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Economic and Environmental Analysis of Solar Thermal and Seasonal Thermal Energy Storage Based on a Renewable Energy Conversion System for Greenhouses

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Abstract: This study investigates the economic benefits of solar thermal and seasonal thermal energy storage based on a renewable energy conversion system for greenhouses. The proposed system consists of solar collectors, seasonal thermal energy storage, hybrid-source heat pumps, and ground-source heat pumps. The heat generated from the proposed system was stored in two types of seasonal thermal energy storage and supplied to the greenhouse using Purme Yeoju Farm in South Korea for experimental analysis. Based on the experimental data gathered over a heating system, the economic benefits of operating cost savings and carbon trading with the greenhouse gas emission reduction of the proposed system were investigated by comparing to a conventional heating season using oil and electric boilers. From October 2021 to March 2022, approximately 38.4% of the total 482 MWh of heat was supplied either directly or indirectly through the solar system. In addition, the coefficient of the performance of the entire proposed system was calculated to be 2.28. Both the operating cost savings and greenhouse gas emission reductions of the proposed system showed over 73% and 82% compared with those of conventional systems.

Keywords: solar thermal; seasonal thermal energy storage; greenhouse; operation cost; greenhouse gas emission

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1. Introduction

Owing to the persistent climate crisis, which includes global warming, a transition to a low-carbon society has been established as an important present-day agenda. The Korean government has set goals for the transition to a low-carbon society, such as the nationally determined contribution (NDC) target and renewable portfolio standards. According to the Food and Agriculture Organization of the United Nations (FAO) [1], the food chain represents 30% of global greenhouse gas (GHG) emissions, and the supply of energy using fossil fuels represents 19 to 29% of carbon emissions. FAO defines sustainable development in the agricultural sector through three aspects: a sustainable increase in agricultural productivity and income, adaptation and a flexible response to climate change, and the reduction and removal of GHG emissions. Consequently, the development of technology to implement a sustainable food system is required to respond to the environmental problems caused by the use of fossil fuels and their increasing cost, and to consider future food security issues due to the prolonged COVID-19 pandemic. In addition, research on agricultural energy independence through the use of renewable energy has been actively conducted worldwide as one of the methods to implement a sustainable food system.

Unfortunately, in the domestic agricultural sector, the proportion of renewable energy supply is low, and a considerable amount of energy depends on fossil fuels. Specifically, the heating and cooling energy consumed in heated greenhouses mainly depends on oil (81%), followed by electricity (9%), solid fuel (7%), ground heat sources (3%), and gas (1%), indicating a high proportion of fossil fuels [2]. According to the Korea Energy Agency [3], GHG emissions from the domestic agricultural sector accounted for 3% of total emissions (701 million $tCO_2eq.$) as of 2019, and their five-year average was 21 million $tCO_2eq.$, showing consistently high emissions. As thermal energy supply through fossil fuels generates a large amount of GHG emissions and consumes considerable energy from the perspective of primary energy, expanding the supply of renewable energy in the agricultural sector is expected to significantly reduce energy consumption and GHG emissions.

Various studies have been conducted on the applicability of renewable energy in the agricultural sector. According to Park et al. [4], the use of ground-source heat pumps (GSHPs) increased paprika production by 9539 kg/10a, and had the effect of replacing 1137 L/10a of petroleum. Nacer et al. [5] examined the GHG reduction effect when constructing an optimal system in seven dairy farms in Algeria by combining the grid power, solar power, wind power generation, and Energy Storage System (ESS) through the analysis of the potential amount of renewable energy. They found that 9000 to 59,000 tons of CO_2 could be reduced per year through system optimization in each case. A representative renewable energy conversion community in South Korea is the Jincheon Eco-Friendly Energy Town. Kim et al. [6,7] verified that, in this community, more than 130% of the total public building power load and 100% of the thermal energy demand are supplied by renewable energy in the town through various renewable energy conversion systems, such as solar power, solar heat, seasonal thermal energy storage, geothermal heat, and sewage heat.

In the agricultural sector, energy cost savings through the application of renewable energy have, in many cases, been pursued only passively because of the availability of various energy-related subsidies. In recent years, studies have been conducted on a reduction in GHG emissions in the agricultural sector and the additional economic benefits for farms through carbon trading [8]. However, most of these studies are focused on policy perspectives based on the production, consumption, and distribution of agriculture. These include analyzing the effect of decision-making by people engaged in agriculture on the carbon emission reduction [9]; analyzing the effect of carbon trading on the carbon emission reduction in the agricultural sector for each EU country [10]; analyzing the influence of carbon trading on the agricultural sector from a policy perspective [11]; and analyzing major factors, such as the effect of renewable energy application on manpower in the national agricultural sector [12] and the effect of GHG on the economic growth of agriculture. In the energy sector, it is hard to find cases that analyze the carbon emission reduction effect through renewable energy equipment in connection with carbon trading. As such, if carbon emission allowances recognize the energy consumption reduced in a farm through the application of renewable energy and carbon trading from a starting point of conventional equipment, it will have a positive impact on the income of the farm, and can be used as an incentive for aggressive efforts to reduce carbon emissions.

In a previous study, Kim et al. proposed an energy-independent smart farm by supplying cooling, heating, and electricity to a heated greenhouse using a renewable energy conversion system, and analyzed the energy cost savings through simulation [13]. Based on this, the operating system of the test site was completed in 2021, and solar collectors and tank type seasonal thermal energy storage (TTES) were implemented.

In this study, based on the demonstrated results of the greenhouse that used renewable energy, such as solar and geothermal heat, the operating cost and GHG emission reduction were analyzed for the first heating period of the first year. In addition, economic analysis was conducted based on the farm income that can be obtained through emission trading to increase the farm household income.

