decarbonization Actions for Specific Sectors

Energy Supply

Accelerating electrification and promoting decarbonization of the electricity supply is crucial for developing a sustainable energy system. Electrification is vital to achieving energy transition, particularly in the heating and residential sectors. Therefore, it is necessary to gradually reduce the consumption of fossil fuels, accelerate the transition to full electric heating, and promote the use of supplementary heating methods such as solar collectors, air-source heat pumps, and seawater-source heat pumps. In addition, it is also essential to increase the electrification rate of energy use in water and land transportation.

Furthermore, accelerating the decarbonization of the electricity supply is also crucial. Local governments can seize three opportunities to increase the proportion of green electricity consumption while meeting the requirements of ecological protection. Specifically, To avoid building large-scale wind and solar projects in the ecological and environmental conservation area, the city government can invest in renewable energy projects and sign long-term green electricity purchase contracts outside the city's boundary, which follows the idea of a cross-regional RE development model named "Feidi Model" in China (Lai et al., 2021). Additionally, exploring opportunities for local eco-friendly renewable energy, such as small-scale distributed rooftop solar, wave energy, tidal energy and. Moreover, explore technological innovations such as " the marine ranch" net cage platform, offshore microgrid, smart grids, and energy storage to ensure the reliability of the power system.

Industrial and Commercial Sector

Reducing carbon emissions in the industrial and commercial sectors requires a multi-faceted approach. Increasing energy efficiency, using renewable energy, and promoting sustainable business practices and consumption patterns are fundamental measures to reduce carbon emissions. These measures alleviate the adverse effects of climate change and bring economic benefits to businesses.

The first measure is to improve energy efficiency. Various ways can be adopted to improve energy efficiency, such as designing energy-efficient buildings, using energy-efficient equipment, improving process design, and implementing energy management systems. For example, installing LED lighting systems and constructing green roofs can significantly reduce energy consumption and costs while reducing carbon emissions. Additionally, energy-saving and emission-reducing can be achieved by improving industrial production processes, such as implementing green production methods and adopting circular economy approaches, which can reduce the environmental impact of industrial production.

Adopting sustainable business practices and promoting sustainable consumption patterns can help reduce carbon emissions in the industrial and commercial sectors. Businesses can adopt sustainable business practices, such as using recycled materials, reducing waste, and adopting sustainable transportation. By promoting sustainable consumption patterns, companies can encourage consumers to choose products and services with a lower carbon footprint.

Land and Water Transportation

To reduce carbon emissions from the transportation sector, short-term measures can focus on promoting fuel efficiency and emissions control of vehicles. However, the long-term goal is to shift away from fossil fuels towards renewable resources, mainly through adopting electric vehicles, electric boats, and renewable energy. While electrification has become an essential strategy for decarbonizing the transportation sector, it requires significant technology and infrastructure investment, as well as collaboration among stakeholders.

A critical step is strengthening the policy framework for the local development of new energy vehicles. Market-oriented methods can be used to implement appropriate policy measures, such as developing promotion plans for fuel vehicles and related incentive policies. For example, replacing urban sanitation vehicles, logistics vehicles, and official cars with new energy vehicles, and encouraging residents to purchase such vehicles through subsidies and other economic means, can increase the overall proportion of new energy vehicles.

In addition, infrastructure construction must be strengthened to support this transformation. Sufficient electric vehicle charging stations should be installed in residential areas, public parking lots, shopping centers, industrial parks, and other locations to solve the problem of "difficult charging" and improve the convenience of using new energy vehicles.

Similarly, upgrading the power grid and building shore power supply systems for water transportation can meet port ships' demand for shore power. This involves transforming docks to replace diesel generators with shore power, directly supplying power to various types of ships berthed at ports and ending the history of continuous fuel consumption by ships.

Furthermore, developing intelligent low-carbon transportation management systems is crucial. Encouraging the development of autonomous driving, smart shipping technologies, and innovative transportation modes can help reduce carbon emissions in the transportation sector. This will help to improve the transportation industry’s operating effectiveness as well as contribute to achieving the dual carbon goals of promoting economic growth while reducing emissions.

In addition to the proposed measures, addressing behavioral change issues in the transportation industry is also critical. Encouraging the public to use public transportation, carpooling, cycling, or walking instead of driving alone can significantly reduce carbon emissions. Education and promotional activities can also promote eco-friendly transportation choices and practices.

Residential Sector

Improving the energy efficiency of residential buildings, especially thermal efficiency, can provide significant development opportunities for reducing carbon emissions in this sector.

