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Techno-economic feasibility of using solar energy in small-scale broiler production

Youssef Doughan [a], Darine A. Salam [b,*]

[a] Department of Agriculture, Faculty of Agricultural and Food Sciences, American University of Beirut, PO Box 11-0236, Bliss Street, Beirut, Lebanon
[b] Department of Civil & Environmental Engineering, Maroun Semaan Faculty of Engineering and Architecture, American University of Beirut, PO Box 11-0236, Bliss Street, Beirut, Lebanon

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ABSTRACT

Poultry farming is an energy intensive industry necessitating a substantial amount of fossil fuel consumption and leading to elevated operational expenses. This study investigated the economic feasibility of implementing renewable energy in small-scale broiler farms to decrease their dependency on fossil fuels and increase their profit. Assessment was based on experimental data collected from broiler production operations carried out in a green poultry house equipped with solar renewable energy systems and a conventional poultry house operated on conventional energy source. The experiments were conducted during both the warm and cold seasons in a semi-arid rural area in Lebanon. Average annual costs and benefits from broiler operations were calculated based on a total of 8 production cycles/year. Cost-benefit analysis was conducted to assess the viability of introducing renewable energy in broiler production. In addition, a twenty-year financial feasibility analysis was performed for both green and conventional systems using two different time value of money parameters; the Net Present Value (NPV) and the Benefit Cost Ratio (BCR). The results showed that broiler production using conventional energy achieved a total cost of 2.25 % lower than the cost incurred using green energy and higher total revenues of 5.55 %. Negative NPV and less than 1 BCR values were computed for both green and conventional systems demonstrating that broiler production in the study area is non-profitable in small-scale broiler farms, independently of the source of energy. Accordingly, it is recommended to adopt renewable energy cooperatives based on partnership between small-scale farms. This cooperative-based partnership model has proven to allow the adoption of renewable energy sources as sustainable and economically viable approach, contributing to increased farmers' revenues. Government subsidies and financial incentives are also essential to ensure the success and sustainability of the renewable energy cooperatives.

Introduction

Broiler chicken farming is considered a profitable industry due to the rapid return on investment. This is because a production cycle of broilers takes on average only 7 weeks. Firdaus and Komalasari (2010), define broilers as chickens that are slaughtered around seven weeks of age and weigh around 1.8 kg. According to the authors, the high turnover of capital is caused by the constant demand for broilers' meat. In Lebanon, poultry industry represents an essential component of the agricultural sector and accounts for 50 % of the national meat supply (Daou & Mikhael, 2016). In 2021, production of poultry meat was 113,997 tons covering domestic demand (Knoema, 2022). Yet, the Lebanese poultry industry is susceptible to foreign competition. Indeed, the high cost of energy needed to satisfy the heating and ventilation requirements in poultry production poses a burden on the sector, and constitutes a key parameter in determining its profitability. In broiler production, the heating cost has the largest share in the total cost (Karaman et al., 2023). Cui et al. (2020) reported that poultry farming is an energy intensive industry, necessitating a substantial amount of fossil fuel consumption to maintain the optimal internal temperature for chicken health and production. Consequently, this leads to elevated operational expenses and contributes to the increase in greenhouse gas (GHG) emissions. The

Abbreviations: GPH, green poultry house; CPH, conventional poultry house; NPV, Net Present Value; BCR, Benefit Cost Ratio.

* Corresponding author: American University of Beirut, Faculty of Engineering and Architecture, P.O. Box 11-0236, Munib and Angela Masri Bldg, M418, Riad El Solh 1107 2020, Beirut, Lebanon.

E-mail address: ds40@aub.edu.lb (D.A. Salam).

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burden of high cost of energy becomes significant in small-scale poultry farms that are unable to reap the benefit of economy of scale.

Firdaus and Komalasari (2010), highlighted the necessity to have local poultry producers in Indonesia improving production efficiency in order to compete with the lesser price of imported chicken. Furthermore, price competition also extends to cover raw material production. A study conducted by Kamaruzzaman et al. (2021) showed that showed that broiler farming incurred most of its cost from its operating input, mainly feed. On the contrary, in developed countries such as in the USA, poultry industry is not affected by feed price with an elasticity of 0.06 (Firdaus & Komalasari, 2010).