2. Renewable Conversion System Overview

The test site was Purme Yeoju Farm located in Yeoju City, Gyeonggi-do, South Korea, as shown in Figure 1. The major components are of solar collectors (462 m^2), photovoltaic and solar thermal (PVT) collectors (234 m^2), and ground-source and multi-source heat pumps (130 RT), providing cooling and heating to the nearby greenhouse in connection with heat storage systems, such as the TTES (1200 m^3), buffer heat storage tank (120 m^3), and borehole-type seasonal thermal energy storage (BTES; 28,500 m^3). The proposed system began to supply heating to the greenhouse at a size of 3942 m^2 starting in October 2021, and the PVT system was constructed in July 2022 and remains in test operation. As such, in this study, analysis was conducted based on the demonstration operation results for the equipment already constructed and the simulation results for the PVT system. Figure 2 shows the system configuration of the proposed system. For the heating operation, the heat produced by the solar collectors from spring to autumn is stored in TTES, and the heat produced by the PVT collectors is stored in BTES. The heat of TTES is directly supplied to the greenhouse during the heating period, but the heat of BTES is supplied as the evaporation heat source of the heat pump (HP2) because it cannot be directly supplied for heating, as the heat storage temperature is lower than the heating supply temperature. When the internal temperature of TTES becomes lower than the heating supply temperature (approximately 40 °C or less), the residual heat of TTES is supplied as the evaporation heat source of the heat pump (HP1). In addition, the heat supply for the greenhouse is produced through the heat pump (HP2) using the heat supplied from TTES and BTES as the evaporation heat source, and GSHP (HP3) for insufficient heat. Other than GSHP, the heat pumps are multi-source heat pumps (MSHPs). They can produce heat and cold energy using the air source, the252 heat pump, and be operated as air-source heat pumps (ASHP). Under the cooling operation, cold energy is supplied to the greenhouse using the air and ground sources. In this study, the operation effect of the cooling supply was excluded from the analysis.

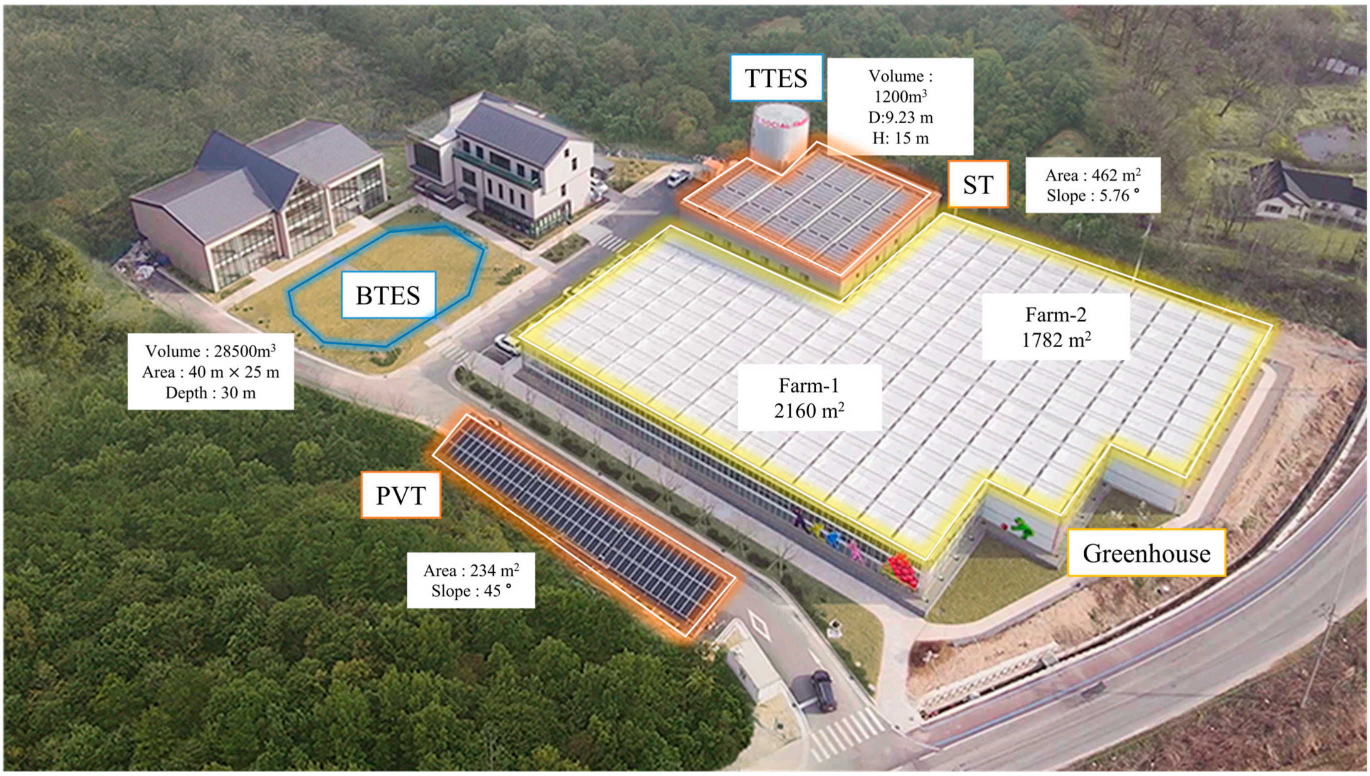

Figure 1. View of the test site.

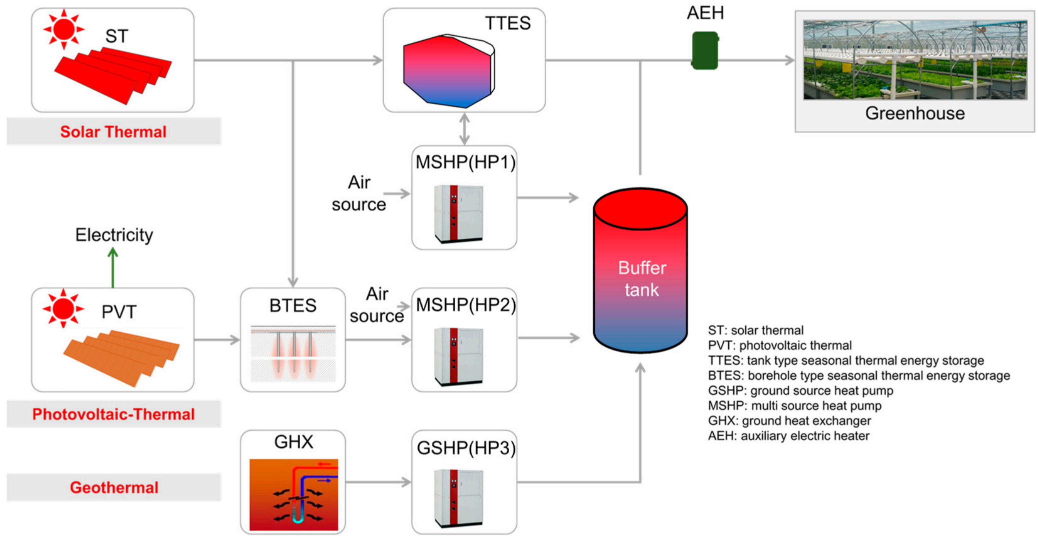

Figure 2. Configuration of the proposed system.