Energy-saving retrofits can be implemented in old communities to improve heating facilities, such as strengthening insulation, replacing energy-efficient doors and windows, and upgrading heating equipment. Clean energy can improve heating efficiency, reduce winter heating pressure, and decrease energy consumption for decrease carbon emissions.

In addition, encouraging the use of low-energy products and efficient appliances, with a focus on low-energy household appliances, can be promoted through subsidies for low-energy equipment such as air conditioners, stoves, and water heaters. Promoting electric kitchens, using clean and efficient electricity, can also facilitate energy-saving and low-carbon development. In old communities, energy and water conservation measures and upgrades can be widely promoted, such as installing water-saving devices, low-flow toilets, and improved water resource utilization efficiency.

Mandatory energy efficiency and green building standards should be strictly enforced for new buildings in urban areas. Green building materials and the latest construction methods, such as prefabricated steel structures, should be promoted. Comprehensive and passive designs, as well as low-energy and nearly zero-energy buildings, should be widely promoted.

Agriculture

As the main driver of agricultural carbon emissions, the fishery sector is critical in carbon reduction efforts alongside the local agricultural industry. It has excellent conditions and space for carbon reduction.

Firstly, the electrification of fishery vessels could be encouraged to replace fossil fuels, thereby reducing the carbon emissions from fishery vessels. Instead of ship generators, solar and wind power generation systems can significantly improve energy efficiency and reduce carbon emissions. In addition, improving fuel management and promoting energy conservation, optimizing navigation routes, and reducing unnecessary rapid acceleration, among other supporting measures, will improve carbon reduction efficiency. Secondly, low-carbon and green technologies can be promoted in fishery production and processing to reduce carbon emissions. Adopting more efficient processing equipment and processes, reducing energy consumption, using energy-saving lamps and insulation materials, and other measures can save energy. Furthermore, the fishery industry can promote more environmentally friendly production methods, such as selecting fishery gear and nets to reduce damage to the marine environment. Waste disposal should also be a priority, reducing waste's environmental impact by using appropriate waste treatment methods to reduce carbon emissions.

In addition, the following measures can be taken to reduce non-carbon greenhouse gas emissions in agriculture. Firstly, scientific and reasonable agricultural management measures should be taken during the agricultural production process in the fishery industry, such as controlling the amount of straw returned to the field and reducing nitrogen fertilizer use to reduce non-carbon greenhouse gas emissions from agricultural activities. Secondly, low-carbon and environmentally friendly production methods should be promoted in the livestock and planting industries, such as using organic fertilizers instead of chemical fertilizers and adopting advanced breeding and planting technologies to reduce livestock excrement and crop greenhouse gas emissions. In addition, low-carbon and environmentally friendly production technologies can reduce energy consumption, such as using clean energy to replace fossil fuels, optimizing production processes, and reducing carbon emissions during industrial production processes. These measures can reduce non-carbon greenhouse gas emissions and carbon emissions from agricultural energy consumption and develop low-carbon agriculture in the fishery industry.

Carbon Sink

With a 60% coverage rate, the case study area has an excellent natural environment with a unique marine ecosystem and abundant forest resources. Furthermore, the area is abundant in fishery, biodiversity, wind energy, and shipping resources and has a high potential for blue economy development. The region's environment and industrial base provide favorable conditions for developing ecological carbon sinks and carbon credits, which will be an essential supplementary means of achieving carbon neutrality and a key market mechanism for realizing the value of ecological products.

Developing ecological carbon sinks must promote afforestation and protect and restore vital ecosystems. Meanwhile, the carbon trading mechanism should be investigated to improve forestry's carbon sink capacity and ecological benefits. Furthermore, actions such as increasing soil organic carbon storage, developing carbon sink agriculture, and investigating the potential of ocean carbon sinks can improve the quality of arable land. Furthermore, the carbon storage and sequestration capacity of coastal wetlands, marine rangelands, and algae and shellfish aquaculture will be enhanced, and novel solutions such as microbially driven integrated carbon sequestration projects will be investigated.

Public Carbon Reduction Efforts

Apart from the efforts of government departments, social organizations, and enterprises, achieving the goals of carbon reduction, carbon caps, and carbon neutrality also requires the participation of the public. Promoting a green lifestyle as an active and conscious choice for the public is a long-term process. Governments, businesses, and the public need to take various measures to encourage people to actively participate in constructing a green and low-carbon living environment, thereby achieving the goals of environmental protection and sustainable development.

The promotion of green products is an essential direction by expanding the market for green and low-carbon products, increasing the promotion of green products, and guiding consumers to choose green products first and, in addition, limiting the production, sales, and use of disposable products, promoting degradable plastic bags or reusable cloth and paper bags, guiding consumers to actively purchase energy-saving and environmentally friendly household appliances, and organic, green, and pollution-free agricultural products.

