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Study on Reducing Carbon Emissions in the Household Cooling：A Case Study in Hainan, China

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Article

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Abstract

In summer, urban residents' demand for cooling electricity consumption shows an explosive growth trend. To achieve the goal of carbon peaking and carbon neutrality, it is necessary to take effective measures to control and reduce the carbon emissions generated by residents' cooling energy consumption. Based on the theory of lifestyle, taking Hainan province as an example, this paper investigates and analyzes residents' cooling energy consumption, cooling equipment, cooling frequency and cooling intensity. Scenario simulation of the effect of reducing the carbon emission of residents' cooling is carried out from the aspects of energy cleaning, using low-carbon cooling equipment, and changing the energy efficiency level. Low-carbon paths for urban rural households' cooling in Hainan Province were proposed.

1 Introduction

With the development of economy, energy consumption for the cooling demand is raising rapidly. As high total refrigeration energy consumption, China's refrigeration electricity consumption accounts for more than 15% of the total social electricity consumption, with an average annual growth rate nearly 20%. Household electricity load of air conditioning accounts for about 60% of the peak load in summer in China and the energy-saving space of main refrigeration products will reach 30–50%(China's National Development and Reform Commission,2019). Residents' cooling energy consumption produces carbon emissions and contributes to global warming.

The impact of climate change on the global environment and human beings is increasingly manifested in different environmental processes, regions and countries. The sustainable development of human beings is facing many uncertainties and severe challenges. People are adopting different coping strategies based on different perspectives of countries, regions and the world to slow down and adapt to the uncertainty of this change. Starting from the reality of being a responsible big country, China government put forward its own "double carbon goal", which attracted global attention, and thus triggered a new round of research and practice of low-carbon development in academic circles. With the full development of China's modernization process, the interaction between China's economic aggregate growth and and the improving living standards has intensified the urgency of low-carbon transformation and carbon control development(Yan Zhang, 2021). There is great potential for energy conservation and emission reduction.The purpose of this study is to find out how to reduce the carbon emission of refrigeration energy consumption. It is of great significance to the goal of carbon neutrality.

2 Literature review

As a substitute for the post-Kyoto Protocol 2015,the Paris Agreement, which came into effect in December, 2008, is global cooperation after 2020. The task and direction of dealing with climate change have been clearly defined and clearly put forward.Global concerted action, in this century, even the whole ball. The temperature rise is controlled within 2℃ of the pre-industrial level, and efforts are made to the

temperature rise is limited to 1.5℃ of the pre-industrial level. Under the framework of the Montreal Protocol, the international community held the 19th Conference of the Parties of the protocol in September 2007 to adopt the adjustment case to accelerate the elimination of HCFCs. In October 2016, the international community further reached the Kigali Amendment to the Montreal Protocol, which proposed the gradual reduction of HFCs with high greenhouse effect, and also clarified the synergistic effect of energy.By cutting HFCs by 2050 to 30 billion tons of CO 2 equivalent by 2050, China could contribute a third of(China's National Development and Reform Commission ,2019) to reducing global warming by 0.5℃. The EU ecological Design Directive (2009 / 125 / EC) covers a wide range of products, including 31 categories of products(China's National Development and Reform Commission, 2019), including refrigeration and air conditioning products including: household air conditioning (No206 / 2012), household refrigerator (No643 / 2009)(Yu Hao,2016).