3. Research Method

3.1. Measurement Instruments

In the test site, measurement sensors, including 82 temperature sensors, 19 pressure sensors, 21 flow rate sensors, five pyranometers, 11 temperature/humidity sensors, three photosynthesis sensors, and 16 watt-hour meters, were installed in major parts to monitor the operation status of each heat source component in real time. The measurements of each sensor were saved every 30 s. Figure 3 and Table 1 show the positions and specifications of the measurement sensors. The heat supply and energy consumption of each heat source component were calculated based on data such as the inlet/outlet temperatures, flow rate, and power of the heat source component among the measured data, and the GHG emissions and operating cost were estimated through the calculated amount of heat and power.

Table 1. Detailed information of measurement instruments.

Measurement Sensor	Specification
Temperature	RTD PT100 Ω, 3 wire
Pressure	Pressure Range (0~10) kgf/cm^2 g, Accuracy 0.039%
Flow rate	Flow Rate (0~180) m^3/h, Accuracy ±0.5%
Irradiance	First class, Range ~2000 W/m^2
Temperature/ Relative Humidity	Temperature Range (−40~60) °C, Accuracy ±0.6 °C Relative Humidity Range (0~100)% Accuracy from (0~40) °C ±3% relative humidity (RH) over (0~90)% ±5% RH over (90~100)% Accuracy from (−40~0, 40~60) °C ±5% RH over (0~90)% ±7% RH over (90~100)%

The analysis period was the heating supply period from 1 October 2021 to 31 March 2022. Based on the total heat energy supplied to the greenhouse, the operating cost and GHG reduction effect were compared between the heat source components applied to the test site and the conventional heat source components. As for the performance specifications of the conventional heat source components, a fuel calorific value (11) of 9.5 kWh/L (8200 kcal/L) was applied to the oil (kerosene) boiler, and an equipment efficiency of 85% was determined for both the oil and electric boilers.

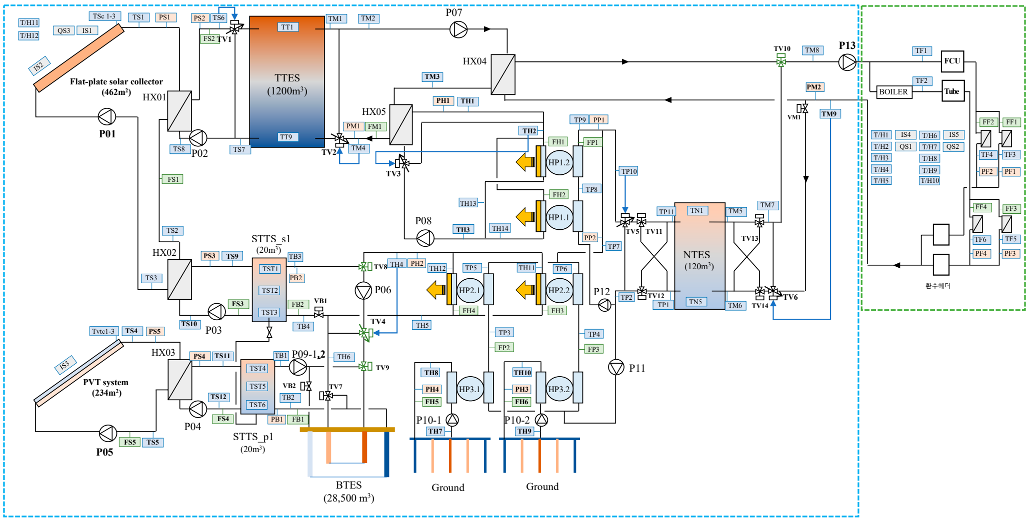

Figure 3. View of detailed monitoring point.

3.2. Economic and Environmental Analysis

The initial investment costs for capital expenditure (CAPEX) analysis were included in the economic analysis (see Table 2), which included the actual costs of purchase for realizing Purme Yeoju Farm. The energy costs, fixed operational costs, fixed equipment costs, and other variables required for annual operation were considered in the operating expense (OPEX) analysis. Furthermore, the cost of fuel for operating the equipment was accounted for in the energy expense analysis, and the personnel expenses for operating the equipment were included in the fixed operational cost analysis. The depreciation and maintenance costs reflecting the lifespan of the equipment were considered for the fixed equipment cost. The costs of operating the other miscellaneous equipment were assumed to be 10% of the operational costs. To consider the fixed equipment cost, the lifespan of seasonal thermal energy storage was assumed to be 50 y, monitoring and components control system was assumed to be 15 y, and that of all remaining equipment was assumed to be 30 y. For the economic analysis, the initial investment cost was included in the OPEXs, amortized over the service life. The equipment was assumed to be operated by 0.3 people and to cost 10,000,000 KRW/y.

Table 2. Investment cost of the systems.

Components	Price	Unit	Case 1	Case 2	Case 3
Oil boiler	0.05	10^6 KRW/kW	50,000		
Electric boiler	0.04	10^6 KRW/kW		40,000	
Solar thermal collectors	0.35	10^6 KRW/m^2			160,000
Heat pumps	1.27	10^6 KRW/RT			310,000
TTES	0.31	10^6 KRW/m^3			320,000
BTES	0.01	10^6 KRW/m^3			340,000
Buffer tank	0.45	10^6 KRW/m^3	90,000	90,000	130,000
Pipeline	250	10^6 KRW/set	25,000	25,000	250,000
System integration and control system	75	10^6 KRW/set	75,000	75,000	75,000
Capital expenditures (CAPEX)			240,000	230,000	1,585,000

In order to analyze and compare various system cases, case studies have been investigated. Case 1 is oil boiler, Case 2 is electric boiler, and Case 3 is proposed system. To observe the impact on the PVT system integration, Case 3-1 is set as the proposed system without PVT system operation, and Case 3-2 is set as the proposed system with PVT system operation.