In addition to promoting green products, it is also important to encourage residents to adopt environmentally friendly lifestyles, such as energy and water conservation. At the same time, guide residents to actively participate in waste classification and integrate waste classification into various aspects of work and life. Furthermore, advocate green travel and reduce transportation carbon emissions. Encourage citizens to use private cars less and public transportation more. Explore carbon-inclusive mechanisms, build an ecosystem that involves everyone, and promote carbon neutrality in various social activities. Establish a "government-led, market-driven, and social participation" green living incentive and reward mechanism.

3.4.6 Guarantee Systems to Catalyze Changes and Ensure Implementation

To ensure the successful implementation of decarbonization actions. The city government should build supportive guarantee systems to improve capacity and catalyze changes.

Establish an authoritative and efficient working mechanism for decarbonization. Set up a leadership organization for long-term decarbonization, clarify the division of responsibilities of various departments, and enhance the professional quality of personnel at all levels.

Prepare the plan and layout for low-carbon and negative-carbon technological innovation. First, develop a green low-carbon technology research and development (R&D) roadmap and action plan, and clarify the layout, key directions, timetable, and investment mechanism. Secondly, accelerate the R&D and deployment of technologies. Focus on promoting technology applications such as smart grids, advanced energy storage, low-carbon material substitution, and energy efficiency improvement. Lastly, increase government guidance and promote the scale and commercial demonstration of advanced and applicable technologies to enhance economies of scale and gradually reduce application costs.

Introduce professional talents and enhance citizens' awareness of climate change. Introduce and cultivate professional management talents in critical fields such as carbon emissions management and carbon finance. Include climate change and earth science education in the education system. Encourage consumers to adopt green and low-carbon lifestyles and provide various incentive policies for consumers.

Increase domestic and international exchanges and cooperation in the low-carbon field and expand funding sources. Focus on introducing low-carbon technology exchanges and social capital, and strengthen multi-channel, multi-level, and multi-form cooperation and exchanges in low-carbon development. Actively learn from the work experience of renowned low-carbon cities in technology deployment, carbon finance, and other aspects.

4. Conclusion and Caveat

Decarbonization planning is a practice and procedure that makes a long-term plan for guiding a city to stop or reduce greenhouse gas emissions from city activities. This report demonstrates a brief guideline with Chinese characteristics for decarbonization planning and presents a case that applies this guideline in an island city in northern China. According to the guideline, planners are suggested to go through three steps in decarbonization planning. Firstly, make a greenhouse gas emissions inventory to understand the construction of greenhouse gases from different sectors and know the foundation and potential for further decarbonization. Secondly, forecasting future emissions based on reliable assumptions will provide clues to making ambitious but achievable decarbonization targets. Finally, design and compile a decarbonization action plan by integrating considerations from current political and socio-economic information and the knowledge from GHG inventory and emissions forecast.

We utilize a case of an island city to demonstrate the application of the guideline. This city has made many efforts in electrification in the past several years, with Scope 2 accounting for 80% of the emissions in the initial planning year. The subsequent challenge of emissions reduction mainly comes from the need to realize decarbonization in the power supply while meeting ecological conservation constraints, as well as to achieve technological substitution in the fishery and transportation sectors within a short time window. In an ideal scenario of renewable energy, efficiency improvement, and electrification, the city can achieve carbon neutrality by 2035. Based on a thorough analysis, we develop a respective decarbonization action plan.

The caveat of this report needs to be mentioned, which is that we only propose one pattern of guideline for decarbonization planning and do not intend to cover all kinds of possible patterns. Simultaneously, the case of the island city adopted in this paper has solid local specificity. It has to satisfy stringent ecological conservation constraints, and its economic structure is relatively simple (without heavy industry). Therefore, the presentation of the case and the recommendations generated may not be able to be directly applied to cities with more complex socioeconomic situations. Therefore, this guideline may only be comprehensive for some types of cities.

