Energetic, environmental and economic aspects of a hybrid renewable energy system: a case study

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Abstract

In this study, the solar irradiation and wind speed data of Balikesir in Turkey are analyzed to assess the techno-economic viability and environmental performance of a hybrid power system. Energy is estimated for a typical commercial poultry house, and a system is then designed to satisfy the load demand. As hybrid Optimization Model for Electric Renewable (HOMER) software is used for the simulation of four respective cases: Diesel only, photovoltaic (PV)–diesel–battery, wind–diesel–battery and photovoltaic–wind–diesel–battery. We also evaluate the cost, environmental advantages and benefit of the demand-side management (DSM) when renewable hybrid energy options are applied to the poultry farming. By implementing light control system and high-efficiency fans (with about 20% efficiency increase), annual electricity consumptions can be reduced by 15% with DSM. When DSM was applied to the cost of energy, certain parameters including unmet electric load, excess electricity and greenhouse gas emissions are calculated for each case. Greenhouse gas emissions are also investigated for the hybrid energy system (by integrating PV and wind turbine only into diesel system). The hybrid system thus reduces CO_2 emissions from 21.8 to 10 t, particulate matter (PM) from 4.1 to 1.9 kg, NO_x from 0.421 to 0.221 t. A break-even analysis is performed to decide the optimum distance where the hybrid energy system is more economical than the extension of the transmission line. Consequently, the results indicate that installation of the hybrid energy system is more economical than the conventional electricity network when the distance is more than 3.21 and 3.13 km for PV–wind–diesel–battery and wind–diesel–battery, respectively.

Keywords: energy; demand-side management; environment; hybrid energy system; life-cycle costing; greenhouse gases; renewable energy

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1 INTRODUCTION

Implementing sustainable energy strategies is one of the most important aspects for a sustainable world. Future energy policies and strategies should put more emphasis on the development of potential energy sources, which should form the base of future global energy structure. Agriculture's role in energy consumption is well known. Farm-based energy production—biofuels and wind-generated electricity—has grown rapidly in recent years, but still remains small relative to the total national energy needs. Energy obviously plays an important role in poultry production [1]. Therefore, the present study investigates the technical and economic potentials of renewable hybrid energy options for poultry farms in Balikesir, Turkey. The poultry sector is one of the most important areas of the food industry in Turkey. At present, there are ∼12 700 broiler companies in this sector and the majority of broiler chicken production is carried out by integrated companies [2]. According to Food and Agriculture Organization of the United Nations (FAO) production statistics, Turkey occupied the 19th rank in the world poultry production. Total poultry meat production reached to 1 063 795 t in 2005. In this regard, poultry production has a great potential in the Balikesir area, which occupies the second rank in poultry production and third rank in total agricultural production in Turkey. In addition, there are about 3000 broiler companies in the Balikesir area [3]. Therefore, this study is expected to serve as a kind of guidance to the respective poultry sector with respect to how efficiently

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and effectively energy can be used and how effectively emissions can be minimized. It is also expected to provide better demand-side management (DSM) strategies.

In the literature, one of the very first studies was conducted by Ref. [4] on the potential of solar electric applications for Delaware's poultry farms in April 2005 and on the feasibility of photovoltaic (PV) system used in poultry farms. The researchers carried out a feasibility study using a simulation model approach and testing alternative scenarios and cost conditions. Their study shows that solar energy is economical for the state's producers under certain policy scenarios. Their results indicate that the electricity needs of an economical PV system used in a typical Delaware poultry house was 1.5 kW. The environmental impact study demonstrated that the 1.5 kW PV system avoided 112 t of CO_2 emissions during its lifetime as well as reducing 1.8 t of sulfur dioxide (SO_x) and 0.4 t of nitrogen oxides (NO_x) [4]. Bazen and Brown [5] analyzed broiler production in five different regions in Tennessee, which accounted for about 46% of total production in the state. They investigated not only the economic feasibility of solar PV energy integration, but also the impact of alternative energy programs and other factors in several solar regions within Tennessee's poultry industry.

The utilization of PV–wind–diesel hybrid energy sources can significantly reduce the system fuel costs. Also, it has positive effects on the system reliability [6]. In the past, high investment rate was an important barrier for consumers. PV price has dropped from US$25 to 3.5 per W in the past 30 years [5]. Several authors have discussed the energy requirements of PV solar energy conversion systems and their energy pay-back-time [7–9]. Wichert *et al.* [10] published an evaluation of technical and economic characteristics of hybrid power systems, and outlined the expected future directions for the development of hybrids. Hybrids are in a more favorable position when the cost of diesel fuel transportation is incorporated in the analysis. Sizes of many hybrid systems have been studied and optimized by the economic analysis based on life-cycle cost (LCC) and energy cost [11–13]. Studying cost and environmental impacts of such hybrid PV–wind–diesel–battery generator systems on other systems is of great importance to diminish global warming problem. Baring [14] outlines the foundations for analysis and design of some hybrid power systems.