.The "Leader Plan" formulated by the Japanese government is mainly to encourage enterprises to recommend more energy-saving products to consumers by promoting the continuous improvement of energy conservation and environmental protection standards. At present, 31 kinds of equipment have become applicable objects (Ministery of Economy, 2015), covering refrigeration and air conditioning products. In 1992, the US Environmental Protection Agency (EPA) and the Department of Energy (DOE) jointly launched the Energy mark "Energy Star" to promote energy conservation in consumer electronics, which was later adopted by Australia, Canada, Japan, Japan, New Zealand and the European Union. The "Energy Star" certification currently includes 63 categories of products(Baidu Encyclopedia,2020), covering refrigeration and air conditioning products including: home air conditioning, air source heat pump, central air conditioning, In June 2019, the National Development and Reform Commission, together with seven ministries and commissions, released the(Regulation(EU)NO517,2014) Green and Efficient Refrigeration Action Plan specifically for the refrigeration and air conditioning industry, indicating that the importance the Chinese government attaches to energy conservation and emission reduction in the refrigeration and air conditioning industry and put it into action. The plan requires that by 2022, the overall energy efficiency of household air conditioners and multi-line refrigeration products will be increased by 30%, and the market share of green and efficient refrigeration products will be increased by more than 20%, achieving an annual power saving of about 100 billion kilowatt-hours. By 2030, the refrigeration energy efficiency of large public buildings will be increased by 30%, the overall energy efficiency of refrigeration will be increased by more than 25%, and the market share of green and efficient refrigeration products will be increased by more than 40%(European Union. Ecodesign requirement,2020), achieving an annual electricity saving of about 400 billion kilowatt-hours.

3 Research methods and data source

3.1 *Sampling location*

The number of cooling days in climate factors has a positive impact on household electricity consumption and per capita residential carbon emissions in cities above prefecture level in China(Sina News Center,2009). Hainan Province is located at the southernmost tip of China, bounded by Qiongzhou

Strait in the north, opposite to Vietnam in the Beibu Gulf in the west, facing Taiwan Province Province in the South China Sea in the east, and bordering the Philippines, Brunei and Malaysia in the South China Sea in the southeast and south. Hainan Province is located between 108 37'-111 03' east longitude and 18 10'-20 10' north latitude, which belongs to the northern edge of tropical zone, and is located in the hot summer and warm winter zone of China's architectural climate division, with great demand for refrigeration. Because it is located in the tropical monsoon climate zone, with long summer and no winter, the annual average temperature is 22 ~ 27℃, the accumulated temperature greater than or equal to 10℃ is 8200℃, the coldest January temperature is still 17 ~ 24℃, the annual sunshine is 1750 ~ 2650 hours, the illumination rate is 50%~60%, and the light temperature is sufficient. Hainan Island has early spring, rapid temperature rise, large daily temperature difference, no frost all year round and warm winter. From 2010 to 2021, the highest average temperature in Hainan Province is mainly from May to July, with an average maximum temperature of 34℃ and the lowest temperature from December to February, with an average cooling days of 688℃ d.

3.2 Methods

Leap Model and scenario simulation analysis were used in this research. In this study, Leap Model was used to analyze energy consumption and carbon emissions in different scenarios, which are based on a series of assumptions about population, economic development and technology. Scenario simulation of the effect of reducing the carbon emission of residents' cooling was carried out from the aspects of cleaning energy types, using low-carbon cooling equipment, and changing the energy efficiency level in Hainan Province from 2021 to 2035.

3.3 Scenario setting

3.3.1 Scenarios of population growth

From 2015 to 2020, the changes of resident population in Hainan Province are shown in Table 4 − 1. In the past five years, the growth rate of resident population in Hainan Province has been accelerating. The Population Development Plan of Hainan Province (2030) predicts that the population of Hainan Province will reach about 12.48 million in 2030. According to the growth rate of resident population in 2020, it is predicted that the resident population of Hainan Province will reach 13.03 million in 2035. In the past few years, the urbanization rate has also increased from 54.9% to 60.3%. According to the planning goal of the 14th Five-Year Plan for National Economic and Social Development of Hainan Province and the Outline of Long-term Goals in 2035, the urbanization rate of permanent residents in Hainan Province will reach 65% in 2035. Therefore, in this study, the permanent population of Hainan Province is 13.03 million in 2035, and the urbanization rate of permanent population is 65% as the basic parameters of LEAP model population.