Broiler chicken raising encounter risks similar to those faced in any type of business enterprise. Broiler chickens are usually raised for their high meat conversion; thus, they generate high profits. However, improper management of broiler chicken including poor maintenance and sanitation affect broiler chickens vulnerability to diseases and leads to high losses (Geo et al., 2020). In addition, inadequate heating of the chicks during the initial brooding stage poses a major threat on chicks development. This is because newly hatched chicks cannot regulate their own body temperature during the first weeks, as they would not have yet developed their heating insulation covers to face the cold weather low temperatures (Asensio, 2016). It is well known that low temperature leads to high death rates because of salmonella bacterial infection, and flocking of suffocated chicks. Moreover, overheated chicks suffer complications like pasting, heat stress, decreased feed intake and body weight, dehydration, and mortality, generating major material losses (Saad et al., 2023). Thus, appropriate enactment, necessitates high levels of monitoring and fine-tuning of brooder house temperatures and ventilation to prevent these circumstances from happening.

Electricity as a source of energy in Lebanon suffers persistent shortages, imbalanced distribution over the different provinces, as well as high expenditures especially in rural areas. This is attributable to the fact that the mass volume of electricity requirements is provided by diesel generators (ESCWA, 2020). Electricity shortages in Lebanon are listed as the second constraint to economic competitiveness after political instabilities (Julian et al., 2020). The nonexistence/primitive electrical grid in distant rural areas or the elevated connection expenditures encourage various organizations to investigate alternative solutions. An independent power system, offering electrical energy to distant consumers is considered one of the most attractive solutions to electrical problems. Diesel power generators for a long time in these distant rural areas have been contemplated as the best economic and trustworthy alternate. However, presently certain problems have developed; most important of which include elevated fuel prices, high operating costs, as well as complicated maintenance that made the diesel power generation not the best reliable solution (Rose & Inskandarani, 2021). Furthermore, concerns regarding environmental matters have led to the continual improvement in renewable energy technologies. The application of these renewable technologies seem to be one of the most proficient and successful solutions for sustainable energy development and environmental pollution prevention.

Lebanon geographical and climatic conditions let it enjoy around 300 sunny days per year, with an average solar radiation of more than 2100 kWh/m^2. Hence, solar energy provides a sustainable alternative to electrical energy shortage and diesel generators usage. In 2010 the Lebanese Ministry of Energy and Water has committed that by 2020, the country will achieve 12 % of electric and thermal supply from renewable energy; and that 30 % will come from solar energy. Moreover, in 2018, the Lebanese Government promised to shift to natural gas and renewable energy. The government also stretched its target proclaiming to achieve 30 % of electricity and heat consumption needed through renewable energy by 2030 (Moore & Collins, 2020). However, due to the current economic and political instability, these values are not yet attained and solid records of such achievements are not available.

Henceforth, Lebanon with its geographic and climatic conditions is a suitable location for solar assisted broiler production. Solar systems can be active or passive. The active solar systems use a combination of equipment to absorb, liberate, deliver, or store energy. Sometimes active solar systems are reinforced by supplementary heating such as electricity, gas etc. to enhance the energy collected from the sun. Passive solar systems on the other hand relies totally on solar energy (Nwanya & Ike, 2012). Implementing solar energy in broiler production could constitute a sustainable option to support small-scale poultry production in rural areas in Lebanon. However, it remains critical to estimate economic returns of such initiative to determine its viability (Ramukhithi et al., 2023).

Most of the current studies conducted on the economic evaluation of different thermal animal welfare systems have concentrated on cost calculations (Sumner et al., 2011; Ellen et al., 2012). These studies revealed that almost all measures used to enhance animal welfare resulted in an escalation of production costs. Conversely, studies that dealt with returns/revenues and potential price premiums as indicators of competitive heating and ventilation systems used in poultry industry are scarce. This is probably due to the limited information on price premiums (Dekker et al., 2011). Accordingly, an economic feasibility study taking into consideration costs and profits resulting from the introduction of renewable energy technologies in broiler production is compulsory to assess the viability of such initiative in small-scale poultry farms. Gocsik et al. (2015) demonstrated that with respect to operating expenses used in broilers production, the conventional system is on average the least economically feasible in the short to medium span. Cui et al. (2020) reported that up to 85 % energy savings can be achieved by using renewable energy systems in poultry production as compared to the traditional poultry houses. The authors calculated a payback time of the used technologies of 3–8 years. Geo et al. (2020) assessed the profitability and financial feasibility of broiler chicken farms in South Konawe Regency and reported that the efficient use of the components of production (land, labor, capital and entrepreneurship) represents a probable cause for producing beneficial results.