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Appendix

Appendix A. Results of GHG Emission Inventory

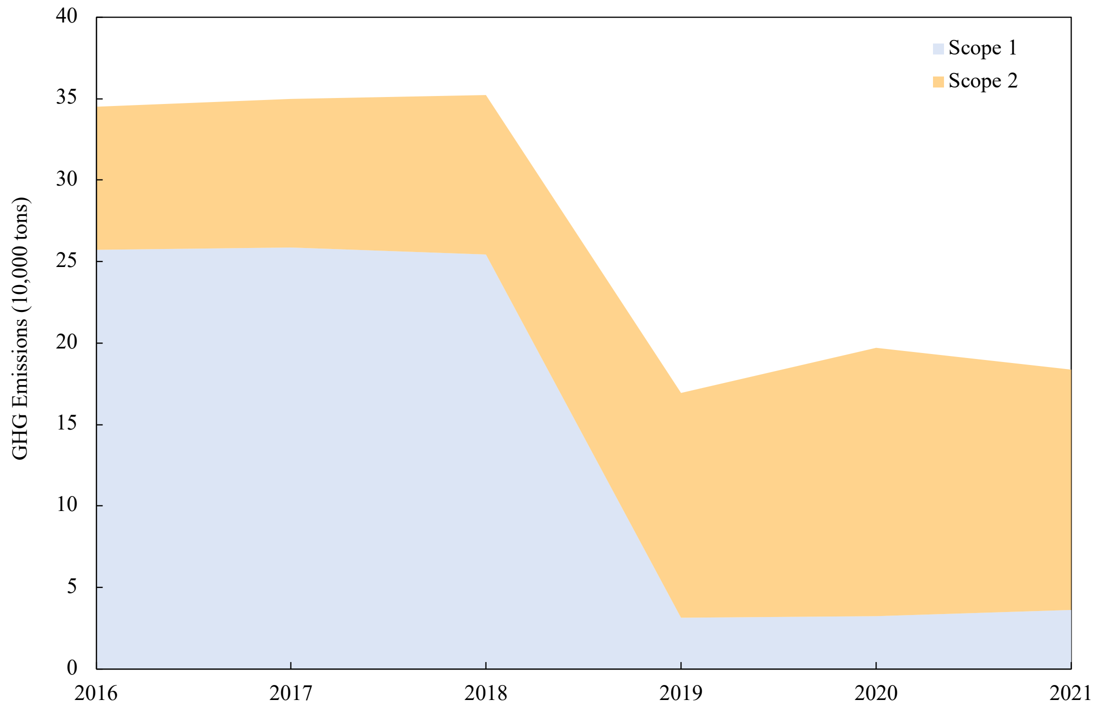

Figure A-1. GHG Emissions of Different Scopes From 2016 to 2021

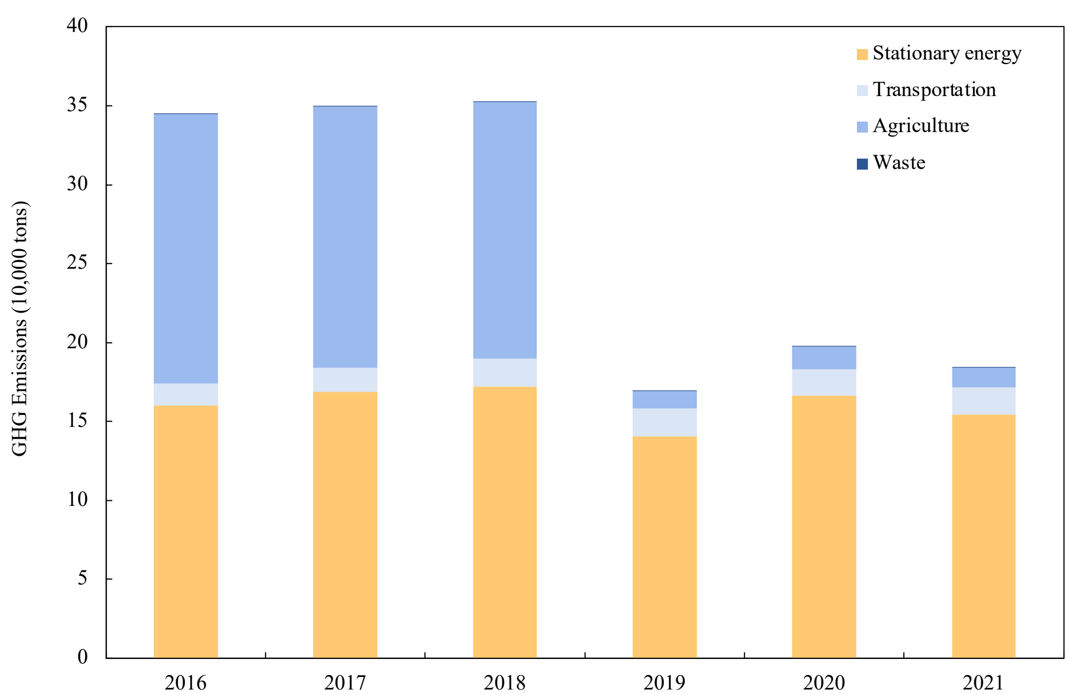

Figure A-2. GHG Emissions of Four Primary Sources From 2016 to 2021

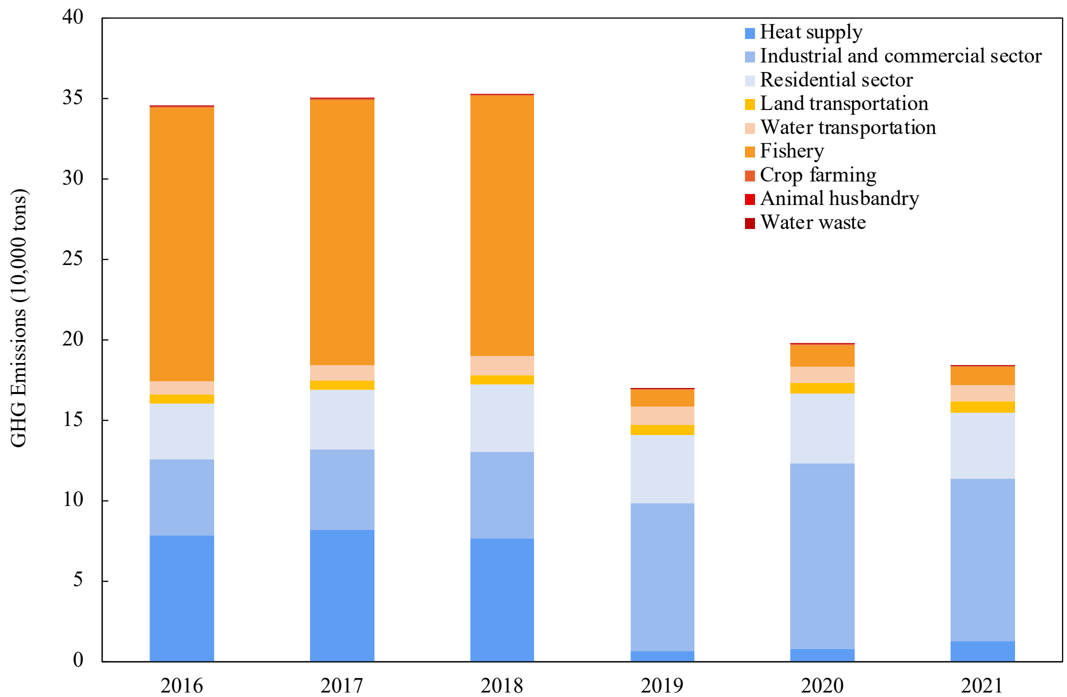

Figure A-3. GHG Emissions of Sub-sectors of Primary Sources From 2016 to 2021

Appendix B. Assumptions and Parameters Setting for the LEAP Model

Parameters set in the LEAP model are based on analysis including historical data inference, regional development plan, comparison of development trajectories of similar cities and potential for energy structure adjustment. The economic factors, such as population and agriculture output values, are the same for all eight scenarios. In contrast, there are different change rates for parameters like energy efficiency improvement rate, the level of electrification, and the proportion of renewable energy from different sources in the power supply, which correspond to different scenarios. This appendix summarizes the parameter settings of all scenarios over time from 2020 to 2060.

