Chapter

Hybrid Energy-Based Chilling System for Food Preservation in Remote Areas

Edwin Mohan, Saranya Nair Mohan and Joseph Sekhar Santhappan

Abstract

The milk processing and preservation is a fast growing business in developing countries and it is facing problems due to high energy cost and environmental concerns in using conventional energy sources. Since the selection of feedstock and conversion technologies, appropriate research must implement renewable energy-based technologies to promote a constant flow of energy services. In this chapter, the focus is on implementing cooling technologies, using locally available energy sources such as biomass, biogas, gobar gas, which is going to be popular in the near future. The renewable energy sources can be used alone or in combination to run the generator of the vapor absorption system. Sufficient study is not available for hybrid energy systems, with the combination of locally available energy sources, focused in this study. Therefore a systematic analysis is needed to find the appropriate mixing of various renewable energy sources to meet the cooling requirements in any region to implement the complete renewable energy-based cooling system. The effect of variations in the combination of renewable energy sources on the overall system COP has been studied. Based on the maximum system performance and best economic performance, suitable combinations that can be preferred in various regions are predicted.

Keywords: hybrid energy, renewable energy, bio-energy, cooling system, remote area

1. Introduction

In developing countries, the gap in the quality life of the urban and rural areas is severely affected by the lack of various facilities which require electricity. Conventional energy sources such as electricity and diesel is not available in many rural regions and the grid connection and transportation of the fossil fuels are very difficult in rural India, because of the large capital investment required for the electrical infrastructure. As a result, marginal and small farmers face difficulty preserving the milk, fruits and vegetables in remote places. However, poor infrastructure, including the lack of integrated cooling facilities (cold chain), has retarded the growth of the milk and food processing industry [1, 2]. Due to a lack of proper storage and transit facilities, about 22% of agricultural produce, especially fruits and vegetables, are spoiled, and the loss is estimated to be worth about Rs. 330 billion. This spoilage could be prevented at the local village level by providing cooling units for short term preservation. Most of the cooling units are operated by vapor compression refrigeration systems. These systems need electrical power, which is not readily available in remote areas. Moreover, the cooling facility has to be located in close proximity of the source of the raw materials, especially perishable agricultural products, because it would help in reducing post-harvest losses and wastes. Since India is blessed with perennial solar energy and surplus bioenergy resources. Implementing cooling technologies, using locally available energy sources such as biomass, biogas, gobar gas, is going to be popular in the near future. With the abundant renewable energy sources in remote areas, it is indeed feasible for biomass, biogas, gobar gas and solar energy to be suitably integrated to operate a thermal driven absorption cooling system. With this the energy deficiency for food preservation could be solved. This unique factual situation motivated the researcher to carry out this work.

When considering a renewable energy system for rural requirements, it is important to design systems that are reliable and require little maintenance, as frequent and guide repairs and replacements might not be feasible. Using a stand-alone renewable energy system, such as solar, biomass and biogas conversion system, it is not possible to produce energy in the off-peak period and transportation of supply of bio-energy sources in a rural area is not easily possible. So integration of locally available energy sources in rural areas can be used to overcome these drawbacks. A hybrid energy system generally consists of a primary renewable source working in parallel with a standby secondary non-renewable module. Instead of using single stand-alone units, larger hybrid systems would be more cost-competitive for remote communities [3, 4]. Hybrid energy system includes several (two or more) energy sources, with appropriate energy conversion technology, connected together to feed power to local load and it would increase the energy reliability and overall efficiency.

In this research, modeling and simulation of hybrid energy (biomass/biogas/gobar gas/solar)-based cooling system has been successfully made using MATLAB software. An improvement in overall system COP (COP_{OS}) and best economic viability of the new renewable energy combination has also been demonstrated in this work.

A number of studies associated to the viability of cooling systems with hybrid energy and renewable energy have been carried out with respect to its application, possibilities, enactment, optimization, combination with another kind of energy conversion techniques and so on. Hybrid energy system generally consists of a primary renewable energy sources working in parallel with a standby secondary non-renewable module. This hybridization reduces 50% of the excess energy and also cost-competitive for remote communities [5, 6]. In hybrid system, two or more power generation sources are balanced to each other's strength and weakness [7, 8]. Suitable combinations of solar, biogas and biomass energy sources to meet the energy demands in order to improve the environment and socio-economic conditions in remote places [9]. Moreover the hybrid combination of renewable energy systems can be a cost-effective, alternative to grid extension, sustainable, techno-economically viable and environmentally sound system [10]. Cost, efficiency, social acceptance, reliability, and potential demand were the important factors to design the hybrid energy model [11, 12]. Even though several kinds of energy resources are obtainable in the villages of developing nations, a sole energy resource cannot meet the energy constraint [13]. Since, inadequate bioenergy resources, solar energy system is nominated to compensate for energy requirement.

Solar and biogas driven aqua-ammonia refrigeration system can be used for improving the quality of milk preservation at remote dairy farms, it shows an economically attractive [14, 15]. The energy demand can be matched with the supply of biogas by an appropriate choice of solar collector [16]. A hybrid cooling system with solar and biomass energy sources used to increase the overall system performance with 0.11. It shows that the performance has more consistency compared with conventional cooling system in remote places [17–20]. Nixon et al. [21] have reported that the hybrid energy system combined with solar and biomass energy sources which decreases the demand of biomass up to 25–30%, it results the constant energy security and reduce the requirement of land. Since, it has environment friendly with long payback period. The drying time of the solar-biomass drier has been reduced to 54–60% [22]. Wind energy conversion system combined with solar, fuel cell, hydro and biomass energy conversion system fulfill the remote consumer's electrification needs and guarantee a long-term energy autonomy, and minimize the consumption of imported oil and the corresponding environmental impacts. Moreover, this hybrid energy system is a better alternative for a wind-diesel system. MATLAB, response surface meta-models (RSM) and genetic algorithm (GA)-based analysis techniques are most widely used methods for optimize such type of hybrid energy system [23–28].