This study assesses the economic feasibility of using renewable energy in small-scale broiler farms, evaluates the limitations of such initiative, and proposes potential strategies to enable rural farms to benefit from renewable energy technologies. For this aim, two broiler production cycles were conducted during the warm and cold seasons in a semi-arid rural area in Lebanon using a green poultry house (GPH) operated on solar energy. Broiler production experiments were replicated in a control conventional poultry house (CPH) operated on conventional energy from fossil fuel. A detailed cost-benefit analysis was then performed based on actual incurred costs and achieved revenues in operating both poultry houses. Furthermore, a sensitivity analysis was conducted to assess the disparity in costs and/or benefits instigated by external factors. In addition, limitations to introducing renewable energy in small-scale broiler farms and recommendations to enable successful implementation of solar energy in smallholder farms were discussed.

Materials and methods

Study area and broilers production experiments

The study was conducted in a farm in the heart of the Beqaa Valley in Lebanon. The climate in the Bekaa is continental, characterized by cold and rainy winters and hot and arid summers. The temperature varies between −1 °C in winter, and could attain 40 °C in summer.

Two poultry houses were used for broilers production; a green poultry house (GPH) and a conventional poultry house (CPH) which was used as control. The poultry houses dimensions were 15 m × 9.5 m × 3 m (L * W * H), with a gable height of 0.5 m. The GPH was equipped with a localized heating system composed of 16 solar collectors (superline high performance flat plate solar collectors, USB series size of 1.891 m * 1.204 m * 0.099 m each) of a total area of 36 m^2. The solar collectors were connected to a 1000 L thermal water heating storage tank equipped with a coil heat exchanger and a built-in electrical backup heat. Heated water in the storage tank circulates in a piping system and transfers heat to 8 fan coil units (YHK 25-2/CR 03-2R HB) placed in the brooding area of the poultry house at 1 m elevation from the ground. Hot water circulating in the fan coil units heats the surrounding air and provides the required temperature at the chicks' level. In addition, 16 photovoltaic collectors (STP280-24/Vd, 280 W) were used to provide the needed electric energy for the system. The photovoltaic panels convert solar energy into electricity that is stored in 24 batteries (OPzS Cell batteries with a total capacity of 656 Ah). The generated electricity is used to light lamps in the poultry house (total of 300 W) and operate the system pumps and controllers. The installed photovoltaic system generates a yearly average electricity of 6800 Wh, which is calculated to cover the electrical energy use of the house. The CPH was operated on conventional electricity.

Two broilers production experiments were carried out; one during the warm season and another during the cold season, to evaluate the green poultry house performance and assess savings in energy consumption and cost, which could be achieved with the introduction of renewable energy in broiler operations. In each broilers production cycle, 1000 newly hatched chicks (Ross 308, an Aviagen brand) were raised in each of the GPH and control CPH, summing up to 2000 chicks per experiment. The chicks were raised until they became of satisfactory weight to be sent to the market. The broilers production cycles lasted 37 days in the warm season and 35 days in the cold season. Recommended guidelines to maintain flock health and welfare were closely followed in broilers production experiments (Aviagen, 2018). Broilers weight, mortality, feed consumption, vaccines administration, and other parameters and remarks pertaining to the general health status of the birds were recorded throughout the broilers production cycles. In addition, temperature and humidity inside and outside the poultry houses were monitored to ensure they comply with the requirements at different stages of broilers production. Furthermore, renewable and conventional electricity consumption were recorded by means of electricity meters.

Economic analysis

All the costs that were incurred to perform the experiments from inception, execution until closure were recorded for both green and conventional poultry houses. Furthermore, all revenues achieved were registered for each poultry house separately. The dollar exchange value used during this study was that of the official exchange rate set by the Lebanese government (1500 LBP/USD).

It is to be noted that the environmental effect was considered in this study. Hence, it was recorded as a cost in the green poultry house analysis and the conventional poultry house analysis.

Finally, the data collected was assorted according to the set objectives. The data was segregated into investment costs, operation and maintenance costs and benefits for each poultry house separately. Data processing and analysis was performed through financial feasibility analysis. The data was analysed using two different time value of money parameters including Net Present Value (NPV) and Benefit Cost Ratio (BCR). In addition, the data analysed was tested for sensitivity analysis in terms of interest rate, interest rate and decreased benefits, interest rate and increased costs, interest rate and decreased benefits and increased costs for each of the two poultry houses.

Financial feasibility analysis

Net Present Value (NPV). NPV is the difference between the present value of benefit and cost over an established time period; where a project or investment is feasible if NPV value is positive.

$$\text{NPV} = \sum_{t=0}^{n} \frac{(B_t - C_t)}{(1+i)^t} \tag{1}$$

where B_t is the total benefit at year t; C_t is the total cost at year t; i is the discounted factor; t is the year; and n is the project duration in years (Etuah et al., 2021).