The maximum heating load for the proposed equipment was determined as 1000 kW, and the capacity of the electric boiler was designed to be 1100 kW. Regarding the calculation of the conventional heat source operational costs, the unit price of kerosene (that is, the average price of duty-free oil determined by the Korea National Oil Corporation in Gyeonggi Province) determined the cost of operating the oil boilers, and industry electricity costs determined the cost of operating the electric boilers, resulting in over 1000 kW of electric capacity priced at the industry cost. The unit price for the monthly consumption of kerosene was between 868.54 and 1140.99 KRW/Liter. The average industry electricity price in South Korea (105 KRW/kWh) was used to determine the operational costs of supplying power to the electric boilers and the current system.

Although the power generation of PVT was not derived in these research results, its power reduction effect can be considered in future operation. In addition, the surplus power obtained through the power generation of PVT can be sold at the system marginal price (SMP). In this study, KRW 150/kWh, which is the transaction amount in January 2022, was used for analysis [14].

The coefficient of GHG emission for kerosene was considered with carbon emission factors for carbon dioxide, methane, and nitrous oxides [15]. The emission factors of kerosene consisted of 112 $tCO_2eq./TJ$, 0.3 $tCO_2eq./TJ$, and 0.004 $tCO_2eq./TJ$ of carbon dioxide, methane, and nitrous oxides, respectively. The global warming potential of those are 1, 21, and 310, in carbon dioxide, methane, and nitrous oxides, respectively. It was found that the kerosene for the oil boiler was set to 0.404262 $tCO_2eq./MWh$. The carbon emission coefficients of the electric boiler were set to 0.45941 $tCO_2eq./MWh$ [16].

3.3. Emission Trading Analysis

In this study, for the analysis of carbon credits, it was assumed that those corresponding to the reduced amount of carbon emissions could be sold based on the carbon emissions caused by the conventional heating system in the greenhouse. The allowable carbon emissions were analyzed based on the allowable emissions from oil and electric boilers, which are conventional heating systems. The carbon allowance price was analyzed based on the transaction amount in the Korea Exchange of South Korea [16] as of January 2022 (35,000 KRW/ $tCO_2eq.$) and the EU Emission Trading System (ETS) carbon price [17] (81 EUR/$tCO_2eq.$; 108,000 KRW/$tCO_2eq.$). In order to compare the impact of carbon prices on the proposed system, various cases have been investigated. Table 3 demonstrates the comparable system cases. Case 3-1 and Case 3-2 are set as a proposed system without carbon trading, Case 3-3 is set as a proposed system with South Korea emission trading with an oil boiler allowance, Case 3-4 is set as a proposed system with South Korea emission trading with an electric boiler allowance, Case 3-5 is set as a proposed system with EU emission trading with an oil boiler allowance, and Case 3-6 is set as a proposed system with EU emission trading with an electric boiler allowance.

Table 3. System cases.

Cases	Description
Case 1	Oil boiler
Case 2	Electric boiler
Case 3-1	Proposed system without PVT system
Case 3-2	Proposed system with PVT system
Case 3-3	Proposed system with South Korea emission trading with oil boiler allowance
Case 3-4	Proposed system with South Korea emission trading with electric boiler allowance
Case 3-5	Proposed system with EU emission trading with oil boiler allowance
Case 3-6	Proposed system with EU emission trading with electric boiler allowance

4. Results

4.1. Experiment Results of the Proposed System during Heating Season

Figure 4 shows the daily ambient temperature and solar radiation of the test site during the analysis period. The average ambient temperature of the test site was 3.4 °C, which was lower than the national average ambient temperature (5.3 °C). The total solar radiation by month was the highest (95.1 kWh/m^2) in March 2022 and the lowest (59.9 kWh/m^2) in December 2021. Figure 5 shows the heat storage, heat supply, and internal average temperature of the TTES. The internal average temperature started at 65.4 °C on 1 October 2021 and was 46.5 °C on 22 October 2021. Most of the heat stored was directly supplied for heating during the month of October and later supplied as the evaporation heat source of the heat pump, thereby causing the lowest temperature of the heat storage tank (9.3 °C) on 23 February 2022. Figure 6 shows the daily heating supply from the heat source components in the test site to the load side. Heat was mainly supplied from the TTES until the end of October 2021, and then it was supplied from the heat pump that used the residual heat of the BTES and GSHP. In addition, the heat pump that used the residual heat of the TTES was operated starting from the end of January 2022 when the heat of the BTES was exhausted. MSHPs were operated using the air source from the end of December 2021 to the beginning of January 2022 when the load was heavy.

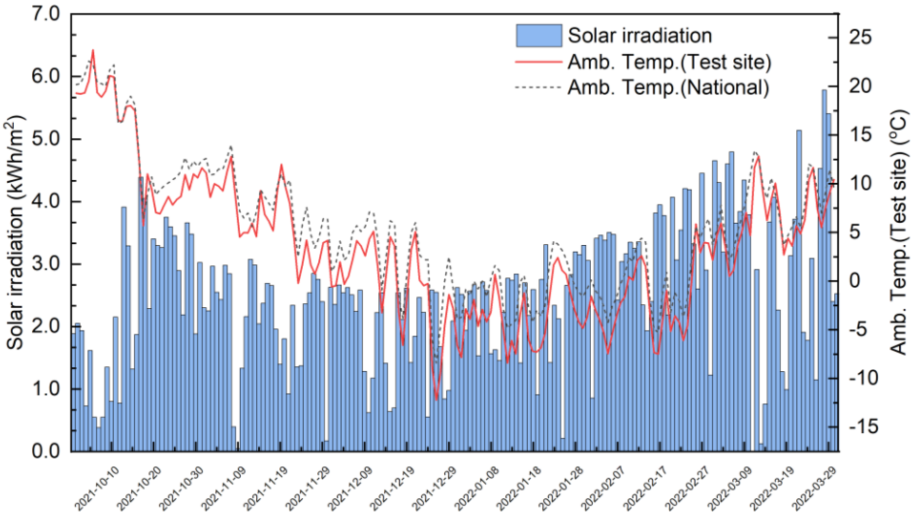

Figure 4. Daily solar irradiation and ambient temperature.