One of the purposes of this study is to evaluate the cost, environmental advantages and the benefits of the DSM when renewable hybrid energy options are used in poultry farming. This concept has been applied to renewable energy (RE) electrification system in order to reduce the peak energy demand and also to have an arrangement where poultry energy operations can be matched to the high potential period of electrical energy produced from hybrid system during the day [15]. To achieve a cost-effective electrical system, components of the system must be chosen carefully and the system must be operated in a way to minimize costs. Generally, more efficient electrical components have higher initial cost, which should be weighted against the future savings to be realized in terms of reduced energy charges [16]. For RE systems, DSM becomes beneficial to strengthen their use. DSM has been used to smooth the daily peaks and fill valleys in the load profile to make the most efficient use of energy resources [e.g. 17,18].

2 METHODOLOGY

2.1 Input parameters for simulation

In the simulations, the actual data including the hourly global solar irradiations on tilted plane (39°) for 2003 and average hourly wind speed were collected from the Department of Turkish State Meteorological Services in Balikesir airport and employed for calculations as given in Table 1. Solar irradiation level is higher in the summer months. The monthly solar global radiation values range from 1.8 to 7.49 kW h/m^2 between December and July. On the other hand, the annual average daily solar global radiation level is determined as 4.48 kW h/m^2. Average monthly wind speed at 25 m varies from 2.80 to 5.83 m/s.

2.2 Description of the poultry house

In general, the design of a hybrid energy system is site-specific and depends upon the available resources and the load profile. For the systems, such as the PV–diesel, wind–diesel and PV–wind–diesel, the design capacity was determined and optimized using the HOMER (Hybrid Optimization Model for Electric Renewable) software program. It was able to test all the proportions regarding the cost of energy (COE) and determine the minimum COE as the optimal design capacity. Hourly wind speed, solar radiation, load profile, and component price were used as input data of the HOMER software.

Energy needs were determined in terms of all actual electrical equipments used in the farmhouse. There was a generator with capacity of 10 kW in the facility. Therefore, no change was made for the backup diesel generator capacity in the simulation for Case 1. Simulations were carried out, and have been applied to design a stand-alone hybrid power system in order to generate energy for a poultry house in Balikesir (39°30′N–28°1′E). The farmhouse is considered to have an average

Table 1. *Monthly average wind speed and global irradiation values.*

	January	February	March	April	May	June	July	August	September	October	November	December
Radiation (kW h/m^2)	2.07	2.82	3.98	5.30	6.37	7.32	7.49	6.75	5.54	3.56	2.28	1.80
Wind speed^a (m/s)	3.49	3.61	4.91	3.09	3.56	3.77	4.23	5.57	6.43	4.63	1.84	3.17

[a] 10 m.

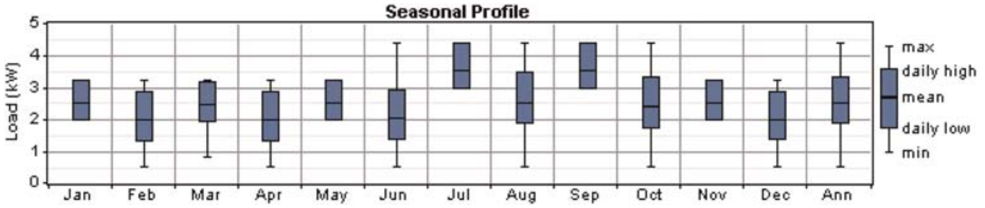

Figure 1. *Load profile for poultry house (without-DSM).*

energy consumption of about 60 kW h per day, with a peak demand of 4.37 kW and mean demand of 2.5 kW. The daily load demand is given in Figure 1. A DSM was considered to make a more efficient design. When DSM was considered, the generator capacity was chosen as 5 kW as being close enough to the peak load. Depending on this consideration, a lower capacity generator could obviously be selected.

A number of broiler companies were interviewed to assess their energy needs in order to estimate the electricity demand. Energy plays an important role in broiler production. In a typical commercial poultry house, energy is used for heating system circulation pumps, ventilation and lighting, and feed lines motors. In winter months, 45% of this potential electric load is derived from ventilation, 25% from lighting, 10% from administrations home, 10% from water pump and 8% from feed lines, etc. However, in summer months, 60% of this potential electric load results from ventilation, 17% from lighting, 8% from administration's homes, 9% from water pumps and 6% from feed lines. Electrical equipment used in the poultry house are presented in Table 2. There is a significant difference in load profile between summer and winter seasons. Owing to the high cooling and ventilation needs, the load demand in broiler companies is higher in summer, while average daily electricity consumptions annually are of 21893 kW h. Temperature and humidity levels in poultry houses are controlled automatically. Temperature of the poultry houses varies from 33°C, in the first week, to 25°C, in the seventh week, as determined by the grower's contract. Most of the poultry houses have 23 000 broilers in the home area of 10 000 m^2 as an average size in Balikesir. There are six growing periods in a year for broilers and each growing period is about 45 days, and 15 days are used for cleaning and preparation.

