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Optimal Design of Grid-Connected Microgrid System for Cold Chain Logistics Centre in China

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Abstract

The growing interest in energy conservation has inspired companies to seek alternatives to highly polluting fuel electricity generation. This study designed an optimised solar wind power generation system to fulfil the energy requirement of a cold chain logistics centre. This study first conducted a thorough analysis of the clarity indicators and daily temperature positions of the cold chain logistics centre, determined the average daily electricity demand, and proposed an effective design scheme. The energy simulation software, RETScreen 8.0, was used to determine the scale of solar photovoltaic and wind power projects that meet the expected energy needs of the cold chain logistics centre. The results indicated that the estimated annual total energy demand was 833689.2 kWh. The annual power generation of 6 kW from solar photovoltaic projects and 150 kW from wind power projects was found to be enough to meet the expected electricity demand. Solar photovoltaic power generation and wind power generation account for 2.44% and 97.56%, respectively. The hybrid energy system achieved a 96.6% reduction in carbon emissions and provides a reasonable payback period of 6.1 years and an electricity generation of 904368.674 kWh per year. The feasibility of the project and the calculated period of investment return are very reasonable. Therefore, this hybrid renewable energy system provides reliable power by combining energy sources.

Keywords

Solar Photovoltaic, Wind Power, Energy, Cold Storage, Microgrid

1. Introduction

Renewable energy is crucial for sustainable economic development. With the rapid population growth, the energy demand is projected to increase by 35% -

56% between 2010 and 2050 [1]. Cold chain logistics is crucial for reducing postharvest losses. Accordingly, it is a component of many fruits, vegetables, and processed products. The timely storage of highly perishable goods facilitates their regular and continuous supply for storage or processing. Notably, energy consumption has become an important consideration in the operation of material handling systems for logistics warehouses. Further, in-building energy consumption consumption contributes approximately 33 percent of global energy consumption. The significance of the exploitation of renewable energy places it at the core of national energy policy, as it has great potential in electrification, improving energy efficiency, and renewable energy generation. Therefore, decreasing fossil fuel consumption in logistics buildings has the potential to decrease carbon emissions [2]. A critical component of cold chains is a reliable electricity supply, as the quality of the products should be guaranteed, and energy consumption directly influences the carbon emission of the cold chain logistics [3]. The logistics centre is a vital part of the cold chain, which is required for all chilled and frozen foods [4]. It has a central role in the proper storage of food, including the storage of finished value-added products for supply to the wholesaler, retailer, and other business sectors. Warehouses are major contributors to carbon emissions in the cold chain, and low-carbon warehousing design has become a popular paradigm [5]. Food refrigeration is a major energy consumer worldwide because approximately 40% of foods need refrigeration [6]. Therefore, cold chain logistics possess huge potential for adopting renewable energy technologies.

Cold chain logistics facilities require continuous power supply, such as cold rooms or walk-in warehousing, which can be large loads. The growing demand for cooling has placed heavy pressure on the grid systems of many countries. Cold chain logistics is one of the most critical blind spots in energy management. However, meeting existing demand remains a challenge to efficient energy management in cold chain logistics centre. Cold chain logistics companies have considerable motivation to reduce energy consumption. In some markets, clean energy can provide this type of electricity at a lower lifespan cost than traditional energy. The integration of renewable energy systems in a frozen food warehouse, which replaces most of the almost free energy, can serve as a cost-effective means to balance the overall power supply and minimise the carbon footprint of the warehouses. Clean energy is a promising energy source in developing countries with sufficient wind power resource and solar radiation [7].

In recent years, hybrid photovoltaic wind turbines have become a popular alternative for sustainable power generation. The most widely used renewable energy sources are wind turbines and solar photovoltaics, as prices have significantly decreased and efficiency has significantly improved. Technological progress and the development of smart microgrid control technology have enabled the effective utilisation and reliable supply of renewable energy. In addition, by integrating solar panels and wind turbines, renewable energy can lower carbon emissions. However, because wind and solar projects involve many technical and economic complexities, their feasibility depends on geographical location and resource availability. In addition, preliminary studies on warehouse-related emissions were summarised and a comprehensive classification scheme was discussed to enable researchers to systematically evaluate the carbon emission of warehouse operations [8].