Standalone conventional electric power generation system retrofitted with renewable energy sources would be a viable option for power production at remote locations. It also stated that the PV/wind/hydro/diesel hybrid system shows the energy cost about $0.207/kWh [29]. Biomass generator is chosen as a major source of power in rural areas due to its high efficiency and cost effectiveness. The lowest energy cost observed is 1.85 Rs/kWh [30]. The hybridization of solar, wind, biogas, biomass, and hydro energy sources is to satisfy the viable electrification option in remote areas. It shows better economical solution and also a reliable option to moderate the present power crisis. It can have a good impression on enlightening the socio-economic situations of rural people [31]. Mixed integer linear programming model defines the optimum configuration of hydro/biogas/biomass/solar operated hybrid energy system with estimation of the economic diffusion levels of photovoltaic array area, and cost optimization [32–35].

Past literature shows that the most of the studies on the hybrid energy systems concentrated on the electrical energy production. More attention is needed for the effective operation of cooling and thermal power energy. Pecuniary environment of proposed combinations of available sustainable power resource frameworks are a significant issue. An epic blend of a few sustainable power source assets with further energy efficient feature is required to diminish the expense of the hybrid energy system. This can doggedness the issues to be challenged by the chilling amenity area in the inaccessible places and furthermore the 100% sustainable power source-based framework gives the ecological advantages.

1.1 Scope and aims of the work

Conventional energy-based vapor compression chilling system and stand-alone renewable energy-based electric power production are well-known technologies that are broadly used in developing countries. In disparity, hybrid thermal energy powered chilling system is a relatively novel notion. The conversion technology of bio-energy resources and solar power has been serious factor for the effective enactment of hybrid energy powered absorption chilling system to preserve the food and other products in remote areas, where the deprived electrical and transport facility. Thus, the primary study contained within this work contributes toward the selection of available renewable energy resources and requirement of cooling load, and mathematical design of a biomass, biogas and gobar gas energy conversion systems for the selected region. In view of this the ensuing objectives were delineated.

1. For different regions and locations, climatic conditions, including the availability of energy resources, requirement of cooling load, and so forth, are always changing. In order to efficiently utilize that the available renewable energy sources in these regions, Proper data collection and data fusing is needed for system process and thermal load requirement.

2. Detailed modeling and simulation analysis on biomass, biogas, gobar gas, solar energy conversion systems and suitable system with absorption chillers accordance with these energy resources.

3. Overall performance of the hybrid energy-based absorption cooling system with various energy proportions suitable to the study region-based on the nature of activities.

4. Economic studies of milk chilling system worked with existing available renewable energy resources.

5. Based on the techno-economic investigations, identification of the appropriate mixture of existing renewable energy sources for milk preservation, with higher overall performance of the system and minimum cost.

2. Materials and methods

2.1 Load/demand assessment

Agriculture-based industry has a vast significance in developing countries since the vital relations and interactions that it endorses between the industry and agriculture. Milk and food preservation covers a variety of yields from sub sectors including agriculture cultivation, farmstead animal farming and fisheries. Agro and milk-based food sectors are anticipated to show a key role in rural farming.

Data pertaining to the bio resources, no's of livestock and requirement of cooling load were composed from the local peoples, Govt. and non-Govt. agencies, etc., and the consistency of the data was inveterate from response received from local societies. Field studies based on household and direct discussion were carried out in the region to gather the information on obtainability of renewable energy resources, existing energy consumption, etc. The significant particulars composed as of the investigation are shown in **Table 1**. The main biomass energy resources (BM) are tapioca stalk, coconut shell, coconut coir pith, coconut rachis, wood pellets, rubber

Particulars	Survey details	Particulars	Survey details
No of villages	6	Geographical area of the region	26 sq km
Total population (Nos)	1750	No of households (Nos)	438
Density of livestock population (Nos)	160	Quantity of dung production (kg/day)	740
Biomass sources (kg/day)	390–640	Biogas sources (kg/day)	640–930
Gobar gas sources (kg/day)	660–880	Quantity of milk production (L/day)	1700

Table 1.
Details of survey data of selected regions.

seed, etc. Likewise the biogas (BG) and gobar gas (GG) resources are considered from the municipal solid waste and as of the populace of cows. The cooling requirement to keep the quality of milk produce also the requirement of heat load to work the cooling framework is to be resolved dependent on the yield of the milk, no of cows and the accessibility of the sustainable power sources.

The capacity of the production of milk in the isolated areas is calculated by the ensuing equation:

$$V_m = (N_{cows} \times \text{milk produced/cow}) + (N_{buffalo} \times \text{milk produced/buffalo}) + (N_{goats} \times \text{milk produced/goat}) \quad (1)$$

where, V_m is the volume of the milk produced per day in L/day. Normally each cow produces 8–16 L of milk per day [36, 37]. N_{cows} is the number of cows/cattle.

The available mass of milk is determined by

$$m_m = V_m \times \rho_m \quad (2)$$

where, m_m is the mass of milk produced per day in kg/day, ρ_m is the density of milk in kg/m^3 (density of milk is taken as 1027 kg/m^3) [38].

2.2 System description

The schematic diagram of a proposed hybrid energy system is shown in **Figure 1**. The proposed hybrid energy-based cooling system consists of two major sub-systems. (1) Energy conversion system; (2) vapor absorption cooling system.

Energy conversion system converts the available energy from the feedstock sources to thermal energy required for supply of heat to the steam generator of a vapor absorption cooling system. The number of conversion devices like biomass gasifier, biogas plant, gobar gas plant and solar collector has been used for the energy conversion process. These devices are selected based on their availability of energy resources and the required cooling load, whichever the Lithium Bromide-water or water-ammonia refrigeration system has been selected as the cooling device. The entire cooling load for the milk chilling is from the evaporator of the vapor absorption cooling system.