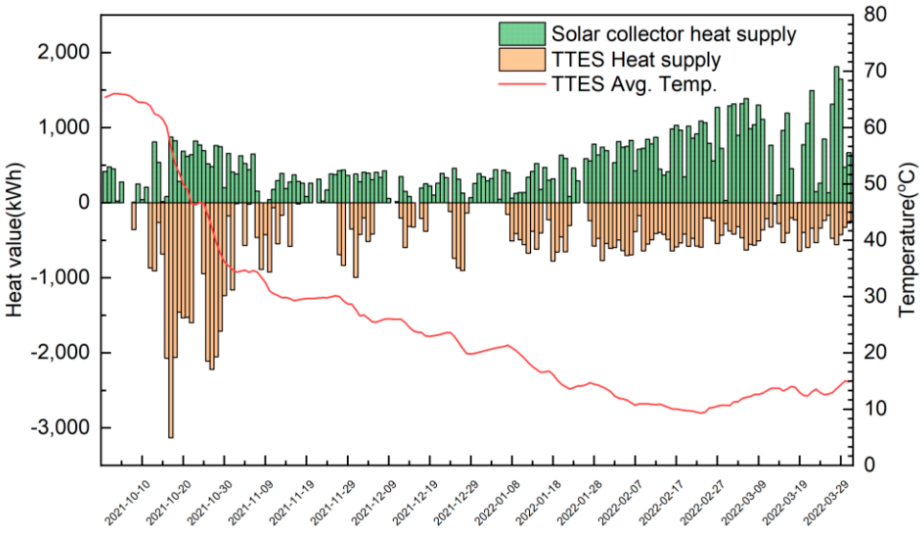

Figure 5. Daily heat balance of the TTES.

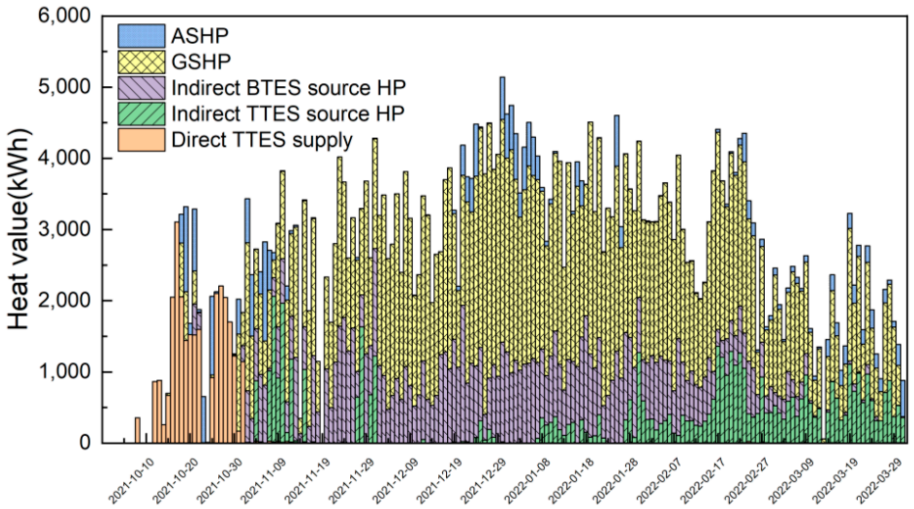

Figure 6. Daily heating supply of each component.

The empirical operational results obtained during the analysis period are summarized in Tables 4 and 5. The total thermal energy supply during the heating period was 489.2 MWh. The indirect TTES heat pump thermal supply refers to the energy supplied from the evaporation heat source of the heat pump when the heat supply is impeded because the temperature of the warm water of the seasonal latent heat storage system is lower than the designed temperature (that is, 40 °C). The direct and indirect thermal supply from the TTES accounted for 38.4% of the total energy supply.

Table 4. Monthly heating supply of the system operation.

	Direct TTES Supply	Indirect TTES-Source Heat Pump	Indirect BTES-Source Heat Pump	Ground-Source Heat Pump	Air-Source Heat Pump	Total
Oct. 2021	26.7	0.0	0.7	3.4	4.9	35.7
Nov. 2021	1.4	12.0	22.0	39.0	4.2	78.6
Dec. 2021	0.0	2.1	29.9	71.9	3.4	107.2
Jan. 2022	0.1	6.2	30.5	73.2	5.7	115.6
Feb. 2022	0.2	15.5	17.5	53.9	1.3	88.5
Mar. 2022	0.1	17.2	3.2	31.1	4.7	56.4
Total	28.4	53.0	103.8	272.5	24.2	481.9
Percentage (%)	5.9	11.0	21.5	56.5	5.0	100.0

Table 5. Monthly electric energy consumption of the system operation.

	Pumps for Solar Collector	Indirect TTES-Source Heat Pump	Indirect BTES-Source Heat Pump	Ground-Source Heat Pump	Air-Source Heat Pump	Pumps for Heat Pumps	Pumps for Thermal Network	Total
Oct. 2021	0.20	0.0	0.9	0.2	1.7	1.2	0.10	4.3
Nov. 2021	0.11	3.3	11.5	7.7	2.1	4.6	0.18	29.3
Dec. 2021	0.14	0.6	19.6	12.4	5.0	7.6	0.26	45.5
Jan. 2022	0.19	2.4	19.8	14.3	9.7	8.7	0.23	55.4
Feb. 2022	0.29	8.1	14.6	8.3	2.1	7.0	0.13	40.6
Mar. 2022	0.33	7.6	8.2	1.4	3.5	4.3	0.00	25.3
Total	1.3	22.0	74.5	44.4	24.1	33.5	0.9	200.5
Percentage (%)	0.6	11.0	37.2	22.1	12.0	16.7	0.5	100.0

The coefficient of performance (COP) was measured to be 3.05 and 1.01 for the heat pumps that used renewable heat sources and the air source, respectively. The system COP in consideration of the heat pumps and heat source circulation pumps was calculated to be 2.28. The heat energy was mainly supplied to the greenhouse at night. Since the ambient temperature of the test site at night in winter was low, the COP was found to be low when MSHPs were operated using the air source. The overall thermal performance and share of the solar heat energy are expected to increase after the second year, when the system stabilizes and the operation of PVT and BTES begins.