Extensive research has been conducted on renewable energy systems comprising solar photovoltaic and wind energy. Ahmad, M *et al.* investigated and compared the technical and economic feasibility of grid-tied photovoltaic power generation in the small and medium-sized enterprise sector of Pakistan's manufacturing industry in 2022 [9]. Gao Haiyang proposed energy-saving methods for various facets of cold chain logistics and summarised energy conservation technologies in the cold storage industry [10]. Nkalo *et al.* conducted technical and economic analysis of a solar wind power generation system to meet the electricity needs of rural communities in Nigeria [11]. Zhang proposed the optimal configuration of a hybrid renewable energy system equipped with photovoltaic and wind turbines systems to fulfil the electricity needs of a workshop in Adabir, Iran [12]. Rehman *et al.* studied the feasibility of grid-tied photovoltaic systems. They identified the best location for installing a photovoltaic power generation system. Imam, Amir A. *et al.* conducted a technical and economic feasibility assessment of a grid-tied photovoltaic energy conversion system of a residential building in Jeddahin, Saudi Arabia. The results revealed that the capacity coefficient and performance ratio were 22% and 78%, respectively [13] [14]. The potential of China's cold chain logistics demand is enormous, cold chain logistics consume large amounts of energy. The cost of cold chain logistics accounts for approximately 70% of the total cost, which is more than twice that of developed countries [15]. Therefore, the power supply structure should be transformed and the generation of renewable energy increased. China has great potential for renewable energy development, and solar photovoltaic is one of the most widely used energy in China.

As stated in above literature, most of the research has focused on renewable energy uses in manufacturing and residential communities. However, design of renewable energy systems in the cold chain logistics centres has not been performed to sufficient depth. Similarly, the current research has focused on improving the energy efficiency of warehouse processes without considering cold chain logistics centres as important nodes in the network. Nonetheless, integrating renewable energy into the supply chain, coupled with energy-saving design, can greatly enhance supply chain sustainability. Therefore, we focus on efficiency and optimisation when designing the hybrid renewable energy system. Decarbonising China's power industry and achieving China's carbon reduction goals is urgently required. The purpose of this study is to optimise the design of a grid-tied microgrid system for a cold chain logistics centre in Guangdong, China. This study designs a grid-tied solar photovoltaic wind system to meet the power demand of a cold chain logistics centre in Guangdong, China. To achieve its purpose, this study conducted an energy analysis to determine the electricity demand. The RETscreen software is used to design and simulate proposed integrated systems to analyse their economic, technical, and carbon emission reduction performance [16] [17].

2. Method and Site Selection

The main data include technical parameters and energy loads, which are collected directly from the cold chain logistics centre through interviews and review records. The secondary sources used in this study were accessed from online databases. They include climate data from selected locations provided by NASA, which are used in the RETScreen software program. RETScreen contains a weather statistics database, which is composed of thousands of sites globally [18]. The RETScreen software is used to implement numerical models and allows various parameter settings from technological, economical, and environmental perspectives to be compared. It also analyses investment, operational, and costs to determine the economic benefits of the energy system.

The economic model of RETScreen software has seven main economic indicators, which are used to measure the economic of energy projects: net present value (NPV), pre-tax internal rate of return (PIRR) and modified internal return on equity (MIRR), and modified internal return on assets, simple and equity payback period (SPP), benefit–cost ratio (BCR), and annual life cycle savings (ALCS) [19] [20].

NPV is a key indicator for evaluating hybrid energy systems. The higher the NPV, the greater the attractiveness of the project [21]. The calculation of NPV is shown in Equation (1).

$$\text{NPV} = \sum_{i=0}^{N} \frac{Cn}{(1+r)^n} \tag{1}$$

C: represents the cost of capital.

N: project lifespan.

r: interest rate.

The internal rate of return refers to the discount rate at which the net present value is zero. The higher the internal rate of return, the greater are the future returns. Therefore, the internal rate of return can be used as a measure of investment profitability [22].

$$\text{IRR} = \sum_{t=1}^{1} \frac{R_t}{(1+r)^t} - c \tag{2}$$

R_t: net cash inflow during period t.

R: the discount rate.

The SPP denotes the period during which the main costs of the proposed construction project exceed their main costs from the generated income and savings, whereas the EPP is the length of time that facility holders recover their initial investment in the form of equity from the cash flows generated by the project. It is a better time indicator of project advantages than SPP. Equation (3) is used to estimate the investment payback period (PBP) of the renewable energy project being studied.

$$\text{PBP} = \frac{C}{R_1} \tag{3}$$

Net BCR is the ratio of a project's net benefit to its cost. It refers to the present value of annual income and savings as project equity. If the ratio is greater than 1, then the project is profitable, and if the ratio is less than 1, the project is typically not profitable.