The preliminary analysis states that the renewable energy resources such as biomass (BM), biogas (BG) and gobar gas (GG) can be taken as main energy resources. When the BM, BG, and GG are not adequate to meet the cooling requirement, solar energy (SO) has to be used beside with the aforementioned renewable energy resources. In most of the areas in the study region, there is a major deviation in solar intensity during 7–9 months in a year because of cloudy condition. Moreover the preliminary cost of the solar conversion system is also very high compared with other renewable energy conversion devices. Hence BM, BG and GG energy resources plays a major renewable energy resources and solar energy has been used where the aforementioned energy resources are not adequate to meet the

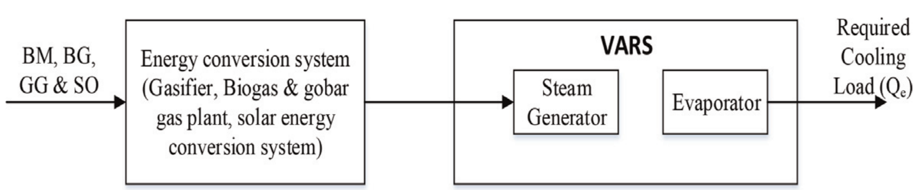

Figure 1.
Proposed hybrid energy-based cooling system.

energy constraint. Wood pellets, tapioca stalk, coconut stalk, coir nub, paddy straw, rice shell, coconut shell, etc., are used as energy harvests in biomass gasifier. Municipal solid waste and food waste from rural households are the resources of energy in the biogas plant. Cow dung is used as an energy yield in the gobar gas plant. A LiBr-water vapor absorption system considered as COP of 0.5–0.75, evaporator temperature of 4–9°C and generator temperature of 95–112°C [39].

2.3 Theoretical modeling

The strategies followed to analyze the hybrid system are depicted in a flow chart shown in **Figure 2**. The energy conversion has been determined, in light of the conversion efficacies of biomass (η_{cBM}), biogas (η_{cBG}) and gobar gas (η_{cGG}), and their qualities are taken as 0.46, 0.26, and 0.35 respectively [40].

The quality amount of agro squanders have been evaluated based on the accessible information. The heat load created as of the biomass gasifier (Q_{BM}) can be resolved from [18–20].

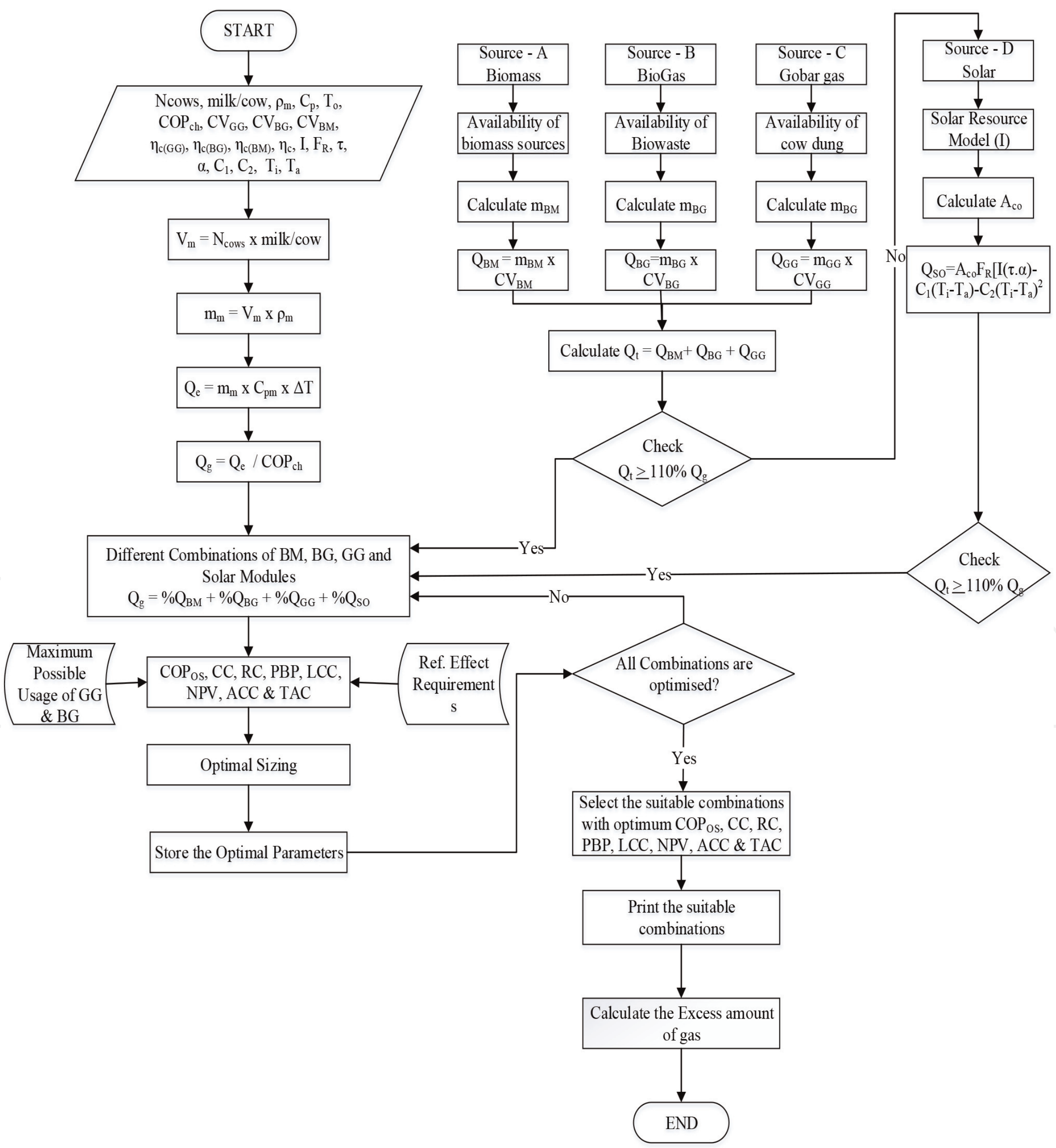

Figure 2.
Flow chart for the simulation of proposed hybrid energy system.

$$Q_{BM} = m_{BM} \times CV_{BM} \times \eta_{cBM} \tag{3}$$

The quantity of solid waste generated per family is taken as 3–6 kg per day [14, 15], and the amount of waste required to produce 1 m^3 gas is assumed as 23 kg [14, 15]. The heat produced from the biogas plant (Q_{BG}) is given as [18–20].