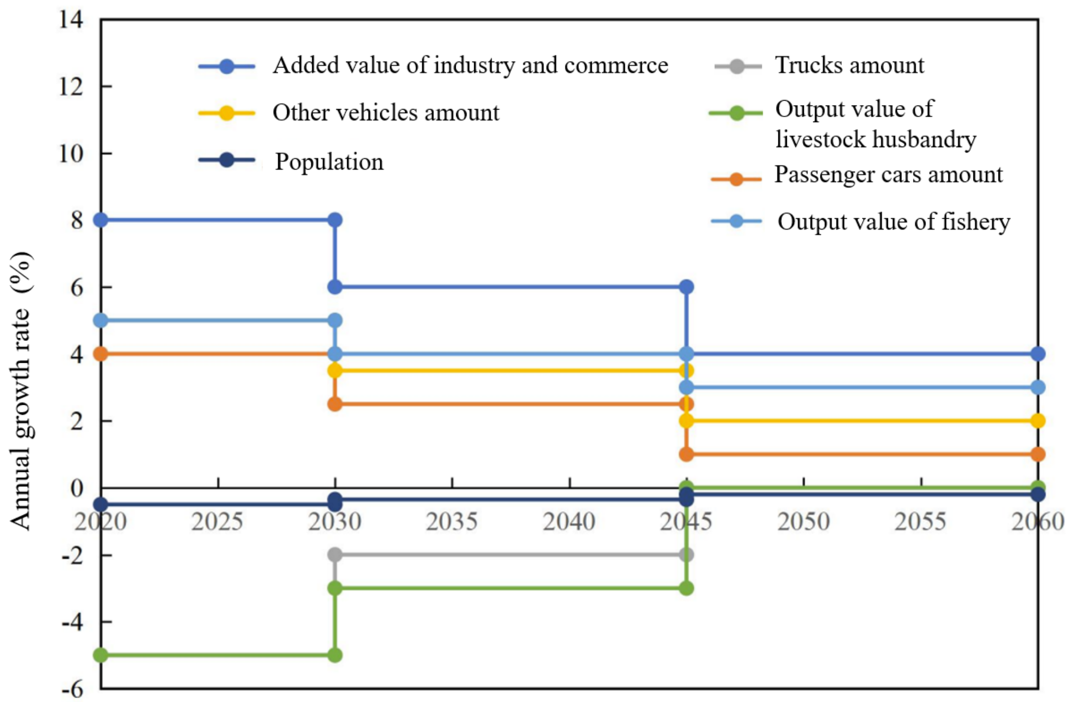

Figure B-1. Elementary Economic Parameters Setting for Emission Forecasts

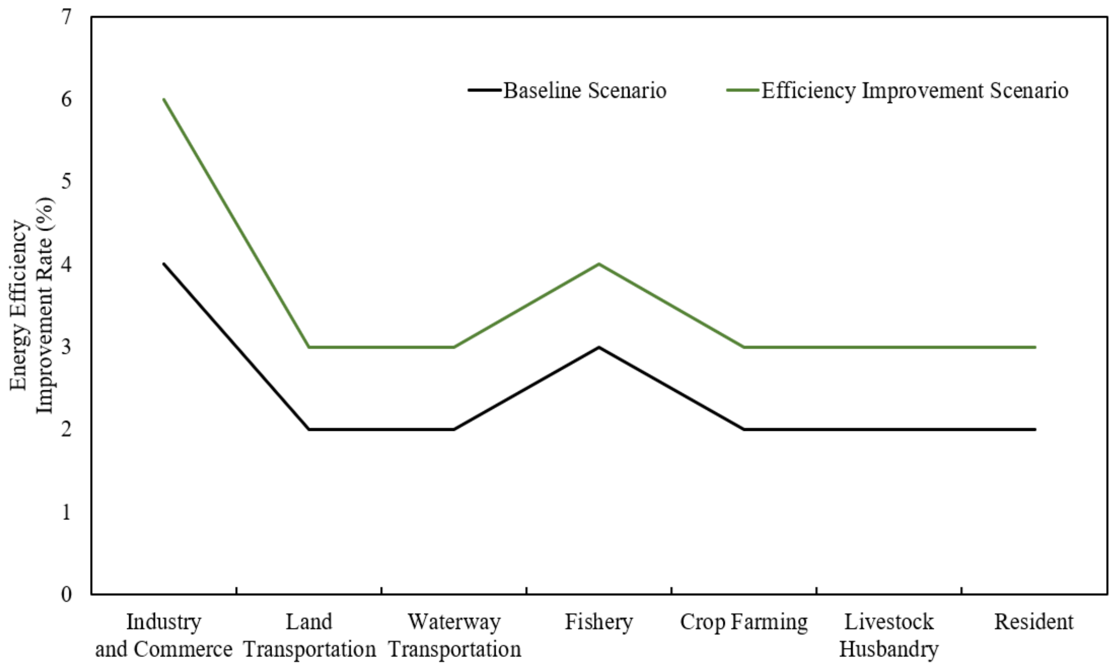

Figure B-2. Parameter Setting of Energy Efficiency Improvement Rate In baseline and Efficiency Improvement Scenarios