4.2. Operating Cost and Greenhouse Gas Emission

The total amount of heat supplied in the test site during the heating period was 481.9 MWh. The operating cost and GHG emissions of the same amount of heat supplied through conventional heat sources are shown in Figure 7. The results showed that GHG emissions from the proposed system were 38.7 and 64.6% lower compared to the methods of using conventional kerosene and electric boilers, respectively. When the annual power generation of PVT (48.0 MWh) was considered [13], it was found that emissions were reduced by 53.4 and 73.1% compared to when using conventional kerosene and electric boilers, respectively. The annual energy operating cost of the proposed system was reduced by 68.8 and 70.4% compared to when using industrial power and the conventional kerosene boiler with duty-free oil, respectively. In addition, when the power generation of PVT was considered, it was found that the energy operating cost was reduced by 81.9 and 82.8%, respectively.

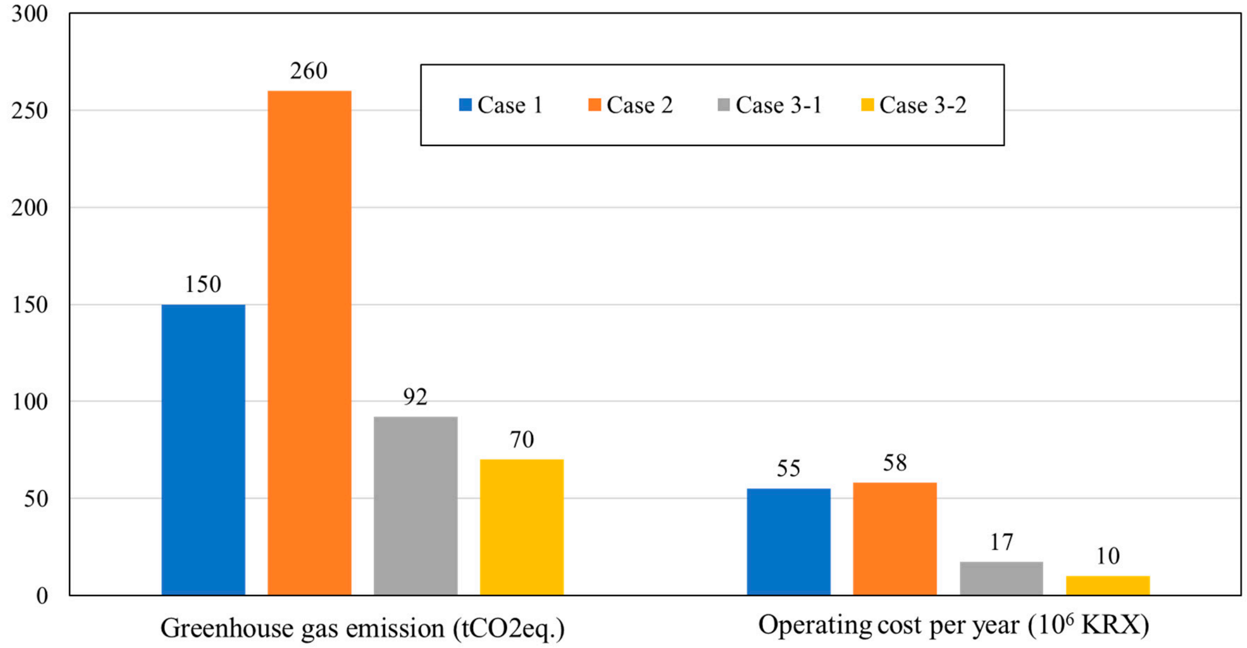

Figure 7. Greenhouse gas emission and operating cost of comparative systems.

In Figure 8, the carbon trading potential was derived according to the GHG emission reduction effect compared to conventional oil and electric boilers. The surplus emissions were found to be approximately 80 and 190 tCO_2eq. for oil and electric boilers, respectively. Based on this, the revenue of GHG emission trading is shown in Figure 9. It was found that additional profits of approximately KRW 2,800,000 and 6,650,000 can be obtained per year compared to the oil boiler and electric boiler allowances, respectively, based on the South Korea emission price. It was also found that additional profits of approximately KRW 8,643,000 and 20,523,000 can be obtained compared to the oil boiler and electric boiler allowances, respectively, based on the EU emission price. Consequently, when the surplus carbon credits of the conventional systems and the proposed system are traded at the EU emission price, additional income can be expected for farm households, as shown in Figure 10.

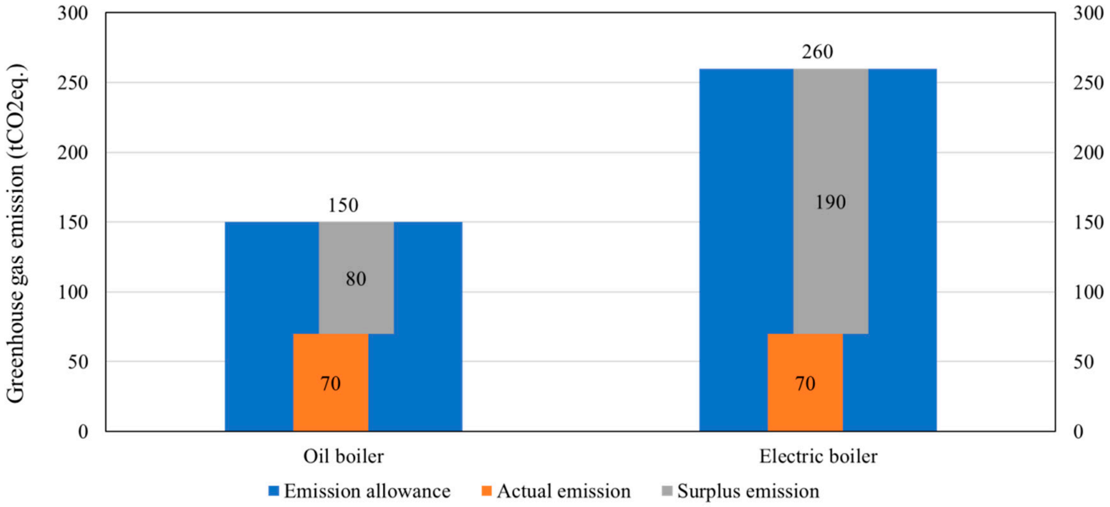

Figure 8. Greenhouse gas emission trading of proposed system.