2.3 Energy management for poultry house

DSM is used in the areas where RE electrification system is supplied to the utilities. DSM has certain benefits to strengthen the RE system. Implementation of energy efficiency measures is projected to reduce the total site load by 18505 kW h/year, about 15% of the present value. In Table 3, two different types of 24-h load profile were identified for poultry farming in Balikesir:

Table 2. *Electrical equipments which are used in poultry house.*

Device	Number	Voltage	Power (W)	Total power (W)
0.91 m Sidewall fans	6	380	300	1800
1.22 m Tunnel fans	4	380	1000	4000
Lighting	50	220	9	450
Water pump	1	380	1000	1000
Feed line motors	2	380	500	1000
Total (W)				8250

(i) The conventional applications are low energy efficient and not optimized for energy efficiency (without DSM). The daily consumptions are 60 kW h/day, peak load is 4.37 kW and average load is 2.5 kW (Case 1).
(ii) Systems with DSM 'high efficiency' is rather scarce on the market and has a higher price than conventional appliances. The daily consumption is 51 kW h/day, peak load and average load are 3.31 and 2.11 kW, respectively (Case 2).

For Case 2, fans are replaced with highly efficient ones and used for the ventilation and optimization of lighting. For this case, parameters like the peak load demand, average daily load and annual electricity consumptions are reduced by 24, 15 and 15%, respectively, when DSM is applied. Optimization of ventilation system means the substitution of the existing fan technology with a more efficient one. At present, asynchronous motors are in use and an even more efficient drive is an electronically commutating (brushless) DC motor. For example, a standard 1.22 m box fan would have an average efficiency of 28.8 m^3/W h, while a high efficiency 1.22 m box fan would move 33.82 m^3/h W or more than a 20% of increase in efficiency [18].

These case systems were modeled for an average commercial poultry house, and accordingly, simulations were carried out. Equipment options included lighting control and highly efficient fans. Lighting and ventilation are potentially the largest-end uses when achieving the recommended lighting and ventilation levels. Results show that peak demand of the poultry farm house reduced from 4.37 to 3.1 kW. In addition, the cost of electricity for hybrid system also decreased.

3 ANALYSIS

3.1 Simulated hybrid energy system

A hybrid energy system, consisting of two or more energy systems, an energy storage system, power conditioning

Table 3. *Twenty-four hours load profiles identified for poultry farming in Case 1 (a) and Case 2 (b).*

For winter (Case 1)																										
	Power (W)	Hour																								DAILY TOTAL (W)
		01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	
Fans (6)	4200	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	8,064
Small fans (4)	1200	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	720	17,280
Feeding motors (4)	2796	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	4,800
Lightings (60)	450	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	14,400
Hidrafor (1)	932				300			300			300			300			300			300			300			2,100
Admirator home (1)	2000	166	132	124	117	117	110	117	157	221	283	414	423	335	270	274	256	289	336	334	322	285	241	194	134	5,651
Boiler (1)	1000	200		200		200		200		200		200		200		200		200		200		200		200		2,400
Water pump	5100		500		500			500		500		500		500		500		500		500		500		500		5,500
Hourly total		2222	2488	2180	2773	2173	1966	2973	2013	2777	2439	2970	2279	3191	2126	2830	2412	2845	2192	3190	2178	2841	2397	2750	1990	60,195
For summer (Case 1)																										
	Power (W)	Hour																								DAILY TOTAL (W)
		01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	
Fans (6)	4200	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	840	20160
Small fans (4)	4000	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	1200	28800
Feeding motors (4)	2796	200	200	200	200	200	200	200	200	300	200	300	200	300	200	200	300	200	300	200	200	200	200	200	200	5300
Lightings (60)	450	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	600	14400
Admirator (1)	2000	166	132	124	117	117	110	117	157	221	283	414	423	335	270	274	256	289	336	334	322	285	241	194	134	5651
Water pump	5100		500		500			1020		1020		1020		1020		1020		1020		1020		1020		1020		10180
Hourly total		3006	3472	2964	3457	2957	2950	3977	2997	4181	3123	4374	3263	4295	3110	4134	3196	4149	3276	4194	3162	4145	3081	4054	2974	84491
For winter (Case 2)																										
	Power (W)	Hour																								DAILY TOTAL (W)
		01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	
Fans (6)	3360	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	336	8064
Small fans (4)	1200	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	576	13824