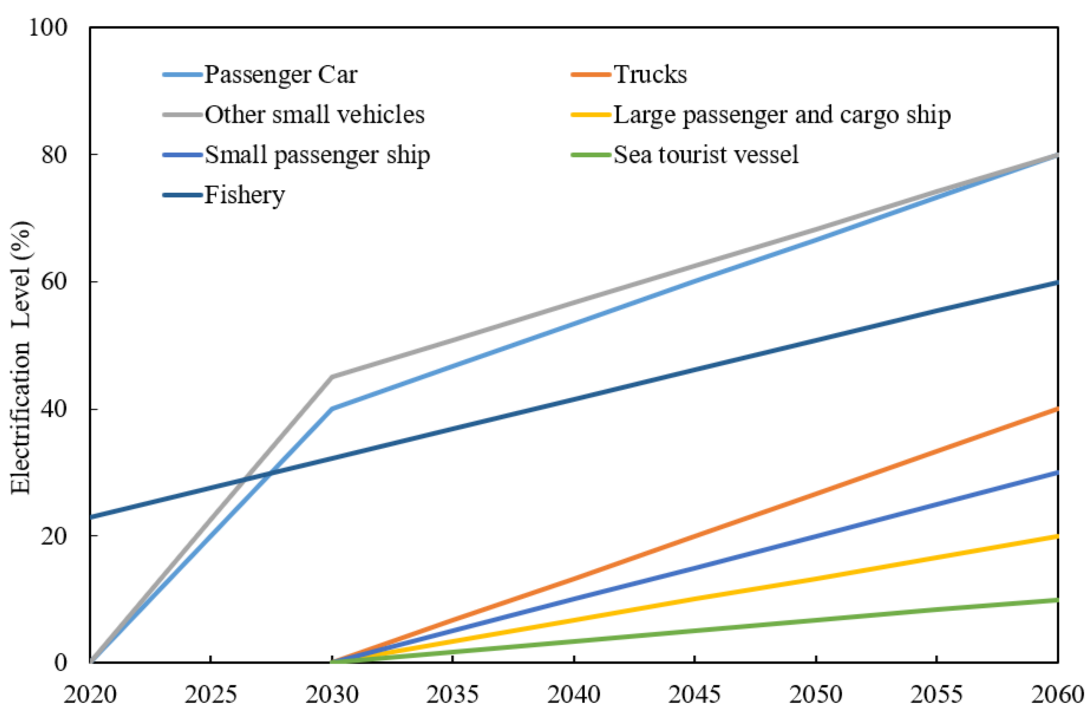

Figure B-3. Parameter Setting of Electrification Level in the Baseline Scenario

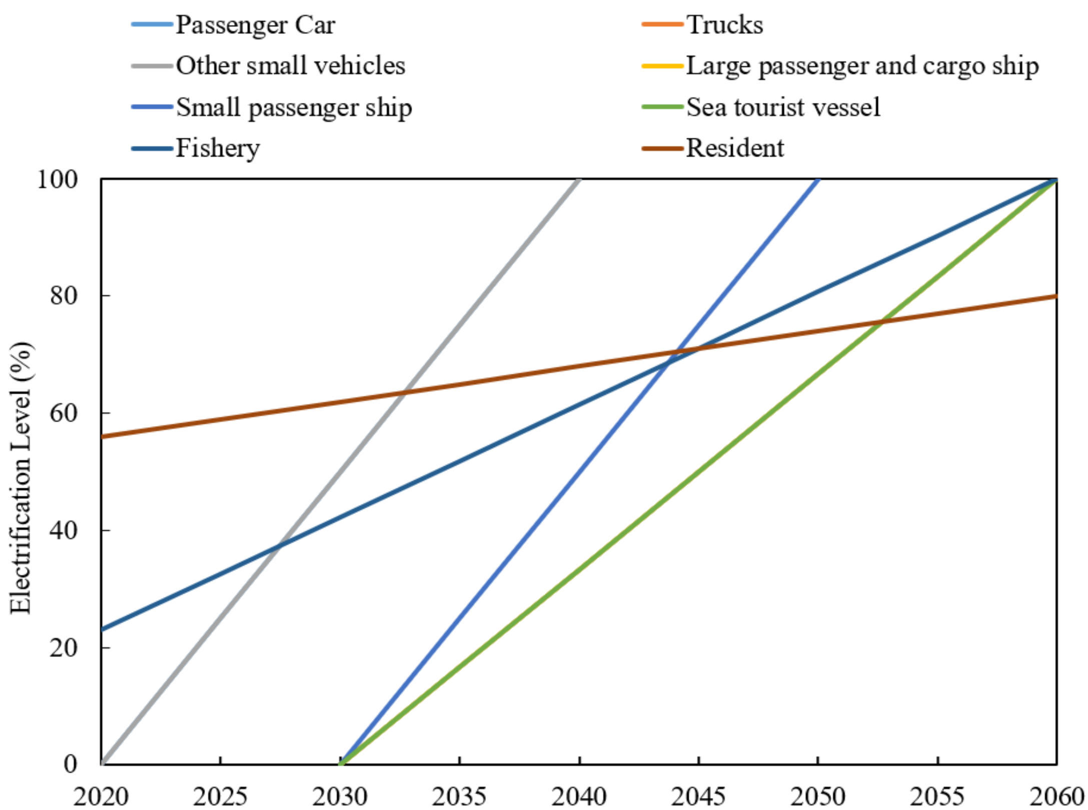

Figure B-4. Parameter Setting of Electrification Level in the Electrification Scenario