$$Q_{BG} = m_{BG} \times CV_{BG} \times \eta_{cBG} \tag{4}$$

Similarly, the biogas produced from cow dung (gobar gas) has been calculated from the cattle population and dung yield per animal. The biogas production from the cow dung has been worked out, based on the assumption that 4–7 kg dung per cow per day is produced [14, 15], and the amount of cow dung required to produce 1 m^3 gas is estimated as 12 kg [15]. The heat produced from the gobar gas plant (Q_{GG}) can be obtained from the equation [18–20].

$$Q_{GG} = m_{GG} \times CV_{GG} \times \eta_{cGG} \tag{5}$$

On a clear day, the average solar radiation is about 700 W/m^2, and the average solar conversion efficiency could be 50%. The useful energy output of a collector (Q_{SO}) in the steady state condition is calculated as follows [21]:

$$Q_{so} = A_{co}F_R\left[(\tau\alpha)I - C_1(T_i - T_a) - C_2(T_i - T_a)^2\right] \tag{6}$$

The entire system design is based on the cooling load of the selected region. The evaporator cooling load (Q_e) of the vapor absorption refrigeration system in the steady state condition, is obtained from the basic relation

$$Q_e = m_m \times C_{p,m} \times \Delta T \tag{7}$$

where, Q_e is the amount of cooling effect, delivered from the evaporator in kJ/kg, $C_{p,m}$ is the specific heat of milk in kJ/kgK, ΔT is the change in temperature of the milk in the evaporator.

The required amount of BM, BG and GG sources are considered based on the requirement cooling capacity and the heat load requirement to the steam generator in the vapor absorption refrigeration system. The required amount of refrigeration capacity is resolved dependent on the Eq. (7). The required heat load is determined dependent on the refrigeration capacity and the performance of the refrigerating system. The amount of heat load provided to the generator is to be calculated from the forthcoming relation [18–20].

$$Q_g = Q_e/COP \tag{8}$$

Where, Q_g is the heat supplied to the generator in kW. Assume COP of the absorption chiller is 0.5 [18, 19].

The overall system performance (COP_{OS}) of the proposed system is determined from the equation

$$COP_{os} = Q_e/(k.IA_{co} + x.m_{BM}CV_{BM} + y.m_{BG}CV_{BG} + z.m_{GG}CV_{GG}) \tag{9}$$

Where x, y, z, and k denote the proportion of biomass, biogas, gobar gas and solar energy in hybrid energy system.

The base energy source is considered as any of the single energy resource, and the mixture element is the combination of another two or three energy resources.

The mixture component ratio is changed from 25, 50, and 75% respectively. In all magnitudes the proportion of the energy resources in the blend component is kept steady for a specific blend.

MATLAB programming has been utilized to simulate the hybrid energy-based chilling system. To discover the COP_{OS} of the framework, all the components are interconnected as per the real system.

2.4 Economic modeling of the proposed hybrid energy system

An optimal mixture of a hybrid renewable energy-based absorption chilling system can be found to fulfill the cooling demand with maximum overall system performance (COP_{OS}) with the best economical feasibility. The economic methodology, based on the conception of capital cost, running cost, payback period, and net present value is determined to the finest level of the overall system economic analysis in this study.

The total aggregate expense is comprised by fittings and common works for the setting up of the plant. Government stipends are additionally reflected with the estimation of the capital expense. The parts considered in the plant for manipulating the capital expense of biomass, biogas and gobar gas plant, biogas and gobar gas burner and heat exchanger, and vapor absorption refrigeration system.

$$\begin{aligned}\text{Capital cost of HRES} = &\ \text{capital cost of BM, BG and GG plant} \\ &+ \text{capital cost of VARS} \\ &+ \text{capital cost of burner and heat exchanger in BG and GG plant} \\ &- \text{Govt.subsidies}\end{aligned} \tag{10}$$

The operating or running cost of a system comprises an operational and maintenance cost and yearly depreciation value.

$$\begin{aligned}\text{Running cost of HES} = &\ \text{cost of the energy resource used} \\ &+ \text{operation and maintenance cost of energy conversion system} \\ &+ \text{operation and maintenance cost of VARS} + \text{labour cost} \\ &+ \text{depreciation value}\end{aligned} \tag{11}$$

The optimum economic value of a hybrid renewable energy-based refrigeration system includes the payback period to retrofitted with conventional cooling system with diesel genset, has been calculated as

$$Payback\ period = \frac{Incremental\ value\ of\ Capital\ cost}{Annual\ savings\ (Profit)} \tag{12}$$

where, the incremental value is the difference between the capital cost of fossil fuel-based cooling system and the hybrid renewable energy-based absorption refrigeration system.

$$\begin{aligned}&\text{Capital cost of fossil fuel} - \text{based refrigeration system} \\ &\quad = \text{cost of diesel generator} + \text{cost of fossil fuel} - \text{based cooling system}\end{aligned} \tag{13}$$

Annual savings is the difference between the running cost of diesel-based VCRS and the hybrid energy-based absorption cooling system. Where,

$$\begin{aligned}&\text{Running cost of fossil fuel} - \text{based refrigeration system}\\&\quad = \text{cost of fossil fuel (diesel)} + \text{maintenance cost of refrigeration system}\\&\qquad + \text{labor cost to operate the system} + \text{depreciation value}\end{aligned} \tag{14}$$

Net present value (NPV) is the existing value of the costs of investment and running cost of a system over its period. Net present value of the investment is the difference between the present worth of the benefits and the costs ensuing from an investment.

$$NPV = \left[S.\left(\frac{(1+i)^n - 1}{i(1+i)^n}\right)\right] - CC \tag{15}$$

where 'S' stands for benefits at the end of the lifetime, CC is the initial capital investment of the system. The acceptance criteria of an investment project as: (a) NPV > 0, accept the system (b) NPV < 0, reject the system.