Continued

Table 3. *Continued*

For winter (Case 1)																										
	Power (W)	Hour																								DAILY TOTAL (W)
		01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	
Feeding motors (4)	2796	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	200	4800
Lightings (60)	450	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	12000
Hidrafor (1)	932				300			300			300			300			300			300			300			2100
Admirator home (1)	2000	166	132	124	117	117	110	117	157	221	283	414	423	335	270	274	256	289	336	334	322	285	241	194	134	5651
Boiler (1)	1000	200		200		200		200		200		200		200		200		200		200		200		200		2400
Water pump	5100		400		400			400		400		400		400		400		400		400		400		400		4400
Hourly total		1978	2144	1936	2429	1929	1722	2629	1769	2433	2195	2626	2035	2847	1882	2486	2168	2501	1948	2846	1934	2497	2153	2406	1746	53239
For summer (Case 2)																										
	Power (W)	Hour																								DAILY TOTAL (W)
		01:00	02:00	03:00	04:00	05:00	06:00	07:00	08:00	09:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	00:00	
Fans (6)	4200	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	538	12912
Small fans (4)	4000	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	960	23040
Feeding motors (4)	2796	200	200	200	200	200	200	200	200	300	200	300	200	300	200	200	300	200	300	200	200	200	200	200	200	5300
Lightings (60)	450	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	500	12000
Admirator (1)	2000	166	132	124	117	117	110	117	157	221	283	414	423	335	270	274	256	289	336	334	322	285	241	194	134	5651
Water pump	5100		500		500			600		600		600		600		600		600		600		600		600		6400
Hourly total		2364	2830	2322	2815	2315	2308	2915	2355	3119	2481	3312	2621	3233	2468	3072	2554	3087	2634	3132	2520	3083	2439	2992	2332	65303

Table 4. *Technical and cost data considered for hybrid energy systems in the analysis.*

Units	Values	Units	Values
PV		Diesel generator units	
Capital (US$/kWp)	7500		
Life time (year)	25	Replacement (US$)	800
Operation and maintenance (US$/year)	0	Capital cost (US$/kW)	800
Tilt angle PV modules	Lat:39°30′N	Operation and maintenance (US$/h)	0.15
Replacement (US$)	6500	Batteries	
Wind		Type of batteries	6FM200D
Southwest Whisper500		Nominal voltage (*V*)	12
Capital Cost (US$)	8500	Nominal capacity	200 Ah
Nominal Electrical Output (kW; DC)	3	State of charge (SOC; %)	70
Replacement (US$)	7000	Capital cost (US$/kW)	800
Operation and maintenance (US$/year)	50	Replacement (US$/kW)	600
Life time (year)	25	Dispatch/operating strategy	Multiple diesel load following
Inverter		Operation and maintenance (US$/year)	0
Nominal Output (kW)	10		
Capital (US$/kW)	1000		

equipment and a controller, is the most appropriate energy producer for isolated communities, especially in remote areas. There are generally two accepted hybrid energy system configurations, namely: (a) systems mainly based on diesel generators with RE used for reduction of the fuel consumption; (b) systems relying on the RE source with a diesel generator used as a back-up supply for the extended periods of low RE input or high load demand.

Some software tools that assess the performance of an RE system for system configurations are SIRENE, RAPSIM and SEU-ARES. Most of these software tools simulate the predefined hybrid RE system based on a mathematical description of the component characteristic operation and system energy flow, and often, financial costing of the system configuration. These packages are valuable to assess certain hybrid system designs and enable viewing the effects of changing component sizes and settings manually. Better system performance and lowered costs could be achieved with many of these designs if the system configurations could be optimized. HYBRID2, developed by NREL in 1993, is simulation software aiming to provide a versatile model for the technical and economical analysis of hybrid system performance. The software INSEL, written at the University of Oldenburg, is a logistic simulation model for RE systems. SIRENE, developed in 1991 by Bezerra *et al.* [19], aims to simulate the electrical network and economic performance of a given type of hybrid system supplying electricity to an isolated grid in order to avoid costly parameter adjustment work during installations [20].

In this study, four systems, namely (i) diesel-only, (ii) PV–diesel–battery, (iii) wind–diesel–battery and (iv) PV–wind–diesel systems, are considered and simulated by HOMER [21] software to assess their techno-economic viability. The HOMER was developed by the National Renewable Energy Laboratory (NREL) in the USA as a potential simulation and optimization tool for RE systems. The HOMER performs three principal tasks: simulation, optimization and sensitivity analysis. In the simulation process, HOMER models the performance of a particular micro power system configuration for each hour of the year to determine its technical feasibility and LCC. In the optimization process, HOMER simulates many different system configurations in search for the one that satisfies the technical constraints at the lowest LCC. In the sensitivity analysis process, it performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. The optimization study determines the optimal values of the variables over which the system designer has control, such as the mix of components that make up the system and the size or quantity of each. A sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price.