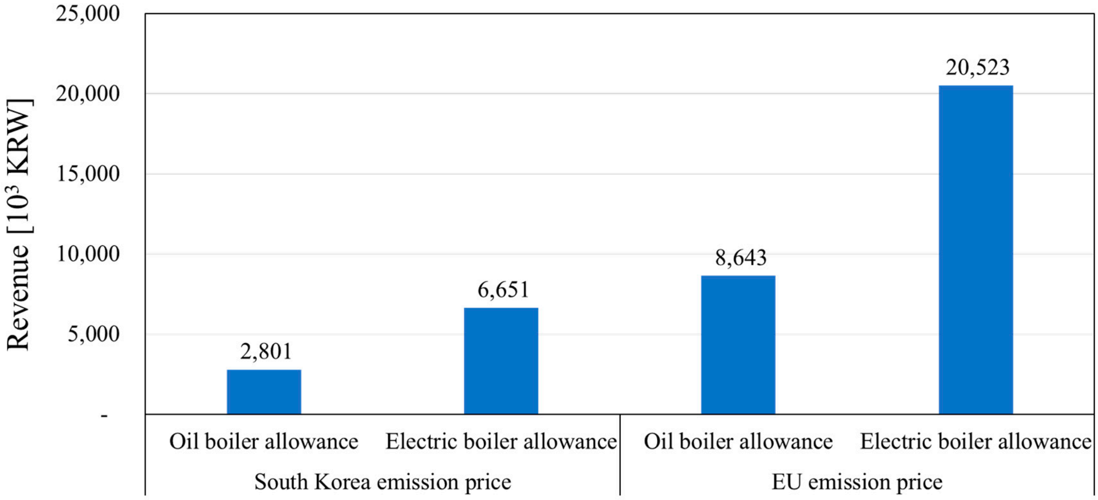

Figure 9. Revenue of greenhouse gas emission trading.

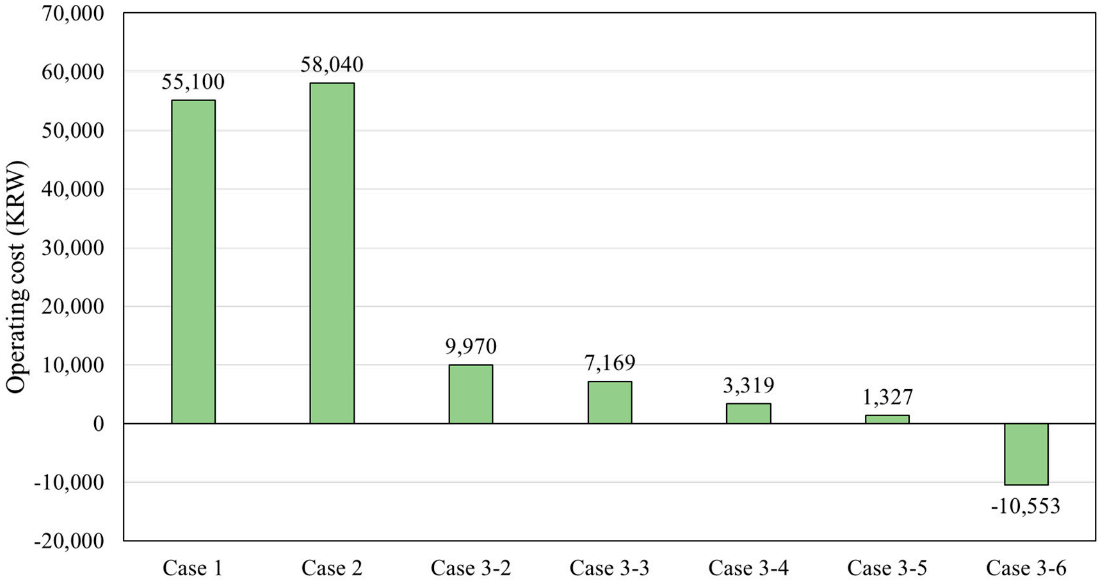

Figure 10. Annual operating cost of systems.

Based on this annual operating cost reduction effect, an economic analysis was conducted considering the initial investment cost capital expenditure (CAPEX) and annual operating expenses (OPEX) of the proposed system. As shown in Figure 11, in Case 3-2, which does not consider the profits of carbon credits, payback periods of approximately 25 and 21 y were derived compared to Case 1 and Case 2 systems, respectively. When Case 3-6, which considers the profits of carbon credits based on the EU emission price, was compared with Case 1 and Case 2, however, payback periods of approximately 13 and 12 y were derived, confirming the high economic efficiency of the proposed system.

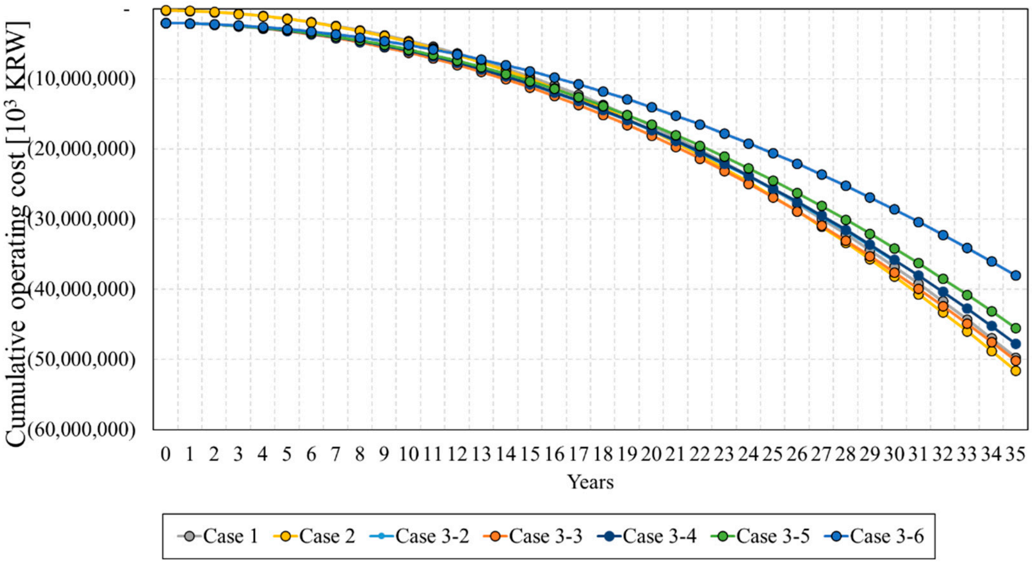

Figure 11. Cumulative operating cost.