The life cycle cost (LCC) analysis based on present worth cost (PWC) method, which includes the initial capital cost, running cost, maintenance cost, replacement cost and salvage values is the useful prediction to analyze the various mixtures of hybrid renewable energy-based refrigeration system in remote locations. A life cycle of 18 years was used to evaluate the PWC of the system.

$$\text{LCC} = \text{initial capital cost} + \text{PWC}_{\text{RC}} + \text{PWC}_{\text{RE}} + \text{PWC}_{\text{SV}} \tag{16}$$

A forthcoming aggregate value for an item transformed into its corresponding existing value is called the present worth of this item. The following equation is used to calculate the PWC of operating costs and maintenance costs.

$$P_{RC} = RC.\left[\frac{(1+i)^n - 1}{i.(1+i)^n}\right] \tag{17}$$

The following equation is used to calculate the PWC of replacement costs and salvage values.

$$P_{RE} = RE.\left[\frac{1}{(1+i)^n}\right] \tag{18}$$

$$P_{SV} = SV.\left[\frac{1}{(1+i)^n}\right] \tag{19}$$

Here the salvage value of the hybrid energy-based absorption system after 18 years is estimated by assuming 7% of total initial costs of the system. The replacement cost of the hybrid energy-based absorption cooling system after 18 years is estimated by assuming 1% of total initial costs of the system.

3. Results and discussion

The results obtained from the modeling and simulation of the techno-economic performance of hybrid energy-based cooling systems for milk preservation in studied region was presented. In most of the studied regions the normal milk production is around 2500 L per day which can be cooled to the preservation temperature at 4°C in 4 hours. Therefore the 5TR system has been considered in this study. The performance parameters such as COP_{OS} (overall system COP), capital cost, running cost, payback period and net present value of a system are suitably analyzed in this chapter.

The amount of every energy source accessible, and the required quantity of energy resource to satisfy the cooling desires in an investigation area is appeared in **Figure 3**. It is seen that the accessible energy resources are less than the required amount. So any sole source accessible in this province does not satisfy the essential cooling demand. Along these lines, to meet the total cooling demand, all the accessible energy sources must be utilized in appropriate blends. Hence the identified three renewable energy resources, BM, BG and GG, are consolidated as BM-BG, BM-GG and BG-GG for this examination. In the graphs, the proportion of the two energy resources is plotted in X-axis so that the use of major energy source ascends from left to right though another energy source rises from right to left. Standard operational range represents that the base and most extreme availability of BM, BG and GG energy resources.

The overall performance of the cooling system with the ratio of energy sources is shown in **Figure 4**. It shows that, the overall system performance (COP_{OS}) increases with increase in the proportion of energy sources for the BM-GG and BM-BG mixtures, because of the high calorific rate of energy resources and the enhanced conversion efficacy of biomass gasifier. However, the COP_{OS} diminishes with increment in proportion of energy resources for the BG-GG mixture. In the mixture of BM-GG energy sources, COP_{OS} changes among 0.185 and 0.23. However the another two blends, BM-BG and BG-GG, indicates an moderately lowest COP_{OS} of 0.13–0.23 and 0.13–0.185 respectively. The BG-GG mixture indicates that the lowest value of COP_{OS}, so this mixture may not be considered in this area.

Figure 5 shows that the capital cost and running cost hybrid energy-based cooling system for different mixtures with the ratio of energy resources in the study area. It states that the BG-GG blends contribute the lowest capital cost, when the influence of the gobar gas contribution is at highest level. When the contribution of gobar gas source is higher than 70–80%, the capital cost variations of the mixtures BM-GG and BG-GG are under 10%. The variations of the capital expense of BM-BG illustrate a higher incentive than different blends. Hence, the BM-BG mixture is not appropriate in the study province. At the point when the impact of the gobar gas

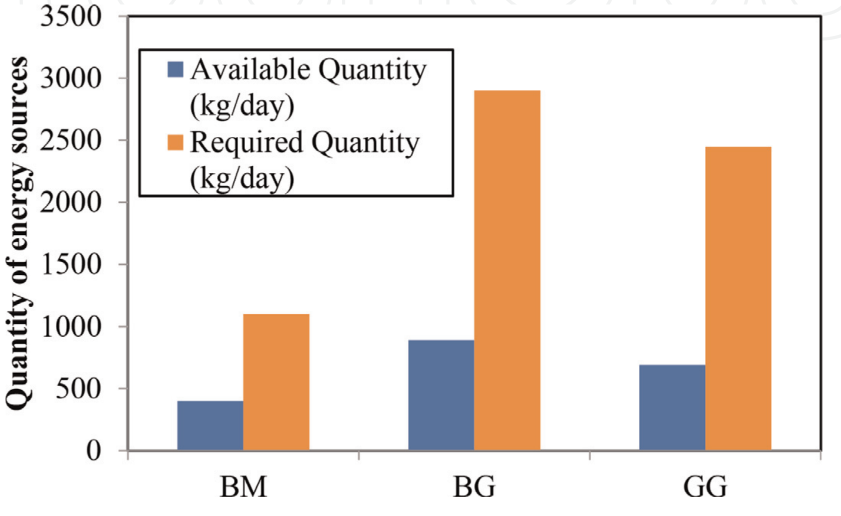

Figure 3.
Available and required quantities of energy sources in study region.

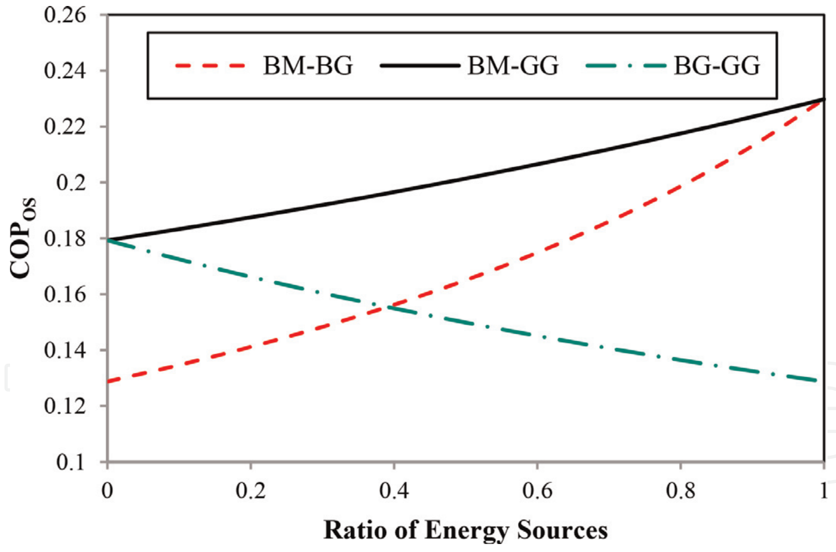

Figure 4.
Overall performances of cooling systems in the study region.