PV–wind-generated energy stored in batteries can be retrieved during nights. Use of diesel system with PV–wind–battery reduces battery storage requirements. Hybrid combination of PV–diesel–battery system represents an economically acceptable compromise between the high capital cost of PV autonomous system and high operation and maintenance and fuel cost of generators [22]. The technical data and economic assumptions of PV, Wind, diesel generator unit, DC–AC inverter and batteries are presented in Table 4.

3.2 Economic analysis

The economic analysis involves calculation of the simple payback time (SPBT) for the PV module and calculation of energy payback time (EPBT) for the PV array. In order to calculate the EPBT it is essential to know the energy required in the construction of the PV array (so-called: embodied energy). In this method, the total energy required is the sum of energies required for raw materials and the energy required in the various processes involved to convert the raw materials into the PV array. The embodied energy of a PV system is given by

Wies *et al.* [23] as:

$$\mathrm{kW\,h_{emb}} = 5600\,\mathrm{kW_p} = 33\,600\,\mathrm{kW\,h}$$
$$\mathrm{EPBT} = \frac{\mathrm{kW\,h_{emb}}}{E_{\mathrm{pv}}} = \frac{33\,600}{8176} = 4.10\ \mathrm{year} \qquad (1)$$

The SPBT can be calculated using the simple formulation below (Equation (2)), [23,24].

$$\mathrm{SPBT} = \frac{\text{Excess cost of hybrid system}}{\text{Rate of saving}} \qquad (2)$$

The SPBTs for the options without DSM hybrid are calculated as 7.9, 5.7 and 12.6 years for PV–wind–diesel–battery, wind–diesel–battery and PV–diesel–battery, respectively. On the other hand, SPBT for the options with DSM hybrid is found as 5.3, 4.7 and 7.3 years for PV–wind–diesel–battery, wind–diesel–battery and PV–diesel–battery, respectively.

The LCC analysis is a tool used to compare the ultimate delivered costs of technologies with different cost structures. Rather than comparing only the initial capital costs or operating costs, LCC analysis seeks to calculate the cost of delivering a service during the whole period of the project. The final cost per kW h is estimated independent of the technology used to deliver the electricity. Levelized energy cost (LEC) can be explained with total present value (TPV), and annual load (AL) kW h, as follows [22]:

$$\mathrm{TPV} = \text{Initial cost} + \Sigma\text{O\&M} + \Sigma\text{Replacement} + \Sigma\text{Fuel cost} \qquad (3)$$

$$\mathrm{LEC} = \frac{\mathrm{TPV} * \mathrm{CRF}}{\mathrm{AL}} \qquad (4)$$

where CRF is the capital recovery factor and defined as:

$$\mathrm{CRF} = \frac{(1+R)^N * R}{(1+R)^N - 1} \qquad (5)$$

Here, R is of 10% of the net discount rate and N is of 25% of the economic evaluation period.

3.3 Break-even analysis

A break-even distance analysis was carried out for hybrid energy system and extension of transmission line. Break-even distance analysis showed how far the site of the stand-alone energy system should be from the existing utility grid in order to make the system cost-effective compared with using conventional transmission line [25]. The total cost obviously changes according to the length of the transmission line. Such a cost is the sum of the operation cost and investment cost. Operational costs of the grid system are the electricity consumption fee and the maintenance costs. Total cost of extension has two parameters; fixed cost and variable cost as given in Table 5. The capital cost per kilometer is calculated as US$ 40 000, O&M cost as 300 $/km/year, grid power price as 0.17 US$/kW h:

Table 5. *Cost parameters of grid extension for break-even analysis.*

Fixed cost	Pile (2790 kg), Distributor transformer: 31.5 kV, 50 kVA, Transformer platform: PL-250 (700 kg), Current transformer: 75/5 A OG fuses: 36 kV, 2–20 A, Fuse separator: 36 kV–630 A, Ground separator: 36 kV–630 A, Power panel, Electric meter 220/380 V Circuit breaker 3 * 80 A compact
Variablecost	Pile installation, Pile transportation, Wire (110 kg/km), Pile 8–12 (2170 kg)

$$C_{\mathrm{Ex,T}} = C_{\mathrm{i}} + C_{\mathrm{op}} \qquad (6)$$

where $C_{\mathrm{Ex,T}}$, C_{i} and C_{op} represent the total cost of extension, initial cost and operation cost, respectively.