3.3.2 Scenarios of Energy Cleanliness

Hainan is adjusting its energy structure, and the proportion of photovoltaic power generation, wind power generation and nuclear power is increasing. According to Hainan's "Tenth Five-Year Plan" and peak

carbon dioxide emissions plan of Hainan Province, the carbon emission per unit electricity consumption in Hainan will be reduced from 381g/kWh in 2021 to 327g/kWh in 2025 (see Table 1).

Table 1
Carbon Reduction Scenarios of Energy Cleanliness

Category	indicator	unit	2021Y	2025Y	2035Y
unit electricity carbon emissions		g/kwh	381	327	270
Clean and low-carbon power generation side	Non-fossil energy electricity ratio	%	41.4	35.9	32.6
	clean energy electricity ratio	%	55.3	70.2	85

3.3.3 Scenarios of refrigeration equipment use

The previous statistical analysis shows that from 2016 to 2020, the number of households' air conditioners in Hainan Province show a rapid growth trend. By the end of 2020, the number of air conditioners per 100 households reach 170.1. With the continuous improvement of residents' income and living standards in Hainan Province, combined with the growth rate of air conditioners in the past decade, it is estimated that by 2025, the number of air conditioners per 100 households in Hainan Province will reach 206.3, and by 2035, will reach 356.1. Due to the relatively stable demand for household refrigerators, the growth rate of refrigerators owned by 100 households in Hainan Province is slow. It is estimated that by 2035, the number of refrigerators owned by 100 households in Hainan Province will reach 100 (see Table 2).

Therefore, the population parameters and demand parameters in the LEAP model are set as follows:

Table 2
Scenarios of refrigeration equipment usage number

category	2021Y	2025Y	2035Y
Number of air conditioners per 100 households	170.1	206.3	356.1
Number of refrigerators per 100 households	99.1	100	100

3.3.4 Scenarios of refrigeration equipment efficiency

Under the condition that the basic parameters are determined, the energy consumption of existing residential refrigeration scenarios in Hainan Province is analyzed. At present, among the residents' air conditioners in Hainan Province, the first, second and third grade energy-efficient air conditioners account for 32%, 38% and 31% respectively. According to the survey results of the project, the average

time for residents in Hainan Province to use air conditioners on a single cooling day is as long as 7.79 hours, and the annual cooling day is about 140 days. According to the average cooling capacity of air conditioners in Hainan Province of 3200W, the first-class energy efficiency of 3.6 saves 57 kWh and 121 kWh per year respectively compared with the second-class energy efficiency of 3.4 and the third-class energy efficiency of 3.2. Hainan residents' household refrigerators are used almost continuously all year round. It is preliminarily estimated that the first-class energy-efficient refrigerators save about 140 kWh a year compared with the third-class energy-efficient refrigerators and 290 kWh compared with the fifth-class energy-efficient refrigerators. At the same time, through literature summary and market research, the average service life of air conditioners and refrigerators in Hainan Province is about 8 years and 15 years. Therefore, improving energy efficiency standards and increasing the proportion of energy-saving products in the market in the future can effectively reduce the total energy consumption and carbon emissions of residential cooling.
According to the target requirements of "Green and Efficient Refrigeration Action Plan" promulgated by the state in 2018, by 2022, the energy efficiency access level of household air conditioners will increase by 30%, and the market share of green and efficient refrigeration products will increase by 20%. By 2030, the energy efficiency access level of major refrigeration products will be increased by 15%, and the market share of green and efficient refrigeration products will be over 40%.

Based on the current inventory status of air-conditioned refrigerators in Hainan Province and the future market incremental trend, the following scenarios are set respectively. Among them, the basic scenario is set according to the target requirements of the National Green Refrigeration Action Plan by default. The promotion scenario is based on Hainan's low-carbon development requirements and the national goal(see Table 3).

At present, most of the air conditioners in Hainan are based on the energy efficiency grades classified by GB1202132010 and GB 21455 – 2013, and the air conditioners with the above energy efficiency grades are expected to serve until 2030. Therefore, the energy efficiency grades of air conditioners are classified into three grades in scenario prediction.