Benefit Cost Ratio (BCR). BCR is the ratio of summation of the discounted revenues over the summation of discounted cost over an established time period. BCR defines how much benefit a project can attain for each dollar spent. A project or investment is feasible if BCR value is greater than one.

$$\text{BCR} = \frac{\sum_{t=0}^{n} B_t \Big/ (1+i)^t}{\sum_{t=0}^{n} C_t \Big/ (1+i)^t} \tag{2}$$

where $B_t/(1+i)^t$ is the discounted benefits (revenues) at year t; $C_t/(1+i)^t$ is the discounted cost at year t; i is the discount rate, t is the year; and n is the project duration in years (Etuah et al., 2021).

Sensitivity analysis

The sensitivity analysis was done to determine the disparity in costs and/or benefits instigated by external factors. In this study the sensitivity analysis was done as described earlier based on interest rate, interest rate and decreased benefits (decreased broiler and manure prices), interest rate and increased costs (increased investment, technology, and energy prices), interest rate and decreased benefits and increased costs for each of the two poultry houses.

Assumptions

In this study, some assumptions were made; these were:

a. The land used for the poultry house is leased.
b. The project duration is twenty years.
c. The interest rates used are 5, 10 and 13 %. These interest rates are the most commonly used in sensitivity analysis.
d. Environmental cost is calculated from United States electric utility, independent power electricity generation from fuel and resulting carbon dioxide emissions in 2020; at a value of 0.95 kg carbon dioxide per kWh, equivalent to 0.26 kg carbon per kWh (USEIA, 2022).
e. The average cost of 1 ton of carbon dioxide equivalent is $50/ton (Hillege, 2021).
f. In a single year, eight broilers production cycles are conducted with an average production period of 35 days in the cold season and 37 days in the warm season.
g. Benefits are dependent on total live weight in kg of chicks sold (primary), and amount of manure produced (secondary).
h. The selling price of live broiler chicks was assumed to be fixed at 1.2 USD/kg and that of manure at 0.025 USD/kg, reflecting the market price at the time when the study was conducted.

Results and analysis

Investment cost

A summary of the investment costs of the green and conventional poultry houses is presented in Table 1. The provided values are actual incurred costs in the construction of the poultry houses and their equipment, as well as in the acquisition of the solar and conventional

Table 1
Green and conventional poultry houses investment cost.

Item	GPH	CPH
Construction and renovation cost ($)	47,440.00	47,440.00
Green/Conventional system cost ($)	46,824.45	850.00
Total investment cost ($)	94,264.45	48,290.00

energy systems.

The cost of construction of the CPH and GPH and equipment used in their daily operation were identical. The higher capital cost registered for the GPH is due to the high initial cost of the installed solar assisted localized heating system including the solar collectors, hot water storage tank, and circulating pumps; the photovoltaic panels and associated inverter and batteries; and the programmable logging and monitoring system. The CPH operated on conventional electricity using relatively cheap electrical heaters to achieve the heating requirements. This has led to an increase in the GPH investment cost by 48.77 %. Detailed investment costs are presented in Table S1 in supplementary information.

Maintenance, operation and environmental cost

A summary of the maintenance, operation, and environmental annual costs incurred in each of the CPH and GPH during the warm and cold broilers production experiments is presented in Table 2. Detailed costs are available in Table S2 in supplementary information. Costs were calculated based on 4 broiler production cycles per season, summing up to 8 cycles/year.

The annual maintenance cost of the structures (poultry houses), and that of the heating and cooling systems were computed at 10 % of their respective capital costs (i.e. 5 % per season). For perishable items such as feeders and drinkers, the maintenance cost was calculated as that of the replacement items necessary per year. For each of the poultry houses, similar maintenance cost was reported during the warm and cold seasons. The maintenance cost for the GPH was higher than that of CPH by 43.75 %, namely due to the higher capital cost of the renewable energy systems used in the first case.