ALCS refers to the normalised nominal annual savings with the same lifespan and net present value as the actual project [23] [24]. It is calculated by considering NPV, discount rate, and project lifespan:

$$\text{ALCS} = \frac{\text{NPV}}{\frac{1}{r}\left(1 - \frac{1}{(1+r)^N}\right)} \tag{4}$$

To determine the electricity demand, a load assessment survey was conducted to analysis the load of the cold chain logistics centre. The survey inquired about the number, rated power, variety of electric appliances, and the operation time of electric devices. The electricity demand of the cold chain logistics Centre is assumed for both desired temperatures in cooling mode. The energy demand is calculated using Equations (5) and (6).

$$\text{Energy Demand}(\text{kW}\cdot\text{h}) = \text{Load demand}(\text{kW}) \times \text{Duration}(\text{h}) \tag{5}$$

$$\text{Total Energy Demand}(\text{kW}\cdot\text{h}) = \sum_{i=1}^{n} \text{Energy Demand}(\text{kW}\cdot\text{h}) \tag{6}$$

The selected site is a cold chain logistics centre located in Jiazi Town, Shanwei City, Guangdong province, which is located approximately 220 km away from Shenzhen City, China. The facility has a north–south orientation, with a longitude of 116.1˚E, and latitude of 22.9˚N. The cold chain logistics Centre was established on September, 1999 and provides refrigeration and transportation services. This study was conducted on its commercial refrigeration and refrigeration warehouse, which is used to preserve vegetables, dairy products, meat, and fish. Meat and fish are frozen and stored in extremely low temperature refrigerators (from −15˚C to 40˚C), whereas other products are stored at relatively high temperatures of 3˚C - 10˚C. The cold chain logistics centre has some cold storage rooms and freezers for storing fruits and vegetables after harvest. It has been working 24 h a day for several consecutive months, thus requiring continuous power supply. The cold chain logistics centre uses the power grid provided by China Electric Power Group.

3. Design Modelling of Hybrid Power Systems

3.1. Meteorological Data Evaluation

The selected location is characterised by hot summers, which stretch from May to November. When the weather is clear, the value of the sunshine index is high. The maximum external temperature of the ambient air used to optimise the load was 40˚C. The average humidity was 85% per year. The solar data were obtained from surface meteorological and solar data from NASA, which are satellite data. Wind energy resources were highest in the winter months, whereas solar energy resources were highest in the summer months. Therefore, the cold chain logistics centre was located in an area with significant potential for wind and solar sources. The solar radiation in this area was available throughout the year, with a daily average of 4.36 kWh/m^2. Regarding wind power, the region experiences moderate wind speed. The average wind speed is the most important parameter for planning wind systems. The average wind speed in this site is 5.5 m/s at a 10 m anemometer height, with the highest wind speeds in November and December being 6.8 and 6.9 m/s, respectively. The minimum wind speeds in August and July are 4.4 and 4.5 m/s, respectively. Table 1 lists the monthly average wind speed at the selected site.

3.2. Overview of Power Load

The national Grid cannot ensure reliable power supply to the cold chain facility. The average power outage time at this site was approximately 450 h per year, with the duration of each power outage varying. The load profile of the cold chain logistics centre was divided into two parts. The first part included all the different electrical equipment except for coolers, whereas the second part included an overview of the load of space cooling. The main load in this facility is vegetable refrigerators and freezers, and refrigeration is one of the main energy consumption components, as well as lighting equipment, material handling

Table 1. Solar radiation and wind speed values for the cold chain logistics centre.

Month	Wind Speed (m/s)	Horizontal Solar Radiation (kWh/m^2/Day)
January	6.4	3.16
February	6.1	3.30
March	5.5	3.77
April	4.8	4.38
May	4.5	4.86
June	4.9	5.30
July	4.5	5.88
August	4.4	5.28
September	4.9	4.91
October	6.5	4.56
November	6.8	3.70
December	6.9	3.26
Average	5.5	4.36

equipment, forklifts, electric vehicles, and office equipment [25] [26]. Table 2 lists the daily load on the site.

The average hourly electrical demand for a day is shown in Figure 1, which shows the daily load when the ambient temperature is 35˚C during the day and 29˚C at night. The maximum load was 94 kW, the minimum load was 65 kW, and the average load was 79.83 kW. In addition, the random load change rate was 3%, so the peak load of the cold chain logistics centre could reach 96.82 kW.

Table 2. Loads per day in the cold chain logistics centre.