Table 3
Scenarios of households' refrigeration equipment efficiency

scenarios	energy efficiency of air conditioners	energy efficiency of refrigerators
benchmark scenario	By 2035, the proportion of primary, secondary and tertiary energy efficiency of household air conditioners will be 38%, 34% and 27% respectively, and the energy efficiency level of air conditioners will remain unchanged; In 2035, the proportion of primary, secondary and tertiary energy efficiency of household air conditioners was 53%, 26% and 21% respectively, and the energy efficiency was increased by 30%.	By 2035, the energy efficiency of domestic refrigerators will account for 28%, 36%, 22%, 8% and 6% respectively, and the energy efficiency level will remain unchanged; By 2035, the energy efficiency of domestic refrigerators will account for 39%, 50%, 7%, 3% and 1% respectively, and the energy efficiency level will increase by 15%.
ascension scenario	By 2035, the proportion of primary, secondary and tertiary energy efficiency of household air conditioners will be 48%, 28% and 23% respectively, and the energy efficiency level of air conditioners will increase by 30%; In 2035, the proportion of primary, secondary and tertiary energy efficiency of household air conditioners will be 63%, 20% and 17% respectively, and the energy efficiency level will increase by 20%.	By 2035, the energy efficiency of household refrigerators will account for 33%, 41%, 16%, 6% and 4% respectively, and the energy efficiency level will increase by 5%; By 2035, the energy efficiency of household refrigerators will account for 43%, 57%, 0%, 0% and 0% respectively, and the energy efficiency level will increase by 20%.

Notes: In order to maintain consistency, GB120213 2010 and GB 21455 − 2013 are used for the classification of air-conditioning energy efficiency, and GB 12021.2–2015 is used for the classification of refrigerator energy efficiency. Since the National Green Refrigeration Action Plan was published before GB214552019, the prediction of energy efficiency improvement is based on the old enclosure standard. Considering that the existing air conditioner and refrigerator markets are gradually replaced, the implementation time of the policy is delayed compared with the market share.

4 Results and analysis

4.1 *Low-carbon simulation results based on clean energy*

Clean energy structure can decouple residents' energy consumption from carbon emissions at the source, thus realizing low-carbon lifestyle. In the energy clean scenario in Table 7 − 1, according to the formula:

$C = Q*EF$ (1)

C is carbon emission, *Q* is electricity consumption, and *EF* is carbon emission per unit electricity consumption. It can be calculated that the carbon emissions of Hainan households can be reduced at the different level of energy cleanliness and at the same level of population and the current consumption (8.14 billion kWh) are maintained by 2025 (see Table 4).

Table 4
Simulation results of household cooling carbon reduction by energy cleanliness in Hainan

category	unit	2021Y	2025Y	2035Y	total carbon reduction by 2035
Carbon emission from residential electricity consumption in Hainan	10^6T	6.10	5.44	4.38	13.9
Carbon emission of Hainan residents for cooling	10^6T	3.05	2.72	2.19	6.95

4.2 Low-carbon simulation results based on the scenario of improving energy efficiency

On the premise that the composition structure of the power generation terminal remains unchanged, the carbon dioxide emissions generated by residents in Hainan Province in 2021 will be about 3 million tons, accounting for about 8% of the total carbon emissions in the province. By 2035, it is estimated that in the baseline scenario, the carbon dioxide generated by residential refrigeration electricity will reach 6.1 million tons, and according to the development of the upgrading scenario, it is estimated that the carbon emissions will be reduced by 1.05 million tons. Under the upgrading scenario, the carbon dioxide emissions generated by residents' refrigeration electricity consumption in Hainan Province will be reduced by 12.44 million tons in the next fifteen years(see Fig. 1). (In the above carbon emission calculation process, the carbon emission level of coal-fired power generation is based on the default emission factor in the IPCC list, the same below.)