The operation cost per broiler production cycle included the cost of day old chicks (1000/cycle) and all other consumables necessary for raising poultry, such as the feed, shaving, water, disinfectant, and vaccines. The cost of land rental, labor, and electricity consumed were also included. The results showed an increased cost in the case of the CPH by 5.53 % and 7.24 % respectively, during the warm and cold seasons. Indeed, besides the slightly higher feed consumption in the case of the CPH, the higher electricity consumption in this house during both the warm and cold seasons (1898 kWh/cycle and 4344 kWh/cycle, respectively, as compared to 44 kWh/cycle and 2184 kWh/cycle, respectively, in the GPH) entailed an overall increase in the operation cost. In fact, the CPH completely relied on conventional electricity to ensure the house heating and cooling requirements. In the GPH, the solar heating system minimized the reliance on conventional electricity and ensured an average heating load of 63.69 ± 39.04 % during daytime and 43.5 ± 24.37 % during night time, with heating coverage of 100 % being attained during sunny days, during the cold season. Electric heaters were only used as auxiliary conventional heating source to meet heating requirements. An additional 432 kWh were provided by the photovoltaic system during the cold season cycle to ensure the operation of the system pumps and the lighting of the poultry house. In the warm season, electric heaters were not used in the GPH and 100 % heating coverage was ensured by the solar assisted localized heating system, namely during night time. Solar power couldn't achieve the electricity demand to operate the cooling system during the warm cycle. In this case, supplemental conventional electricity (44 kWh) was used in addition to the 643 kWh provided by the photovoltaic system. Hence, these results indicate that the solar system achieved its purpose in reducing electricity usage and, hence, the overall associated operation and environmental costs. This compensates for the higher investment cost incurred for the acquisition and installation of the green system.

Table 2
Green and conventional poultry houses annual maintenance, operation and environmental costs.

GPH			
Item	Warm season *4 cycles*	Cold season *4 cycles*	Total annual cost *8 cycles*
Maintenance cost ($)	4555.00	4555.00	9110.01
Operation cost ($)	16,466.88	16,859.68	33,326.56
Environmental cost ($)	8.36	414.96	423.32
Total cost ($)	21,030.24	21,829.64	42,859.89

CPH				
Item	Warm season *4 cycles*	Cold season *4 cycles*	Total annual cost *8 cycles*	*Annual Cost Difference* ($)
Maintenance cost ($)	2562.00	2562.00	5124.00	−3986.01
Operation cost ($)	17,430.96	18,174.88	35,605.84	2279.28
Environmental cost ($)	360.62	825.36	1185.98	762.66
Total cost ($)	20,353.58	21,562.24	41,915.82	−944.07

The environmental cost was calculated based on carbon dioxide emissions from electricity consumption, which constitutes the major source of environmental degradation in broiler operations, as well as the main difference in the operation between the two poultry houses. Other sources of environmental degradation contributing to increased environmental cost, such as ammonia production from poultry manure, were considered similar for both the conventional and green houses and were thus not accounted for in the assessment of the environmental cost difference between both houses. Carbon dioxide emissions were calculated based on the United States electric utility, independent power electricity generation and resulting carbon dioxide emissions by fuel in 2020, which is equivalent to 0.95 kg of carbon dioxide/kWh (or 0.26 kg C/kWh) (USEIA, 2022). The average cost of carbon dioxide equivalent was estimated to $50/ton (Hillege, 2021). As expected, elevated annual environmental cost was calculated in the case of the CPH, and was 64.31 % higher than that calculated for the GPH (1185.98 $/year for the CPH vs. 423.32 $/year for the GPH). On a seasonal basis, the CPH cost was 97.68 % and 49.72 % higher than that calculated for the GPH during the warm and cold seasons, respectively. For the same poultry house, the environmental cost associated with the broiler operations was higher in the case of the cold season as compared to the warm season by 97.99 % and 56.31 % for the GPH and CPH, respectively. This percentage variation in environmental cost between the CPH and GPH is associated to the variation in fuel and power requirements, which is directly correlated to weather, heating and cooling requirements, and has substantially contributed to the increase in the overall broiler production cost in the case of the CPH. It is worth noting that the difference in the calculated environmental cost between the two houses might entail significant effect on the overall broiler production cost in large-scale farms.

Finally, when comparing total incurred costs in GPH and CPH, it was found that CPH has a lower total cost percentage of 2.25 % or a lower total cost of $ 944.07 as shown in Table 2 and Table S2. This indicates that, although the GPH was able to fulfil its purpose in reducing the energy and environmental costs, it was not economically competitive with the CPH in small-scale broilers production. This is mainly due to the relatively higher maintenance cost of the green system.

Benefits resulting from the operation of the green and conventional poultry houses

The total live weight of chicks and the manure produced by the end of each broilers production cycle were reported as benefits. The first was considered as the primary benefit source while the second was considered as the secondary one. The total annual benefits were calculated based on the market price in USD per kilogram for each category at the time of the study. Table 3 presents the annual total benefits for the green and conventional poultry houses.

For both green and conventional poultry houses, total revenues from

Table 3
Green and conventional poultry houses total annual benefits.