Load	Rated Power (W)	No. of Units	Operating Hours	Load (kWh)
Refrigeration room	4000	8	24	768
Freezing room	4500	6	24	648
Refrigerator	200	2	24	9.6
Exhaust fan	100	5	6	3.0
Air conditioning	3000	5	6	90
Laptops	50	5	6	1.5
Down lamp	50	5	8	0.9
Printer	1000	5	8	2.0
Compact fluorescent light bulbs	20	3	8	0.48
Desktop computer	300	10	12	36
Kettle	100	4	3	1.2
Electric vehicles	2000	5	12	120
Forklifts	4000	6	10	240
Automatic guidance vehicles	3000	10	12	360
Wi-Fi router	20	5	24	2.4
	Total			2284.08

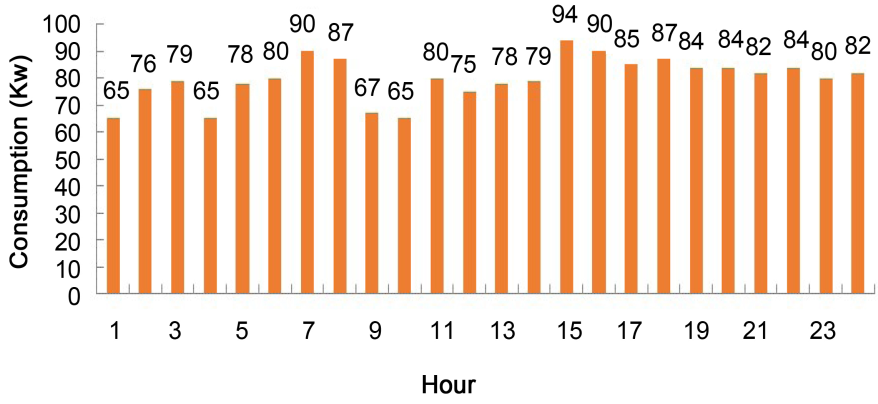


Figure 1. Hourly load of cold chain logistics centre.

The cold logistics centre requires an average of 1915.92 kWh of electricity every day.

Figure 2 shows an overview of the monthly load with peak demand starting in July and decreasing from August to the end of the year. The growth is attributable to the high temperature in summer, which imposes heavy loads on the cold chain logistics centre. The average daily consumption of scaled power was 92.67 kWh/day, with a peak of 2780 kWh in July. The increasing consumption is attributable to the June harvest, during which the owner stores the harvested food in the refrigerator warehouse. During the period from storage to sales, as all refrigerators are in operation, electricity consumption increases. Further, electricity consumption is low from August to November.

In addition, the load increase was due to the impact of changes in surrounding environment and evaporation temperature, resulting in an increase in temperature in the cold chain logistics centre [27]. According to Star Refrigeration (Pearson, 2019), the specific energy consumption for a well-managed 100,000 m^3 refrigeration warehouse should be 10 kWh/m^3/year, whereas for a 500,000 m^3 warehouse, it may be less than 5 kWh/m^3/year [28].

3.3. Physical Modelling and Specification

This study focused on the renewable energy system optimisation design of a cold chain logistics centre in China because refrigeration energy consumption in cold storage accounts for the majority of the total energy consumption. Additionally, to ensure refrigeration efficiency and reduce the total energy consumption, it can effectively reduce operating costs. The optimal configuration of an integrated renewable energy system depends on various modelling parameters, such as technical and economic parameters.

The proposed hybrid system was designed based on energy requirements. The hybrid system consists of a wind turbine, solar photovoltaic array, a grid-tied inverter, and a national home appliance grid. The grid-tied system requires an inverter to adapt to the DC current generated by the photovoltaic array and feed it to the AC bus connected to the load [29] [11]. Solar photovoltaic/wind energy

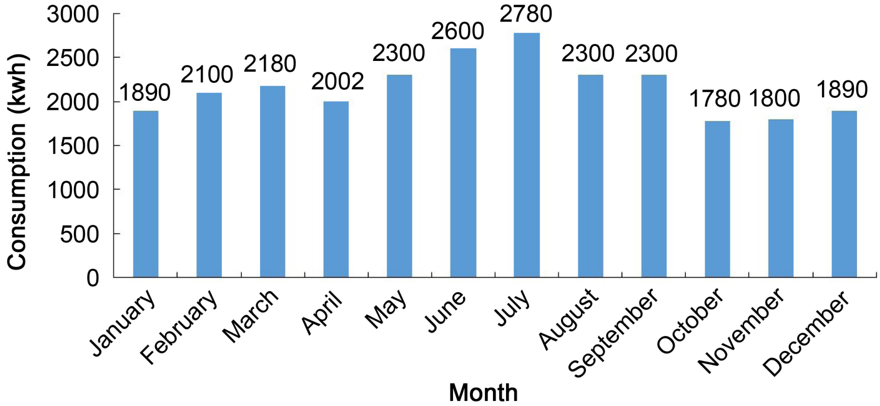


Figure 2. Monthly load of cold chain logistics centre.

systems rely solely on renewable energy. However, if solar photovoltaic and wind power meet the load requirements, the redundant electricity will be exported to the grid at a certain price. Figure 3 shows a schematic of the proposed system.