The total operation cost of the extended transmission line is given by

$$C_{\mathrm{op,T}} = C_{\mathrm{M,T}} + C_{\mathrm{E,T}} \qquad (7)$$

where $C_{\mathrm{op,T}}$, $C_{\mathrm{M,T}}$ and $C_{\mathrm{E,T}}$ represent total operation cost, total maintenance cost and total electric cost, respectively.

As can be seen from Table 6, the result of the break-even analysis shows that the distance was more than 4.7 km for PV–wind–diesel–battery, 4.8 km for wind–diesel–battery and 6.15 km for PV–diesel–battery. Results also were calculated with DSM option; and the distance was found to be more than 3.21 km for PV–wind–diesel–battery, 3.13 km for wind–diesel–battery and 4.11 km for PV–diesel–battery.

3.4 Environmental impact

Increasing concerns over global warming as a potential result of greenhouse gas emissions caused by fossil-fuel-based energy sources have motivated many to do research on cleaner and greener energy options, e.g. PV, and wind systems for various applications. The environmental benefits of integrating hybrid RE in poultry farming are very important in terms of greenhouse gas emissions. The amount of pollutant emissions was calculated and compared with the diesel-only option. The annual pollutant emissions are given for each system in Figure 2. The diesel-only electricity generation mainly depends on fuel. Therefore, the amount of fuel usage and its negative effects on the environment are high. As it is shown in Figure 2, diesel-only system produced 27 997 kW h electric energy and 36.8 t of CO_2, 6.9 kg of PM, 0.812 t of NO_x emission in a year time as a result of diesel fuel usage. Replacing the diesel-only system with 4 kW PV array and 9 kW wind turbine reduces the greenhouse gas emission to 10.8 t for CO_2, 2.02 kg for PM and 0.239 t for NO_x and produces 339 196 kW h of electricity on top of that.

In the diesel-only system for DSM simulation, greenhouse gas emission is reduced to 21.8 t for CO_2, 4.1 kg for PM and 0.421 t for NO_x. Integrating PV and wind turbine with a diesel

Table 6. *Simulation results for each system studied (without-DSM: Case 1 and with-DSM: Case 2).*

Parameters	PV–wind–diesel–battery		Wind–diesel–battery		PV–diesel–battery		Diesel-Only	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
COE (US$/kW h)	1.039	0.872	1.061	0.855	1.306	1.069	1.76	1.143
Fuel consumed (l/year)	4120	4450	4645	4238	5750	5200	13880	8272
CO_2 emitted (t/year)	10.84	10	12.23	11.1	15.14	13.7	36.8	21.78
PM emitted (kg/year)	2.02	1.87	2.28	2	2.82	2.55	6.86	4.05
NO_x emitted (kg/year)	239	221	269	246	333	302	812	480
System load (kW h/year)	21900	18505	21900	18505	21900	18505	21900	18505
Total energy (kW h/year)	39771	26614	43196	33747	29637	21824	27996	19704
PV (kW h)	4kWp 5450 (14%)	3kWp 4088 (14%)	0	0	9kWp 12264 (41%)	6kWp 8176 (37%)	0	0 (0%)
Wind (kW h)	3*3 kW 21852 (55%)	2*3 kWp 14568 (50%)	4*3 kW 29136 (67%)	3*3 kW 21852 (69%)	0	0	0	0 (0%)
Generator (kW h)[a]	12162 (%31)	10359 (%36)	14060 (33%)	9685 (31%)	17374 (59%)	13648 (63%)	27490 (100%)	19704 (100%)
Renewable fraction (%)	69	64	67	69	41	38	0	0
Excess electricity (kW h)	12187 (31.5%)	7914 (27.3%)	15314 (35.5%)	11563 (36.7%)	1283 (4.33%)	1142 (5.2%)	5590 (20.3%)	568 (2%)
Autonomy (h)	8.06	5.45	13.8	5.45	6.91	5.45	0	0
Grid extension (km)	4.7	3.21	4.82	3.13	6.15	4.11	8.58	4.45

[a] 10 kW for Case 1, 5 kW for Case 2.

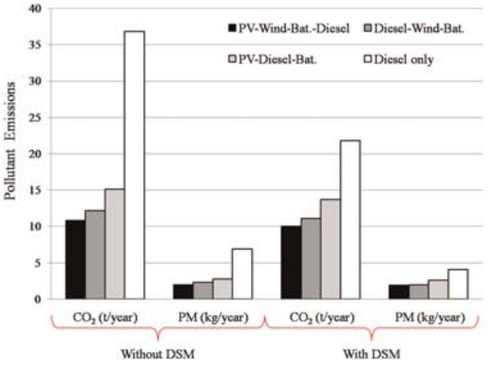

Figure 2. *Comparison of pollutants for various cases.*

only system reduces the greenhouse gas emissions to 10 t for CO_2, 1.9 kg for PM and 0.221 t for NO_x.