Annual Benefits for the GPH								
Item	Warm season			Cold season			*Average benefits/cycle ($)*	*Total annual benefits ($) (8 cycles)*
	Unit price ($/kg)	*Quantity (kg)*	*Total ($)*	*Unit price ($/kg)*	*Quantity (kg)*	*Total ($)*		
Live weight of chicks sold	1.2	1903.8	2284.56	0.9	1646.93	1482.24	1883.40	15,067.2
Manure	0.025	361.72	9.04	0.025	312.92	7.82	8.43	67.46
Total benefits			2293.60			1490.06	1891.83	15,134.65

Annual benefits for the CPH									
Item	Warm season			Cold season			*Average benefits/ cycle ($)*	*Total annual benefits ($) (8 cycles)*	*Annual benefits difference ($)*
	Unit price ($/kg)	*Quantity (kg)*	*Total ($)*	*Unit price ($/kg)*	*Quantity (kg)*	*Total ($)*			
Live weight of chicks sold	1.2	1953.4	2344.08	0.9	1826.8	1644.12	1994.10	15,952.80	885.6
Manure	0.025	371.15	9.28	0.025	347.09	8.68	8.98	71.82	4.36
Total benefits			2353.36			1652.80	2003.08	16,024.62	889.96

chicks sold by the end of the broiler production cycles were higher in the case of the warm season by 35.12 % and 29.86 % for the GPH and CPH, respectively, as compared to revenues recorded during the cold season. The reason behind this might be that feed conversion during the warm season is more diverted into producing meat rather than maintaining basic body metabolism during the cold season (Cui et al., 2020). In addition, according to Junghans et al. (2022), the average slaughter weight is influenced by seasonal variations with the highest broiler weight in fall and the lowest in spring. This could have also contributed to the observed variation in broilers weight between the warm and cold seasons.

For the same season, revenues from selling chicks at the end of the broiler production cycles were 2.54 % and 9.85 % higher for the CPH as compared to the GPH, in the warm and cold seasons respectively. Average total annual revenues from selling chicks were 5.55 % higher for the CPH. This is directly associated with the higher average weight of broilers in the CPH, which is attributed to the clustering of chicks in pens in that house as compared to the open space in the GPH. This resulted in more feed consumption as the chicks were closer to the feeders and drinkers at all times.

Similar trends were observed for revenues calculated from manure production. In this case, revenues were 13.49 % and 6.48 % higher in the warm season than those recorded in the cold season, for the GPH and CPH respectively. Moreover, manure production in the CPH was higher than that reported in the GPH by 2.54 % and 9.84 %, during the warm and cold seasons, respectively. The average total annual revenues from manure production were 6.07 % higher in the case of the CPH.

The total annual benefits from broilers and manure were 5.55 % higher in the case of the CPH corresponding to a difference in revenues of $889.96/year. Total annual benefits are expected to increase with the increase in the farm size and number of chicks raised. It is noticeable that the higher total annual benefits of 5.5 % in the case of CPH compensate for the higher total annual operating cost of 6.40 % incurred in this house. When considering the total annual differences in costs and benefits between the two houses, it is seen that the extra cost incurred in the CPH ($944.07) is compensated by the extra benefits generated in this house ($889.96). Accordingly, none of the tested systems is economically more advantageous than the other.

Sensitivity analysis

A 20 years period sensitivity analysis was performed to test if there is inconsistency in costs and/or benefits induced by external factors for both GPH and CPH. Interest rate sensitivity was first assessed at rates of 5, 10 and 13 %, and changes in NPV and BCR values were determined for the green and conventional poultry houses in each case. The different tested interest rates resulted in negative NPV and a less than one BCR values for both poultry houses (Table 4), suggesting that broilers production performed in both systems is non-profitable. Computed NPV values varied within a limited range between -412.54×10^3 and -260.42×10^3 in the case of the GPH and between -347.04×10^3 and -209.41×10^3 in the case of the CPH, decreasing with increased interest rates in both cases. Similarly, BCR slightly decreased with increased interest rates with values ranging between 0.30 and 0.26 for the GPH and between 0.35 and 0.32 for the CPH (Table 4). The main contributor to this insensitivity to changes in interest rates was the high cost incurred for broiler production as compared to the revenues. This is coherent with the conclusions attained by Gocsik et al. (2013) in their study on the economic feasibility of production systems with different levels of livestock welfare including broiler. The authors reported the producer price as the principle factor affecting the economic feasibility of broiler production. They demonstrated that not only the level of the price premium is important in the decision to convert to an alternative system, but also the certainty and variability of this premium.