The renewable power capacity; specifications of the photovoltaic modules, wind turbines, and inverters for the proposed system; system economic indicators; and search criteria for each component of the cold chain logistics centre are described below. The simulation software RETScreen for renewable energy projects was used to determine the capacity of solar photovoltaic or wind turbines to meet the estimated total energy demand. We proposed a hybrid system consisting of a 6 kW photovoltaic system and a 150 kW wind power system based on the electricity demand.

The first specification of the RETScreen wind power system is wind speed, which was 3.2 m/s at a height of 10 m. Atmospheric pressure and air temperature are important considerations in wind electricity projects, as they can be used to estimate the air density on site. This study estimated the atmospheric pressure and air temperature of RETScreen as 100.7 kPa and 26˚C, respectively. This resulted in a pressure coefficient of 0.0998 and a temperature coefficient of 0.961. The capacity factor was calculated based on all these specified inputs. Generally, the capacity factor of wind power system ranges from 20% to 40%. The RETScreen input for this part is presented in Table 3.

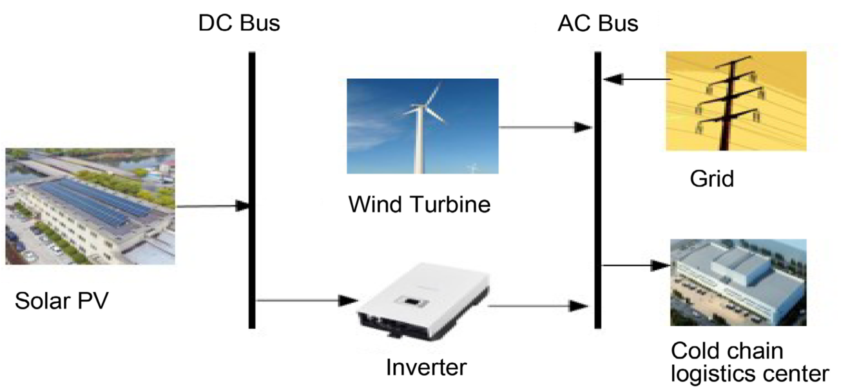


Figure 3. Schematic of the proposed system.

Table 3. RETscreen input for 150 kW wind power system.

Parameter	Values
Electricity price	0.1$
Array loss	0%
Miscellaneous losses	6%
Wing loss	2%
Availability	98%
Initial cost ($/Kwh)	1500
Q&M cost ($/Kwh)	40

This section determines the type, quantity, miscellaneous losses, tracking mode azimuth, slope of the solar panel, and efficiency of solar panels, and the miscellaneous losses, capacity, and efficiency of the inverter are specified. Miscellaneous loss refers to the array loss (%) caused by miscellaneous sources not considered elsewhere in the model. For example, this includes losses caused by mismatches or dirt on the module and wiring losses. **Table 4** provides a summary of the inputs used for the energy modelling of 6 kW solar facilities.

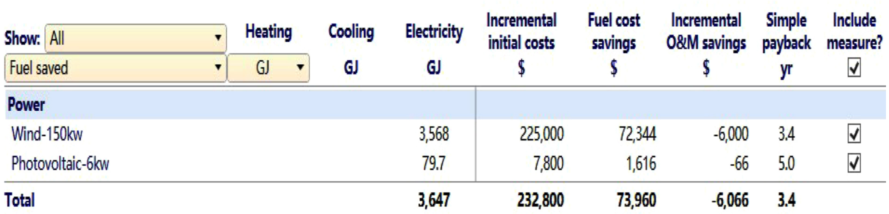
The recommended hybrid system includes AC and DC power sources. The inverter is used to transmit power between two bus bars, and it has a service life of 15 years. The peak electricity demand of the system determines the size of the inverters used in the hybrid system. Ideally, the inverter should be large enough to always meet the system demand, which means it must fully meet the total peak power requirements. Therefore, an inverter that is around 30% larger than the total load is recommended [30]. The hybrid system model established in RETScreen is shown in **Figure 4**, which consists of a 150 kW wind power generation system and a 6 kW photovoltaic facility.

4. Simulation Results and Discussion

RETscreen Pro simulates each feasible power configuration as well as the technical, economic, and environmental analysis of power generation systems configured as cold chain logistics centre loads based on available energy and load

Table 4. RETscreen inputs for 6 kW photovoltaic equipment.