Refrigerant control is the most effective means to reduce greenhouse gas emissions besides energy consumption control. Indirect greenhouse gas emissions caused by HFCs can be effectively controlled by gradually restricting the entry of refrigerant air conditioners with GWP>150 into Hainan market. In 2020, the greenhouse gas emissions generated by residents' air-conditioning refrigerants in Hainan Province are equivalent to about 2.4 million tons of CO_2. In the upgrading scenario, carbon emissions will be reduced by 16 million tons in the next 15 years through the control of refrigerant types. Therefore, through energy efficiency improvement and refrigerant control, residents' green refrigeration behavior will reduce CO_2 emissions by 22.3 million tons in the next 15 years. There is great potential to carry out green refrigeration in the field of residents' life.

5 Discussion

According to the above simulation results, it can be concluded that the low-carbon residential refrigeration construction paths are the low-carbon path based on energy cleaning and the low-carbon path based on improving energy efficiency. The mechanistic of low carbonation of the two paths is different, as shown in Table 5.

Table 5
Comparison of different emission reduction paths

category	mechanism of low carbon carbonization	process of realization	path
The low-carbon path based on energy cleaning	Carbon emission decouples from refrigeration energy consumption .	Reducing carbon emission from domestic energy supply.	Providing clean power supply
The low-carbon path based on improving energy efficiency	Reducing energy consumption	Reducing energy consumption	Residents buy high efficiency electrical appliances.

5.1 *Discussion on the low-carbon path based on energy cleaning*

The mechanism of this carbon reduction path is to achieve carbon reduction by decoupling domestic energy from carbon emissions, and to achieve carbon reduction from domestic energy sources only by providing clean power from power grids or households. It can provide a carbon reduction scheme for low-carbon household electricity consumption, cooling electricity consumption and cooking electricity consumption. With the adjustment of energy structure in Hainan Province, the proportion of photovoltaic power generation, wind power and nuclear power is increasing day by day, and the clean level of Hainan's electric energy is increasing day by day. Therefore, the low-carbon path of energy-saving residential lifestyle can be successfully realized.

5.2 *Discussion on the low-carbon path based on improving energy efficiency*

This path is to reduce carbon from the process of domestic energy use. It requires residents to buy high-efficiency energy cooling appliances and household cooling appliance manufacturers can generate high-efficiency household cooling appliances. To improve the energy efficiency, manufacturers need to develop and produce high-efficiency electrical appliances. At the same time, due to the limitation of the price and service life of electrical appliances and the influence of residents' cognition and acceptance, the realization of this path is uncertain.

5.3 *Discussion on the applicability of two emission reduction paths to urban and rural families*

5.3.1 Comparison of energy-using lifestyles of households in provincial capitals and townships in Hainan.

Due to the difference of economic development level between urban and rural areas, the living style and consumption level of urban and rural households are different. The amount of energy-consuming household appliances such as air conditioners and refrigerators owned by 100 households in rural areas is far less than that of urban households(see Table 6). The residential energy lifestyle of urban households' cooling is characterized by high energy consumption, large energy consumption and high carbon emissions. The residential energy lifestyle of rural households' cooling is characterized by less high-energy appliances, less energy consumption and lower carbon emissions (see Table 7).

Table 6
Number of air conditioners and refrigerators for 100 households in Hainan Province from 2016 to 2020

Air conditioning ownership of 100 households	**2016Y**	**2017Y**	**2018Y**	**2019Y**	**2020Y**
Urban residents	120.4	126.5	152	168.4	170.1
Rural residents	34.6	37	56.1	74.8	78.7
Refrigerator ownership of 100 households	2016Y	2017Y	2018Y	2019Y	2020Y
Urban residents	93	94.7	96.7	98.4	99.1
Rural residents	67.2	69.5	76.8	84.7	85.2

Table 7
Comparison of Cooling Energy Consumption and Carbon Emissions between Urban and Rural Residents in Hainan Province

Residents	**Energy consumption level**	**Number of household appliances with high energy consumption**	**The amount of carbon emission**
Urban residents	high	big	big
Rural residents	low	small	small