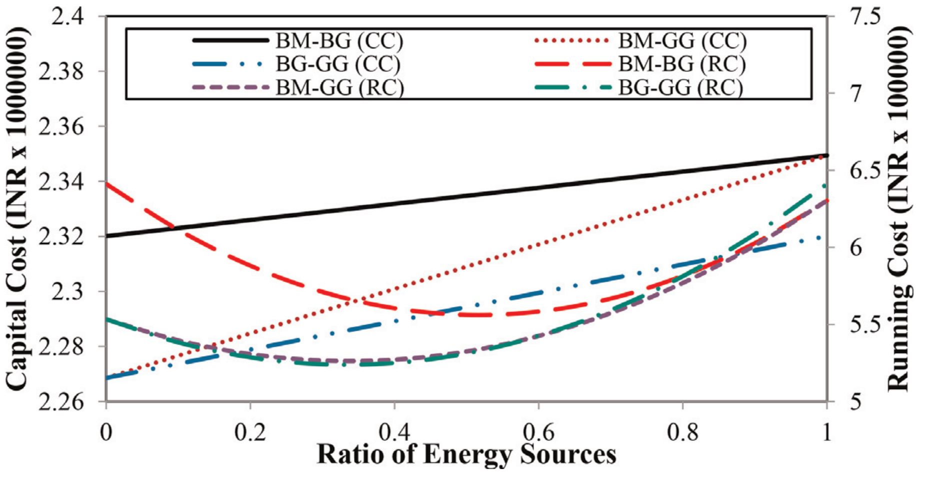

Figure 5.
Variations in capital and running cost of the hybrid energy-based cooling systems in the study region with various combinations.

commitment is 60–70%, the BM-GG and BG-GG blends demonstrate a low running expense contrasted with BM-BG blends. So, gobar gas influence is kept at 65–75% in BM-GG and BG-GG mixtures to attain a low running expense. So the mix of energy sources with gobar gas commitment is very essentialness to diminish the capital and running expense in the study province.

Figure 6 show that the variation of payback period of hybrid energy-based cooling system with the ratio of energy sources in study region. The mixtures of BM-GG and BG-GG illustrates a lowest payback period, when the influence of gobar gas contribution is higher level, as it reflects the lowest running cost of the process. It is identified that the overall system with the influence of 70% gobar gas contribution is suitable mixing value in that region. However, the influence of gobar gas contribution is more than 80% in the mixture of energy sources, a highest value of payback period has been observed. It concludes, it is not suitable to maintain the gobar gas contribution is above 80% in the mixture of energy sources. It is advisable that the influence of GG should be 60–70% in BM-GG and BG-GG mixtures to attain the lowest payback period.

Figure 7 shows that the net present value (NPV) of the various mixtures of hybrid renewable energy-based cooling system with the ratio of energy sources.

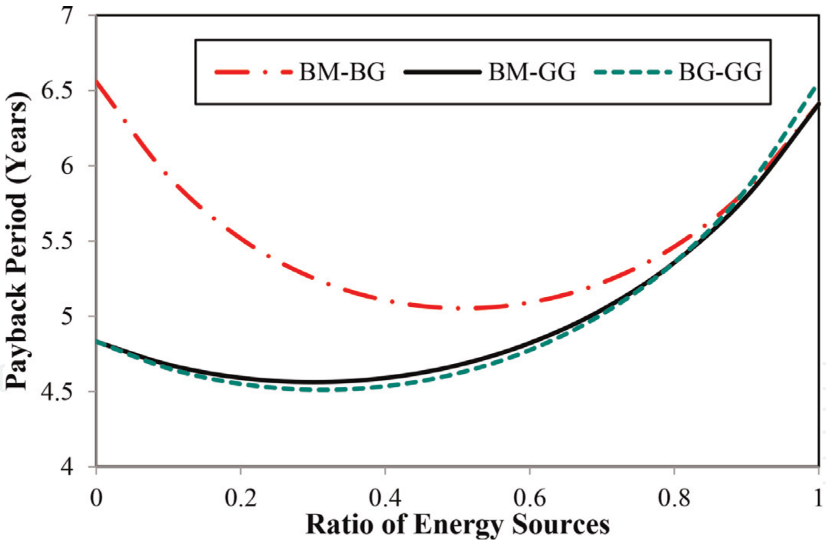

Figure 6.
Payback period of the cooling systems in the study region with various combinations.

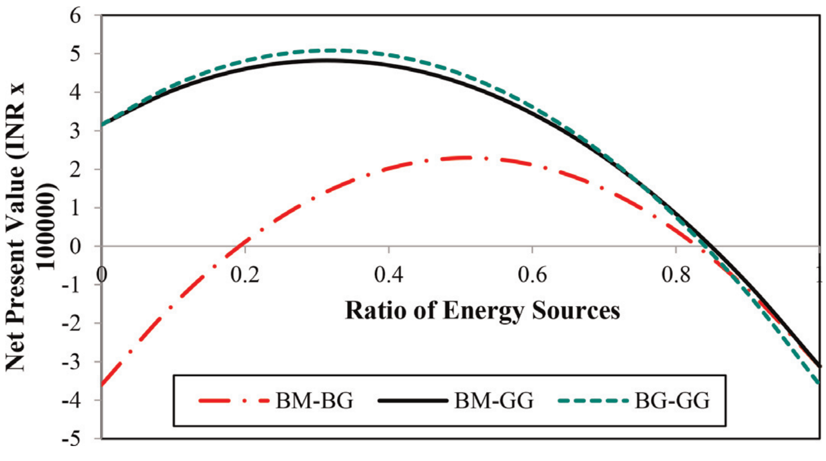

Figure 7.
NPV of the cooling systems in HR with various combinations.