5. Discussion and Conclusions

In this study, a renewable energy conversion system applied to a heated greenhouse was proposed, and the operation results and greenhouse gas (GHG) reduction effect were analyzed through a test operation in winter by constructing the proposed system in an actual greenhouse. Based on the derived test results, the energy operating cost and carbon emission reduction effect were compared with those of conventional oil and electric boilers, which are commonly used in heated greenhouses. In addition, profits that can be obtained through the trading of carbon credits due to the carbon emission reduction effect were analyzed, and the economic efficiency of the proposed system was analyzed through CAPEX and OPEX analysis that considers the initial investment cost of the actual system and the cost required for operation.

It was confirmed that the operation of the solar heat and heat pump systems constructed in the test site could supply heating with 53.4–73.1% carbon emission reduction and 81.9–82.8% operating cost savings compared to conventional oil and electric boilers. In addition, when economic efficiency was compared considering the initial investment and operating cost for cases in which the cost of carbon credits reaches the South Korea or EU level, it was found that the proposed system has high economic efficiency.

Due to the high initial investment cost, however, the payback period was analyzed to be approximately 14 y compared to the conventional systems when the trading of carbon credits was considered. The payback period was analyzed to be approximately 25 y when carbon credits were not considered. Therefore, if carbon trading is added in the form of a subsidy to agricultural systems as an incentive to apply low-carbon energy systems, along with national efforts to reduce carbon emissions, it is expected that high economic efficiency will be achieved.

The prices of fossil fuels, including kerosene, significantly vary depending on the time period. In South Korea, with a particularly high dependency on imported fossil fuels, the prices frequently fluctuate depending on external factors. Therefore, increasing the energy independence rate has become essential for the goal of reducing carbon emissions and stable farm operation.

The analysis results of the current test system were calculated based on the initial test operation data. When the system stabilizes, larger operating cost savings and a higher GHG reduction effect than the current operation results can be expected.

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References

1. FAO. *The Contribution of Agriculture to Greenhouse Gas Emissions*; FAO: Rome, Italy, 2020.
2. Nam, J.J. Agricultural Energy Use, Actual Condition and Improvement Plan. *Agric. Policy Res.* **2020**, *73*, 72–95.
3. Korea Energy Agency. *Energy Statistics Handbook*; Korea Energy Agency: Ulsan, Korea, 2020.
4. Park, J.; Kim, Y. The Effects of Renewable Energy in Agricultural Sector. *J. Korea Acad.-Ind. Coop. Soc.* **2019**, *20*, 224–235.
5. Nacer, T.; Hamidat, A.; Nadjemi, O. A Comprehensive Method to Assess the Feasibility of Renewable Energy on Algerian Dairy Farms. *J. Clean. Prod.* **2016**, *112*, 3631–3642. [CrossRef]
6. Kim, M.-H.; Kim, D.; Heo, J.; Lee, D.-W. Energy Performance Investigation of Net plus Energy Town: Energy Balance of the Jincheon Eco-Friendly Energy Town. *Renew Energy* **2020**, *147*, 1784–1800. [CrossRef]
7. Kim, M.-H.; Kim, D.; Heo, J.; Lee, D.-W. Techno-Economic Analysis of Hybrid Renewable Energy System with Solar District Heating for Net Zero Energy Community. *Energy* **2019**, *187*, 115916. [CrossRef]
8. Valin, H.; Havlík, P.; Mosnier, A.; Herrero, M.; Schmid, E.; Obersteiner, M. Agricultural Productivity and Greenhouse Gas Emissions: Trade-Offs or Synergies between Mitigation and Food Security? *Environ. Res. Lett.* **2013**, *8*, 035019. [CrossRef]
9. Bakam, I.; Matthews, R.B.; Bakam, I.; Matthews Macaulay, R.B.; Matthews, R.B. Emission Trading in Agriculture: A Study of Design Options Using an Agent-Based Approach. *Mitig. Adapt. Strateg. Glob. Change* **2009**, *14*, 755–776. [CrossRef]
10. Mielcarek-Boché Nska, P.; Rze´znik, W.R.; Sharifi, A.; Feng, C.; Yang, J. Greenhouse Gas Emissions from Agriculture in EU Countries-State and Perspectives. *Atmosphere* **2021**, *12*, 1396. [CrossRef]
11. Yu, D.; Liu, L.; Gao, S.; Yuan, S.; Shen, Q.; Chen, H. Impact of Carbon Trading on Agricultural Green Total Factor Productivity in China. *J. Clean. Prod.* **2022**, *367*, 132789. [CrossRef]
12. Sharma, G.D.; Shah, M.I.; Shahzad, U.; Jain, M.; Chopra, R. Exploring the Nexus between Agriculture and Greenhouse Gas Emissions in BIMSTEC Region: The Role of Renewable Energy and Human Capital as Moderators. *J. Environ. Manag.* **2021**, *297*, 113316. [CrossRef]
13. Kim, M.; Kim, D.; Lee, D.; Heo, J. Applicability of a Renewable Energy Convergence System based on Seasonal Thermal Energy Storage for Greenhouse. *Korean J. Air-Cond. Refrig. Eng.* **2021**, *33*, 395–403. [CrossRef]
14. KPX Korea Power Exchange. Available online: https://new.kpx.or.kr/eng/ (accessed on 21 August 2022).
15. IPCC. *IPCC Guidelines for National Greenhouse Gas Inventories; Prepared by the National Greenhouse Gas Inventories Programme*; IPCC: Geneva, Switzerland, 2006; pp. 10–11.
16. Korea Environment Corporation. *ETS Insight*; Korea Environment Corporation: Incheon, Korea, 2020.
17. European Commission. EU Emission Trading System (EU ETS). Available online: https://ec.europa.eu/clima/eu-action/eu-emissions-trading-system-eu-ets_en (accessed on 21 August 2022).