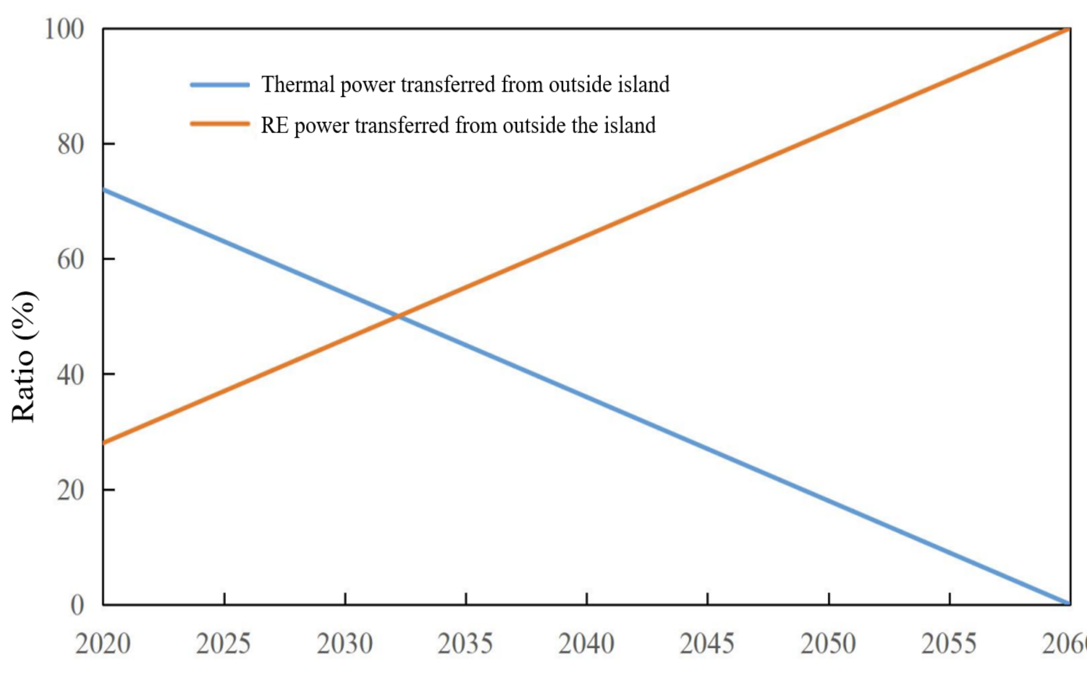

Figure B-5. Parameter Setting of Renewable Energy Ratio in Baseline Scenario

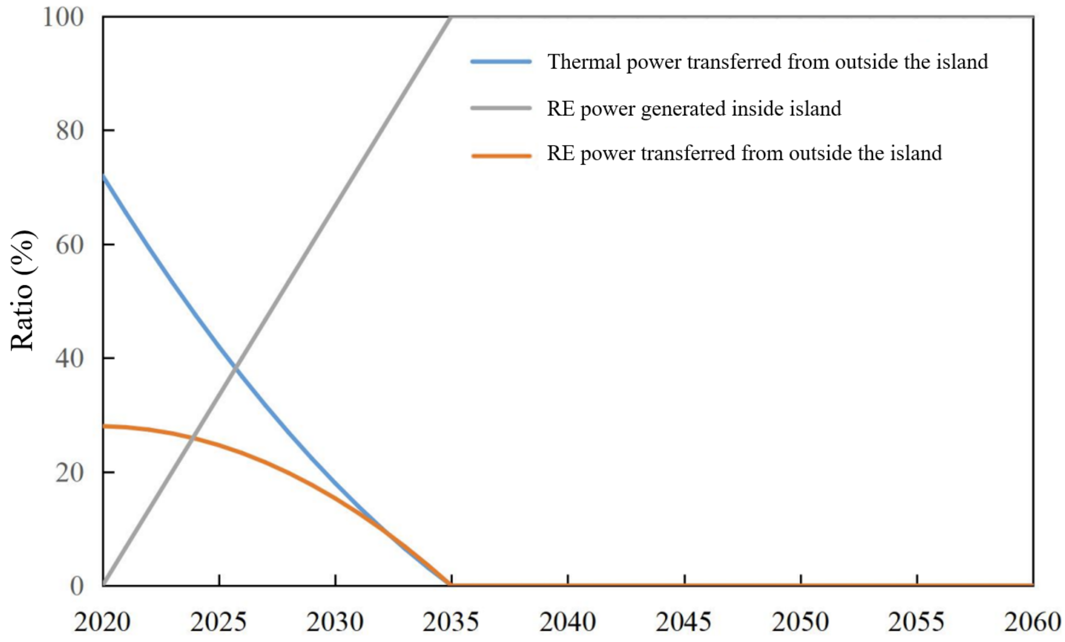

Figure B-6. Parameter Setting of Renewable Energy Ratio in Renewable Energy Scenario