Parameter	Values
PV type	Amorphous silicon
Solar tracking mode	Two-axis
Electricity price	0.1$
Photovoltaic power generation	6 kW
Inverter efficiency	98%
PV miscellaneous losses	5%
Inverter capacity	10 kW
Initial cost ($/kWh)	$1300
Miscellaneous losses of inverters	0%
Q&M cost ($/kWh)	11$



Show: All / Fuel saved	Heating GJ	Cooling GJ	Electricity GJ	Incremental initial costs $	Fuel cost savings $	Incremental O&M savings $	Simple payback yr	Include measure?
Power								
Wind-150kw			3,568	225,000	72,344	-6,000	3.4	✓
Photovoltaic-6kw			79.7	7,800	1,616	-66	5.0	✓
Total			3,647	232,800	73,960	-6,066	3.4	

Figure 4. Wind solar energy system in RETScreen.

requirements. The results indicate that compared to the electricity prices of the national grid, this system not only meets the energy needs of the cold chain logistics centre but also yields economic benefits. We compared the technical and economic details of different scenarios, as well as electricity production, and then considered the carbon dioxide emissions reduced under the defined scenario [31].

4.1. Technical Feasibility

The technical feasibility of integrated system depends on the solar irradiance accepted and the electricity generated. To a large extent, the efficiency and effective utilisation of the system depend on the specifications of the products used. The annual power generation of wind turbines is 882.238 MWh, and the energy generated by wind power modules mainly depends on the local wind speed, which ultimately affects the annual export electricity of the system. The increase in total electricity exports has had a positive impact on the revenue of the cold chain logistics centre. The analysis using RETScreen reveals the annual wind speed of the module. The energy output in January was the highest (86663.533 kWh), whereas the energy output was the lowest (59933.6 kWh). **Table 5** summarises the wind speed and electricity export from the RETScreen software.

The annual power generation of photovoltaic generators was 22.131 MWh, and the power generation of solar photovoltaic modules depends on the solar irradiance, sunny days, and sunny hours of the cold chain logistics centre, ultimately affecting the total annual export electricity of the system. The increase in

Table 5. Wind speed and electricity export summary.

Month	Solar radiation Horizontal (kWh/m²/d)	Solar radiation titled (KWh/m²/d)	Electricity rate annual ($/kWh)	Electricity production (kWh)
January	3.16	4.49	0.1	1531.929
February	3.30	4.20	0.1	1292.794
March	3.77	4.47	0.1	1520.652
April	4.38	5.03	0.1	1650.843
May	4.86	5.77	0.1	1947.020
June	5.30	6.40	0.1	2085.319
July	5.88	7.37	0.1	2474.628
August	5.28	6.27	0.1	2108.000
September	4.91	6.12	0.1	1992.442
October	4.56	6.34	0.1	2134.676
November	3.70	5.22	0.1	1710.244
December	3.26	4.95	0.1	1682.127
Annual	4.37	5.56	0.1	22130.674

total electricity exports has a positive impact on the revenue of this facility, whereas a decrease in exports leads to a decrease in revenue.

RETScreen analysis reveals that July had the highest energy export volume (2474.628 kWh), whereas December had the lowest energy export volume (1292.794 kWh) when considering the inherent high irradiance. This distribution was consistent with the weather conditions in Guangzhou, where July is the peak season of the high temperature season. **Table 6** summarises the irradiance and power exports from the RET-Screen software.

4.2. Economic Viability

Mehmood *et al.* described the economic feasibility of a project as a measure of its NPV, IRR, annual lifecycle savings, and payback period, all of which are important determining factors for the financial feasibility of the project [32]. RET-Screen software calculates annual living savings and other financial indicators. The output of financial parameters is shown in **Figure 5**, which presents the annual cash flow of the proposed hybrid system. Considering the payback period, the cash flow of the hybrid system was positive, indicating a positive income.

Figure 6 shows the cumulative cash flow of the hybrid system. The equity recovery period of this project was the 11th month of the 3rd year. These findings have attracted renewable energy investors. **Figure 7** shows the time required to recover the investment in years, and it may be the most widely used financial indicator in investment. Noticeably, the ALCS value of this project is high. **Figure 7** also shows the financial feasibility of the proposed system.

Table 6. Irradiance and electricity export summary.