When the influence of gobar gas is more than 20% in the ratio of energy mixture, BM-GG and BG-GG are shows the positive trends. Therefore these combinations are preferable once in the study region.

The life cycle cost (LCC) variation with the proportion of energy resources has been analyzed and noted in **Figure 8**. The pattern of BM-GG and BG-GG blends demonstrates that the LCC is low for BM-BG mixture, when the gobar gas commitment is kept at the most extreme. It is seen that the system with the GG influence of 70% is the most suitable meanwhile LCC worth is very low for this contribution.

The purpose of techno-economic analysis is to achieve, within a given system structure, a balance between the overall system performance and the various economical factors which will give an preeminent overall COP and cost of the system. In general, an overall system requires two conflicting objectives: one being an increase in overall system performance and the other is economical viability. Both of these factors should be satisfied simultaneously. The overall system performance is decided by the COP_{OS} and the economical viability is confirmed based on capital cost, running cost, payback period, net present value, life cycle cost, etc. Therefore the COP_{OS} and the economic parameters obtained from the study for the identified combinations are discussed in this section.

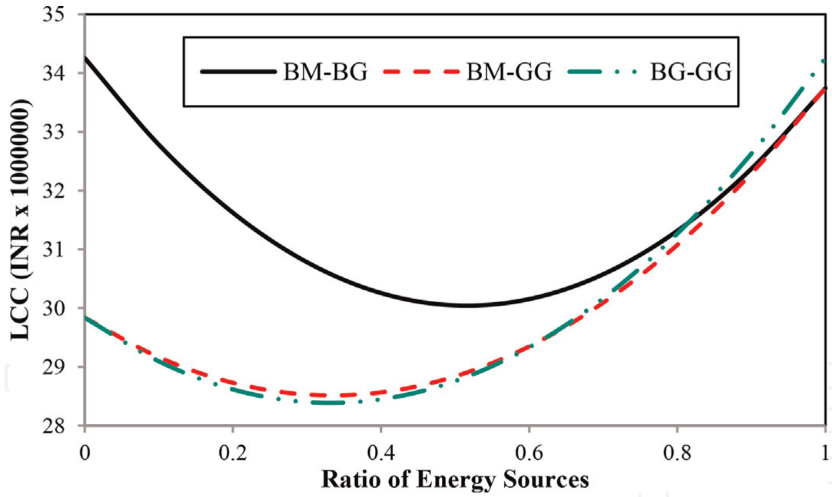

Figure 8.
LCC variation of hybrid energy-based cooling systems in the study region.

Sl. No	Combinations	COP_{OS}	CC (INR × 10^6)	RC (INR × 10^6)	PBP (years)	NPV (INR × 10^6)	LCC (INR × 10^7)
1	BM—BG	0.13–0.23	2.32–2.35	0.56–0.64	5.0–6.5	−0.36–0.22	3.0–3.42
2	BM—GG	0.18–0.23	2.27–2.35	0.53–0.63	4.6–6.4	−0.31–0.48	2.85–3.37
3	BG—GG	0.13–0.18	2.27–2.32	0.52–0.64	4.5–6.5	−0.36–0.50	2.84–3.42

Table 2.
Technical and economic performance of the hybrid energy-based cooling system in the study region.

The possible three combinations identified in the study region along with their COP_{OS} and economic factors are presented in **Table 2**. The values are obtained from **Figures 4–8**.

Table 2 demonstrates that the BM-GG mixture gives the most astounding COP_{OS} (0.185–0.235) because of the higher calorific range and conversion efficacies of biomass and gobar gas resources besides the lower running expense. Notwithstanding, this blend has higher capital expense than BM-BG and BG-GG mixture. This is because of the cost associated with the establishment of biomass plant. In addition, the payback period of BM-GG mixture is low and it's NPV and LCC is superior to the next two mixes. Hence, the hybrid energy system working with BM-GG mixture is the most suitable for the study province.

The simulation results expose that the gobar gas influence has extraordinary effect in all the economic values in the study provinces. Consequently 70% of gobar gas commitment in any mixture can be considered as the appropriate mixture in the study area.

4. Conclusions

The present investigation is focused on the development of environment friendly, energy efficient, 100% renewable energy-based cooling system for milk and agro preservation in remote areas. Alternative cooling systems have been studied by integrating the available renewable energy sources of biomass, biogas, and gobar gas with vapor absorption cooling system to solve the high energy demand and high emissions issues associated with conventional cooling systems. Based on the nature of activities taking place, the study area has been selected. The techno-economic study has been performed to identify the appropriate composition of available renewable energy sources to meet the cooling demand of a particular area. Based on the analysis the following conclusions are drawn.

In the study region, a single energy source cannot meet the energy required to produce the required cooling load. Therefore, a combination of energy sources could help us to implement 100% renewable energy-based cooling systems in villages.

In the study region, the combination of biomass and gobar gas (BM-GG) is the appropriate pair of energy sources. It offers higher COP_{OS} (0.18–0.23) due to the higher heating value and conversion efficiencies of biomass and gobar gas sources besides the lower running cost. Moreover, BM-GG combination requires lower payback period (4.6–6.4 years) in comparison with the other combinations such as BM-BG (5–6.5 years) and BG-GG (4.5–6.5 years). Additionally, the life cycle cost of the BM-GG combination is less than the other two combinations because of the lower running cost and replacement cost. Based on the reasons given above, the BM-GG combination-based cooling system can be considered as the most appropriate combination in the study Region.

All the observations show that the maximum usage of biomass energy source highly influences the COP_{OS}. Hence, BM could be utilized to the maximum in hybrid energy systems, to improve the overall performance.