Furthermore, the validity of the model was tested by fluctuating different variables including benefits and/or costs along with interest rates. Table 4 shows the sensitivity analysis of the economic evaluation of both green and conventional systems, which was performed by combining the effect of increasing interest rates with: a) 1 or 2 % decrease in total achieved benefits; b) 1 or 2 % increase in total incurred costs; c) 1 % decrease in total benefits and 1 % increase in total costs; and d) 2 % decrease in total benefits and 2 % increase in total costs. Only the 5 and 10 % interest rates were maintained in this analysis and changes in NPV and BCR values were recorded for each scenario. The results showed negative NPV values and less than 1 BCR values under the different conducted sensitivity analysis for both poultry houses (Table 4), indicating that both systems are economically non-lucrative. It is rational that if a decrease in total benefits shows a negative NPV values and a less than one BCR values, an increase in total costs would lead to the same results for both GPH and CPH over the study period (Table 4). For the same tested interest rate, insignificant or no changes in NPV and BCR values were recorded under the different sensitivity analysis scenarios for both GPH and CPH, asserting that the model is insensitive to external factors. Furthermore, all results attained showed slightly higher NPV and BCR values for the CPH as compared to values recorded for the GPH. Although the use of solar energy contributed to savings in energy and electricity usage in the GPH, this contribution remains minimal as compared to total incurred costs in each of the green

Table 4
Sensitivity analysis results.

	GPH				CPH			
	IR = 5 %		*IR* = 10 %		*IR* = 5 %		*IR* = 10 %	
	NPV ($\times 10^3$)	BCR	NPV ($\times 10^3$)	BCR	NPV ($\times 10^3$)	BCR	NPV ($\times 10^3$)	BCR
*Fixed B & C	−412.54	0.30	−302.47	0.28	−347.04	0.35	−247.14	0.33
1 % DB	−414.28	0.29	−303.62	0.27	−348.88	0.34	−248.46	0.33
2 % DB	−416.02	0.29	−304.77	0.27	−350.73	0.34	−249.68	0.32
1 % IC	−418.40	0.29	−306.65	0.27	−352.36	0.34	−250.93	0.33
2 % IC	−424.27	0.29	−310.82	0.27	−357.67	0.34	−254.62	0.32
1 % DB & 1 % IC	−420.15	0.29	−307.80	0.27	−354.20	0.34	−252.15	0.32
2 % DB & 2 % IC	−427.76	0.29	−313.12	0.26	−361.36	0.33	−257.06	0.32

IR = interest rate; B = benefits; C = costs; DB = decreased benefits; IC = increased costs.
[*] At fixed benefits and costs, the interest rate of 13 % (IR = 13 %) was tested and generated VPN values of -260.42×10^3 and -209.41×10^3, and BCR values of 0.26 and 0.32, for the green and conventional poultry houses respectively, and was not maintained in further analysis.

and conventional poultry houses. Particularly, the feed cost in the green and conventional houses constituted respectively 38.16 % and 36.26 % of the total incurred operation costs in both houses. Compared to feed, electricity accounted for only 3.47 % and 9.11 % of the total operation costs in the green and conventional houses, respectively. In their study on the profit and financial feasibility analysis of broiler chicken livestock in Indonesia, Geo et al. (2020) reported electricity costs as the smallest contributor to the overall cost structure of broiler chicken farms amounting to 0.4 %, while the largest cost was that of feed with a percentage of 70.68 %. In addition, the small flock size tested in both poultry houses minimizes revenues and renders broilers production in small-scale farms non-lucrative. This becomes even more significant in the case of the green poultry house where the small flock size does not justify the high initial investment cost. Abdallah and Al Khraisat (2013) conducted an economic analysis of poultry production in small, medium, and large-scale farms in Amman and Ibrid district in Jordan. The authors reported that productivity is not promising for investors in this sector in the case of small farms who are unable to reap the benefit of economy of scale. Indeed, the smaller the broilers flock size, the less resilience it shows towards a reduction in broiler price and an escalation in the operating costs (Firdaus & Komalasari, 2010).