Month	Wind speed m/s	Atmospheric Pressure (kPa)	Air temperature (˚C)	Electricity rate annual ($/kWh)	Electricity production (kWh)
January	6.4	101.7	16.4	0.1	86663.533
February	6.1	101.5	17.2	0.1	77537.896
March	5.5	101.3	19.4	0.1	80466.243
April	4.8	101.0	22.4	0.1	66942.470
May	4.5	101.6	25.2	0.1	62872.399
June	4.9	101.3	27.2	0.1	67153.699
July	4.5	101.3	28.1	0.1	62056.387
August	4.4	101.2	28.0	0.1	59933.666
September	4.9	101.5	27.1	0.1	67350.246
October	6.5	101.1	24.5	0.1	83821.822
November	6.8	101.4	21.3	0.1	81951.158
December	6.9	101.7	17.6	0.1	85488.037
Annual	5.5	101.0	22.9	0.1	882,238

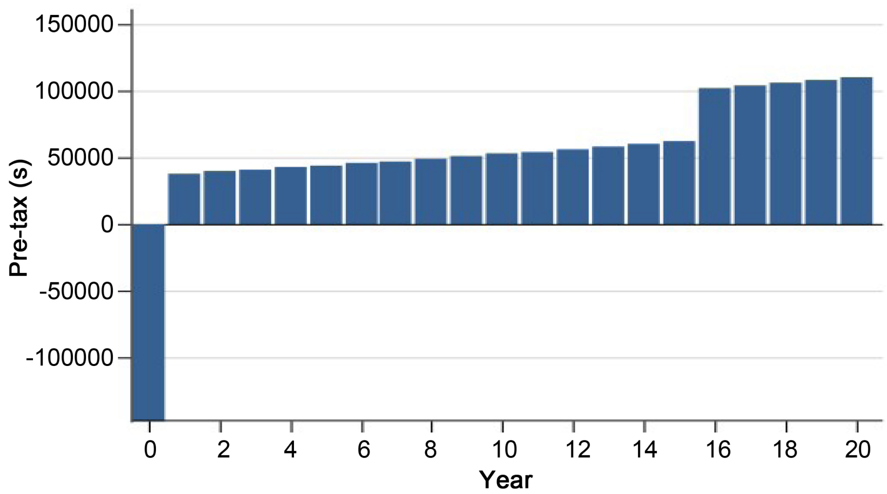


Figure 5. Annual cash flow of the proposed hybrid system.

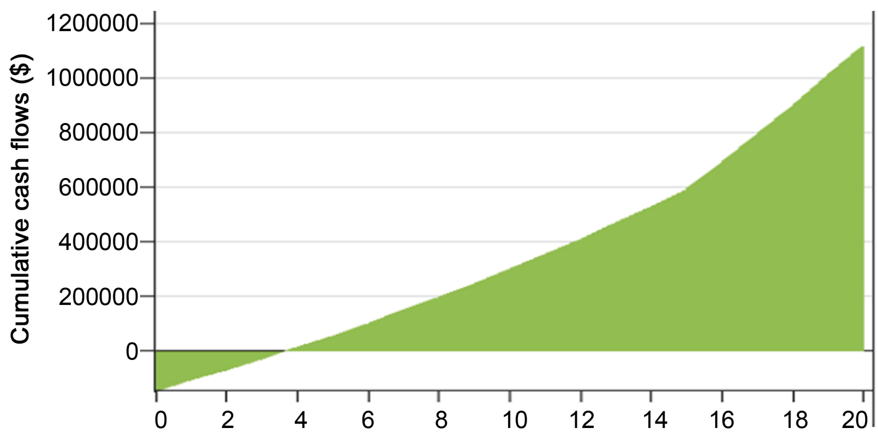


Figure 6. Accumulated cash flow.

Financial viability		
Pre-tax IRR - equity	%	29.2%
Pre-tax MIRR - equity	%	15.7%
Pre-tax IRR - assets	%	8.9%
Pre-tax MIRR - assets	%	8.9%
Simple payback	yr	6.1
Equity payback	yr	3.7
Net Present Value (NPV)	$	339,014
Annual life cycle savings	$/yr	37,138
Benefit-Cost (B-C) ratio		3.3
Debt service coverage		2
GHG reduction cost	$/tCO$_2$	-47.56

Figure 7. Financial viability from RETScreen.

4.3. Emission Reduction

Figure 8 shows the total emission reduction, initial baseline GHG emissions, and proposed case carbon emissions of the hybrid system. The basic GHG emissions were 714 t CO_2, whereas those of the proposed hybrid system were 24.1 t CO_2. If the proposed hybrid system is implemented, the total greenhouse gas emissions can be reduced by 690 tons of carbon dioxide. This supports the argument that the proposed design is environmentally friendly and, therefore, acceptable.