6 Conclusion and discussion

6.1 Low-carbon paths for urban households' cooling in Hainan Province

The residential cooling energy consumption level of urban households in Hainan Province is rising continuously, and the consumption level is higher than that in rural areas. The households have a large number of high-energy cooling household appliances such as air conditioners and refrigerators, and the residential energy lifestyle is characterized by high-energy appliances, high energy consumption and high

carbon emissions. According to this feature, low-carbon paths for urban households' cooling in Hainan Province are proposed as following:
Promote the use of clean energy. In addition to the clean energy supplied by the power grid, urban families are encouraged to install household photovoltaic power generation facilities to meet the daily electricity consumption and cooling demand of families, and clean at the source;
Improve the energy efficiency of refrigerators and air conditioners. By purchasing and using high-energy and energy-saving high-power appliances, improve energy efficiency and reduce energy consumption, thus reducing carbon emissions.

6.2 Low-carbon paths for rural households' cooling in Hainan Province

The residential energy consumption level of rural household cooling in Hainan Province is rising continuously, and the consumption level is lower than that of cities and towns. The amount of high-energy household cooling appliances such as air conditioners and refrigerators owned by rural households is relatively small, and the lifestyle of residential energy consumption is characterized by less high-energy household appliances, less energy consumption and less carbon emissions. There is little potential to reduce the carbon emissions of rural households by improving energy efficiency, and the purchasing power of rural residents is limited, and their acceptance of high-priced energy-saving products is small. According to this feature, low-carbon paths for rural households' cooling in Hainan Province are proposed as following:

Use clean energy supplied by the power grid. Encourage rural households to install household photovoltaic power generation facilities on the roof to meet their daily electricity consumption and cooling electricity demand so that the households' cooling energy consumption is decoupled from carbon emission.

Declarations

Author Contribution

Author Contributions:Yan Zhang conceived and designed the study and acquired funding and supervised the project.Fengxian Lu developed the methodology and performed the experiments. Ziying Zhou analyzed the data. All authors have read and agreed to the published version of the manuscript.

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Data Availability

The Ungdata surveys that support the findings of this study are available from Norwegian Social Research (NOVA), but restrictions apply to the availability of these data, which were used under licence for the current study and so are not publicly available. The data are, however, available upon request and with the permission of Norwegian Social Research (NOVA).