Green system limitations

While the green system successfully achieved substantial savings in electricity consumption during both cold and hot seasons contributing to the decrease in the overall broilers production cost, optimization of the system to satisfy temperature requirements during peak weather conditions remains necessary. This would eliminate the use of auxiliary conventional energy in the green poultry house and ensure the economic profitability of introducing renewable energy in small-scale poultry farms. To increase energy efficiency of photovoltaic systems, Amrizal et al. (2021) have suggested the use of hybrid photovoltaic panels with double pass solar collectors to minimize the dissipation of sunlight into thermal energy. The authors demonstrated a high potential for the development of the proposed technology in tropical climate. In addition, Elahi Gol and Ščasný (2023) demonstrated that an automatic one-axis sun tracker system produces about 20 %–30 % more energy compared to a photovoltaic system with a fixed flat structure having the same capacity. Furthermore, Hussein et al. (2023) used a novel double pass solar air heater with tubular solar absorber involving a set of tubes with a circular cross-section as an alternative to the conventional flat plate absorber. The authors reported enhancement in thermal performance using the novel system, both experimentally and numerically. Future work on the use of renewable energy systems in poultry production could consider the adoption of these newly tested systems with improved electrical and thermal efficiencies. In the case of this study, it is recommended to optimize the existing green system to become fully autonomous, minimizing reliance on auxiliary conventional electricity and enhancing the economic profitability of the system. This is crucial when considering the high capital cost of the green system, mostly beyond the purchase capacity of the farmers in rural areas. In addition, the relatively low number of chicks of the tested broiler flock (1000 chicks/poultry house) minimizes the profitability from the green system and makes the high initial investment cost unjustifiable. According to Firdaus and Komalasari (2010), a 25,000 bird flock is more feasible than a 10,000 bird capacity, as it shows more resilience towards a reduction in broiler price and an escalation in the operating cost. Accordingly, to enable the adoption of green energy systems in poultry farming in rural areas in Lebanon, the government should initially provide financial incentives through investment subsidies and soft loans provision to the farmers until cost of solar project investment declines. This was also recommended by Wattana and Aungyut (2022) as part of their proposed strategy to address the barriers facing the Thai electricity industry.

Recommendations

Although the green system contributed to decreased electricity and environmental costs, it proved to be economically non-profitable. Accordingly, renewable energy cooperatives based on partnership between small broiler farms is encouraged. In recent years, cooperatives played a significant role in renewable energy utilization. Rather than acting individually, farmers would act collectively to benefit from renewable energy sources as sustainable and economically viable approach to reduce energy costs, decrease environmental impacts, and enhance the resilience of poultry farming operations. Recent studies have reported the benefits from cooperative-based partnership models. Hartanto et al. (2021) studied the feasibility of potential cooperative-based partnership in broiler agribusiness in North Maluku in Indonesia to address the limited resources of smallholder farmers. The authors concluded that such a model would enhance broilers production and increase the farmers' revenues. Everest (2021) investigated the willingness of farmers to act collectively to benefit from renewable energy sources in Northwestern provinces in Turkey and reported that 65.88 % of the participant farmers were willing to establish a renewable energy cooperative. The authors also reported the economic benefits of such initiative. Other studies have also highlighted the role of renewable energy cooperatives in the forthcoming energy transition process and as a mechanism of rural economic development (Capellán-Pérez et al., 2018; Paredes & Loveridge, 2018; Roesler & Hassler, 2019). Nonetheless, it is essential to note that, the feasibility of renewable energy cooperatives is mostly conditional the government support in subsidizing the purchase of solar energy systems and providing adequate training to farmers on their operation and maintenance. This is critical in the case of Lebanon where the recent economic crisis has substantially contributed to increased fuel poverty.

Conclusion

This study experimentally investigated the economic feasibility of implementing renewable energy in broiler production in a small-scale farm, in a semi-arid region in Lebanon. The results showed that, although the implemented energy system contributed to decreased electricity and environmental costs, it incurred higher total broiler production costs and lower total revenues. Sensitivity analysis conducted over a period of 20 years resulted in negative NPV and BCR values for both tested green and conventional energy systems, demonstrating that both systems are infeasible economically. Future studies should consider the optimization of the green system to become fully autonomous and economically profitable. In addition, it is recommended to assess the feasibility of implementing renewable energy cooperative-based partnership in broiler agribusiness in the studied area as a sustainable and economically viable approach to reduce energy costs in poultry production and enhance the resilience of small-scale poultry farms.

Ethical considerations in animal experiments

Broiler production operations adhered to a high standard (best practice) of veterinary care to maintain flock health and welfare and achieve good flock performance. The "Ross Broiler Management Handbook" was strictly followed. Animal experiments were carried out in accordance with EU Directive 2010/63/EU.

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CRediT authorship contribution statement

YD: Analysis, Writing, Visualization; DAS: Conceptualization, Methodology, Validation, Analysis, Investigation; Resources, Data curation, Writing, Review & Editing, Visualization, Supervision, Project administration, Funding acquisition. Both authors have equally contributed to the writing of the manuscript. Both authors had read and approved the final manuscript.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.esd.2023.101337.

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