The results indicate that the proposed wind/photovoltaic project has good economic benefits in the cold chain logistics centre. The analysis results indicate that the hybrid system is a more economical than wind power projects, as the values of NPV and ALCS are higher and the simple payback is shorter. In addition, Figure 8 shows that this hybrid energy system helps to reduce greenhouse gas emissions.

This article proposes an integrated solar photovoltaic and wind energy system that with the power grid to support existing power generation capabilities. In addition, the NPV was $339.014, and the pretax IRR was 29.2%, indicating that the hybrid system is economically feasible. The environmental assessment in this article shows that the greenhouse gas emissions from solar, photovoltaic, and wind hybrid power generation have decreased by 96.6%. If China had a greenhouse gas reduction credit rate, such as $25 per ton of carbon dioxide emissions, the proposed system would generate an annual greenhouse gas reduction income of $2415.00. This greenhouse gas policy will encourage businesses to make direct efforts and adopt procedures to reduce their greenhouse gas emissions. This will gradually accelerate the national goal of increasing the proportion of renewable energy.

The total power generation of this system indicates that the renewable energy system can effectively fulfil the annual electricity demand of the cold chain

GHG emission			
Base case	tCO_2	714	
Proposed case	tCO_2	24.1	
Gross annual GHG emission reduction	tCO_2	690	96.6%

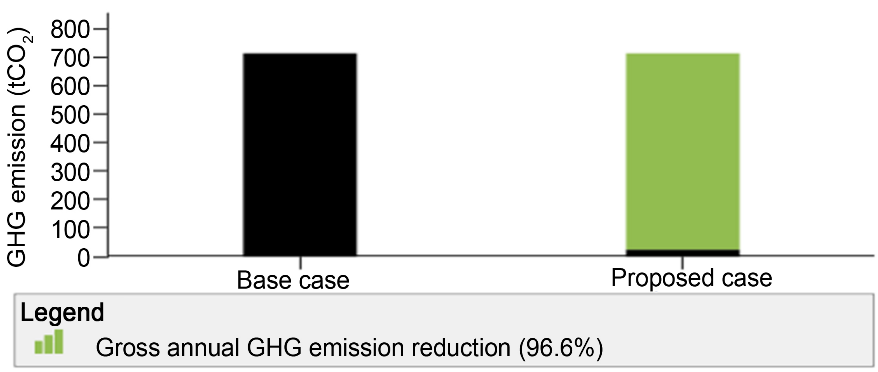


Figure 8. Carbon emission reduction.

logistics centre. Compared with a single energy system, this system can provide loads more effectively. It is observed that renewable energy systems can conveniently provide loads. Although renewable energy systems are usually technically easy to implement, their economic feasibility faces many major obstacles. In the past year, the price of solar photovoltaic cells has been very high. Wind energy saving technology is limited to developed countries, which makes it very expensive in developing countries with these resources. China's solar power generation technology is not as mature as wave energy. These barriers make renewable energy system too expensive and shorten their lifespan.

5. Conclusions

Renewable energy systems can be economical and feasible, especially in developing countries with abundant renewable energies. This study investigates the technological and economic feasibility of solar photovoltaic and wind energy systems in a cold chain logistics centre in China. The main conclusion that can be drawn is that an integrated system with a wind power installed capacity of 150 kW and a solar photovoltaic installed capacity of 6 kW is feasible. The feasibility of the designed hybrid system indicates that it can meet the energy needs of the cold chain logistics centre.

The load distribution of a 156 kW grid-connected solar photovoltaic wind power hybrid system was simulated using RETScreen software. Solar photovoltaic power generation reaches 22130.674 kWh, whereas wind power generation reaches 882,238 kWh. In addition, the lifespan of the project is 20 years, and the simple payback period is approximately 6 years and 1 month, which confirms the economic feasibility of the system.

The limitation of this research was by the use of secondary data to design the hybrid energy system. The data used in the technical feasibility analyses were based on the historical climate data of China. Future research directions that may improve the economic performance should be further investigated in dynamical values. In addition, land availability was not taken into account considered in this study. Thus, measuring land area required for grid-tied renewable energy system will be future research. The feasibility of renewable energy projects could be better assessed by using cost of power grid limitations and labor. Therefore, further studies would be recommended to confirm the actual energy required by cold chain logistics Centre operations and the requirements for fulfilling the renewable energy project of choice.

In general, the implementation of solar PV (PV) wind systems in this cold chain logistics could be economically feasible and environmentally. An integrated solar PV wind system will help to reduce carbon emissions and save energy in China because of the high potential in the renewable energy industry. Therefore, the finding of this study could be helpful for the government and the concerned stakeholders to extend these systems into the similar environmental conditions for applied to other industry.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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