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054916676255s.shtml

Figures

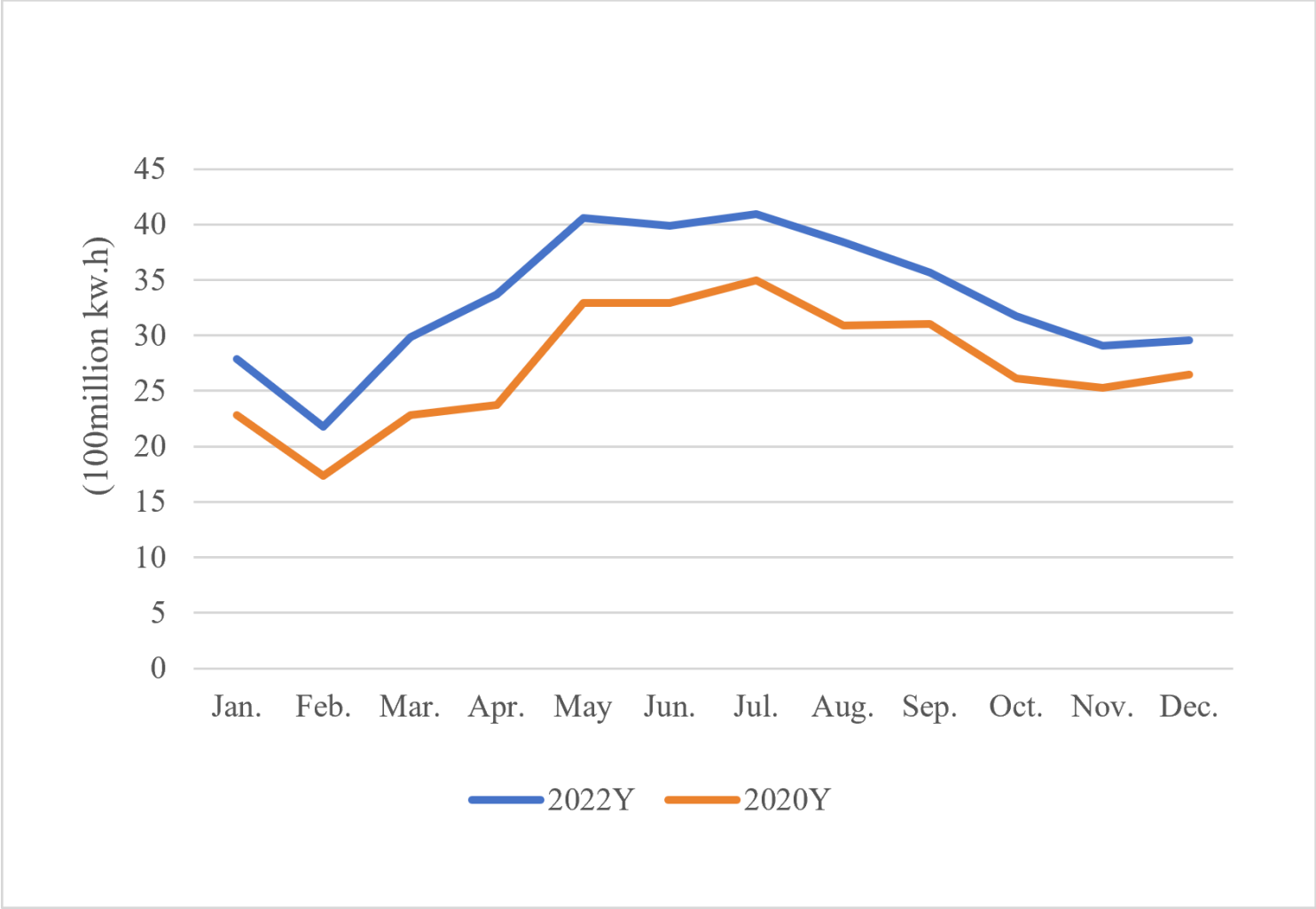


Figure 1

Electricity demand in Hainan from January to December

Note：The data comes from Hainan Power Grid Dispatching Center.

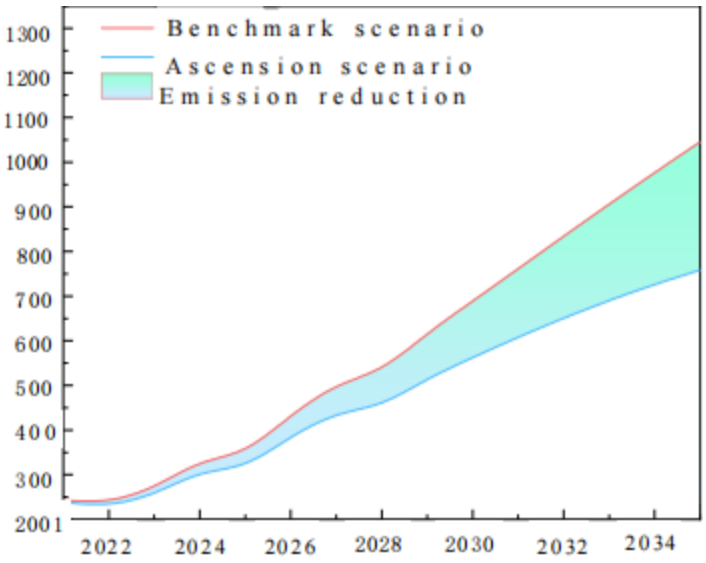


Figure 2

Figure 1 Simulation results of household cooling carbon reduction by improving households' refrigeration energy efficiency