4 RESULTS AND DISCUSSION

Both load profiles for poultry house (with/without DSM) were developed and simulated with HOMER in order to evaluate the operational characteristics, namely the annual electrical energy production, excess electricity, renewable fractions. Annual diesel consumption and environmental impact parameters namely carbon emissions were calculated. In addition, a break-even analysis was performed to decide the optimum distance where the hybrid energy system should be more economical than the extension of the transmission line. Moreover, a cost analysis of the hybrid power system and a sensitivity analysis for the effect of diesel price on the COE produced by the hybrid systems were also conducted. At present, the average diesel price in Turkey is 1.45 US$/l. An annual interest rate of 10% and a project lifetime of 25 years were used in the economic calculations. Both percent and annual energy productions of each sources are shown in Figure 3 for both cases. The results of the simulation showed that the PV–wind–battery–diesel system had a total annual electrical energy production of 39 771 kW h. When DSM was applied, PV–wind–diesel–battery annual energy output was reduced to 26 614 kW h.

The variations of solar and wind energy generations do not match with the time distribution of the load demand. As given in Table 6, the PV–wind–diesel–battery hybrid system is suitable for the load profile without DSM in terms of COE, and the wind–diesel–battery is suitable for DSM load profile. This option change is to the reason that the COE depends mostly on fuel consumption. When the four options were compared in terms of fuel consumed rate, PV–wind–diesel–battery option was found as 4120 l/year, which is the lowest value for without the DSM case. Also, for the DSM case, fuel consumed rate of wind–diesel–battery was found to be the lowest. Because of low fuel consume rate, both COE and greenhouse gas emissions (CO_2, PM, NO_x) emitted to atmosphere became lower. In addition, the load profile of system matches the RE generations. PV–wind–diesel–battery system, COE of Case 1 and Case 2 is smaller than PV and wind options. This result can be attributed to the fact that the fuel consumption is lower than the other systems. Also, load profile of system matched with RE generations.

The results of sensitivity analysis are presented for without DSM in Figure 4. As can be seen in this figure, in the sensitivity analysis, seven diesel price values (from 1.45 to 2 US$/l) were

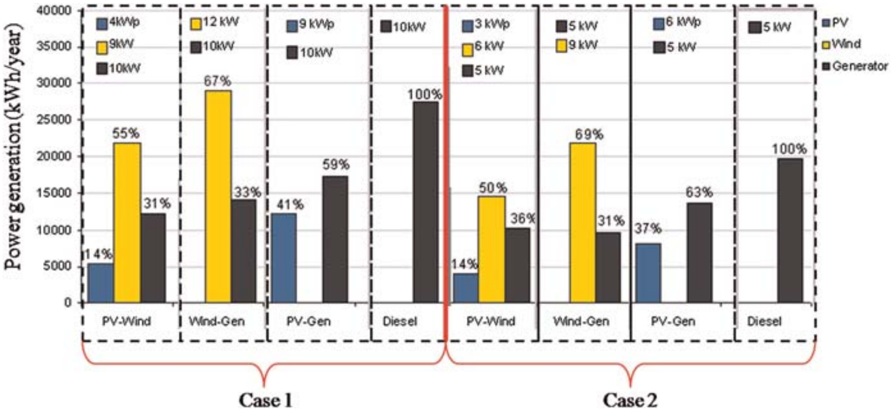

Figure 3. *Utilization of each option for both cases.*

Table 7. *Comparison for LEC for diesel price 1.45 US$/l.*

Parameters	PV–wind–diesel–battery		Wind–diesel–battery		PV–diesel–battery		Diesel-Only	
	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2	Case 1	Case 2
Capital (US$)	84 700	54 900	71 200	40 900	95 100	60 400	8000	4000
Replacement (US$)	75 132	33 510	81 726	24 887	93 757	35 107	47 811	23 909
O&M (US$)	21 664	25 598	24 744	37 965	28 149	35 795	140 234	70 133
Fuel (US$)	63 764	59 056	71 892	65 598	88 997	80 493	216 770	128 044
Total cost (US$)	242 988	172 266	247 973	168 841	305 306	211 090	412 334	225 853
AL (kW h)	21 900	18 505	21 900	18 505	21 900	18 505	21 900	18 505
COE (U$/kW h)	1.039	0.872	1.061	0.855	1.306	1.069	1.76	1.143

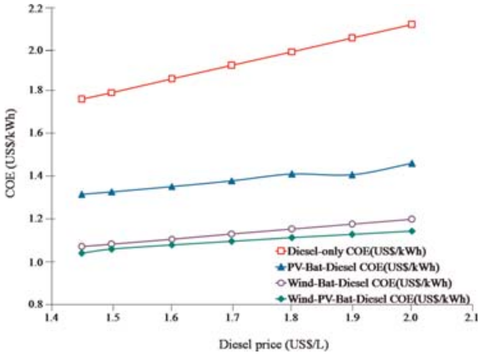

Figure 4. *Effect of diesel fuel price on COE for Case 1.*

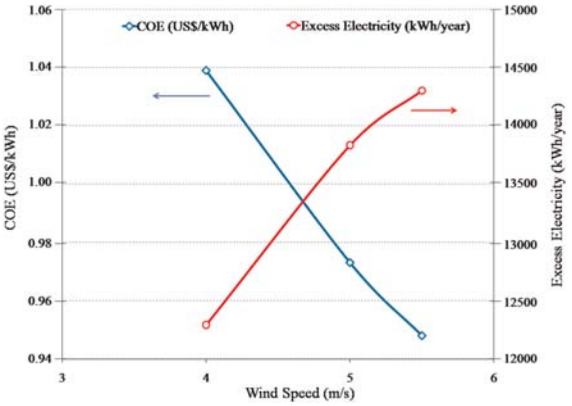

Figure 5. *Effect of varying wind speed on COE and excess electricity of PV–wind–diesel–battery system for Case 1.*

used to calculate the COE energy of each systems. The increase rate is the lowest for PV–wind–diesel–battery option. PV–diesel–battery system and only diesel options are mostly dependent on fuel price. When DSM was applied, COE ranged from US$ 0.872–0.974 for wind–PV–diesel–battery system. As the diesel price increased in sensitivity analysis, fuel cost also increased for both DSM and without DSM cases. Different wind speed and solar irradiation values were used in the sensitivity analysis in order to calculate the COE for various locations around Balikesir. In addition, the effect of wind speed was also investigated and shown in Figure 5. Wind speed values varying between 4 and 5.5 m/s were used as sensitivity variables to calculate the effect of COE and excess electricity produced from system. As can be seen from Table 7, wind–diesel–battery is a suitable case in terms of COE. It is clear in Figure 5 that while COE decreases from US$ 1.039–0.95 for the wind values varying between 4 and 5.5 m/s for Case 1 option, excess electricity increases from 12 187 to 14 350 kW h. If DSM is applied to the system (Case 2), COE decreases from US$ 0.853–0.669 for the wind values varying between 4 and 5.5 m/s and excess electricity needs decrease from 12 829 to 19 180 kW h.

Table 8. *Testing for the reliability of the program results.*

	HOMER	Calculation
Generator output (kW)	9724.4	10 627.6
Wind output (kW))	21 673	21 677.9
Generator fuel (l)	4320	4635
Annual cost ($)	15 858	16 413
COE ($/kW)	0.857	0.887
	Error	3.38%

The simulation results of wind–diesel–battery system for Case 2 are selected to test the reliability/validity of the program. The output power of WS Whisper 500 wind turbine power is fitted with a sixth degree polynomial curve, and wind output power is calculated with a MS Excel program using hourly (8760 h) wind speed data. The amount of time required for diesel generator to work is determined for a farm, the hourly load demand of which is known, and fuel consumption is calculated depending on this value. For economic calculations, the unit prices, 25-year economic life and inflation rates of components used in simulation were taken into account to calculate the annualized cost. Reliability of the program results is shown in Table 8.

5 CONCLUSIONS

This study has examined a hybrid, RE-based power generation system and studied electrical loads of a poultry farm in the Balikesir region for potential replacements to system components and other energy efficiency improvements which will help reduce the peak and overall electrical load at the poultry farm houses.

Four power generation systems have then been simulated. The base system is that of a stand-alone diesel generator. Other alternative systems include a combination of PV and wind as a generation source. The 25-year LCCs associated with each power system was calculated for each case. Besides, break-even distance analysis was carried out for hybrid energy systems and extension of transmission line. The distance, more than 4.7 km for PV–wind–diesel–battery, was found economical. In addition, the distance more than 3.12 km was also economical when DSM was implemented.

At present, RE-based hybrid energy systems may not appear as cost-competitive against conventional fossil-fuel-based stand-alone or grid interfaced power sources. As a result of the need for cleaner energy sources, improvements in alternative energy technologies and increase in fuel price, it is expected that there will be widespread use of various alternative energy sources in the future.

In future studies, it is planned to investigate the simulation models experimentally. In order to reduce the greenhouse gases emission and have the system work more reliably, some fuel cell and small hydro options will also be integrated to the hybrid system. Integration of the hybrid energy system with hydrogen storage, which is system excess energy, will enable the system to work more efficiently.

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