The analysis demonstrates that the greatest utilization of biomass can improve the COP_{OS}, while the gobar gas diminishes the capital cost, running expense and payback period. Consequently, biomass and gobar gas resources could be used to the maximum in hybrid energy systems to enhance the COP_{OS}, and diminish the capital cost, running expense and payback period.

In this work, a new methodology has been developed to account for the sustainable cooling system to preserve milk and agro products for remote communities using renewable energy sources. The method applied here is generally applicable to any region.

Author details

Edwin Mohan[1*], Saranya Nair Mohan[2] and Joseph Sekhar Santhappan[3]

1 Department of Mechanical Engineering, University College of Engineering, Nagercoil, Anna University Constituent College, Nagercoil, India

2 School of Electronics Engineering, Vellore Institute of Technology, Chennai, India

3 Department of Mechanical Engineering, Shinas College of Technology, Sultanate of Oman

*Address all correspondence to: edwinme1980@gmail.com

References

[1] Kumar A. Solar-biomass hybrid cold storage-cum-power generation system for rural applications. Energetica India. 2012;**30**:54-55

[2] TIFAC. Agro-Food Processing Technology Vision 2020 Fruits & Vegetables—Current Status & Vision. Technology Vision 2020 Reports, TIFAC:V: 01: DR(FV); 2012

[3] Khan MJ, Iqbal MT. Dynamic modeling and simulation of a small wind-fuel cell hybrid energy system. Renewable Energy. 2005;**30**:421-439. DOI: 10.1016/j.renene.2004.05.013

[4] Khan MJ, Iqbal MT. Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland. Renewable Energy. 2005;**30**:835-854. DOI: 10.1016/j.renene.2004.09.001

[5] Khan MJ, Iqbal MT. Analysis of a small wind-hydrogen stand-alone hybrid energy system. Applied Energy. 2009;**86**:2429-2442. DOI: 10.1016/j.apenergy.2008.10.024

[6] Juhari AR, Kamaruzzaman S. Optimization of renewable energy hybrid system by minimizing excess capacity. International Journal of Energy Research. 2007;**1**(3):77-81

[7] Ashok S. Optimised model for community-based hybrid energy system. Renewable Energy. 2007;**32**:1155-1164. DOI: 10.1016/j.renene.2006.04. 008

[8] Ashok S. Hybrid energy systems-prospects and initiatives at NIT Calicut. NITC-Research Review. 2009;**3**(1):3-16

[9] Singal SK, Varun SRP. Rural electrification of a remote island by renewable energy sources. Renewable Energy. 2007;**32**:2491-2501. DOI: 10.1016/j.renene.2006.12.013

[10] Rohit S, Subhes C. Off-grid electricity generation with renewable energy technologies in India: An application of HOMER. Renewable Energy. 2014;**62**:388-398. DOI: 10.1016/j.renene.2013.07.028

[11] Iniyan S, Sumathy K. An optimal renewable energy model for various end-uses. Energy. 2000;**25**:563-575. DOI: 10.1016/S0360-5442(99)00090-0

[12] Craig G, Eilin W, Kevin PM, Philip O. Regional integration of renewable energy systems in Ireland—The role of hybrid energy systems for small communities. Electrical Power and Energy Systems. 2013;**44**:713-720. DOI: 10.1016/j.ijepes.2012.08.012

[13] Rahman MM, Hasan MM, Paatero JV, Lahdelma R. Hybrid application of biogas and solar resources to fulfill household energy needs: A potentially viable option in rural areas of developing countries. Renewable Energy. 2014;**68**:35-45. DOI: 10.1016/j.renene.2014.01.030

[14] Alvares SG, Trepp TH. Simulation of a solar driven aqua-ammonia absorption refrigeration system part 1: Mathematical description and system optimization. International Journal of Refrigeration. 1987;**10**:40-48. DOI: 10.1016/0140-7007(87)90095-8

[15] Alvares SG, Trepp TH. Simulation of a solar driven aqua-ammonia absorption refrigeration system part 2: Viability for milk cooling at remote Brazilian dairy farms. International Journal of Refrigeration. 1987;**10**:70-76. DOI: 10.1016/0140-7007(87)90023-5

[16] Kaushika ND, Mishra A, Chakravarty MN. Thermal analysis of solar biomass hybrid co-generation plants. International Journal of Sustainable Energy. 2005;**24**(4):175-186. DOI: 10.1080/14786450500291909

[17] Prasartkaew B, Kumar S. A low carbon cooling system using renewable energy resources and technologies. Energy and Buildings. 2010;**42**: 1453-1462. DOI: 10.1016/j.enbuild.2010.03.015

[18] Prasartkaew B, Kumar S. Experimental study on the performance of a solar-biomass hybrid air-conditioning system. Renewable Energy. 2013;**57**:86-93. DOI: 10.1016/j.renene.2013.01.034

[19] Prasartkaew B. Mathematical modeling of an absorption chiller system energized by a hybrid thermal system: Model validation. Energy Procedia. 2013;**34**: 159-172. DOI: 10.1016/j.egypro.2013.06.744

[20] Prasartkaew B, Kumar S. The quasi-steady state performance of a solar-biomass hybrid cooling system. In: Proceedings of the Second TSME International Conference on Mechanical Engineering; 19-21 October 2011; Krabi. 2011. pp. 19-21

[21] Nixon JD, Dey PK, Davies PA. The feasibility of hybrid solar-biomass power plants in India. Energy. 2012;**56**: 541-554. DOI: 10.1016/j.energy.2012.07.058

[22] Jaishree P, Vijay VK. Experimental studies on drying of Zingiberofficinale, Curcuma longa l and Tinosporacordifolia in solar-biomass hybrid drier. Renewable Energy. 2005; **30**:2097-2109. DOI: 10.1016/j.renene.2005.02.007

[23] Iqbal MT. Modeling and control of a wind fuel cell hybrid energy system. Renewable Energy. 2003;**28**:223-237. DOI: 10.1016/S0960-1481(02)00016-2

[24] Jaramillo OA, Borja MA, Huacuz JM. Using hydropower to complement wind energy: A hybrid system to provide firm power. Renewable Energy. 2004;**29**:1887-1909. DOI: 10.1016/j.renene.2004.02.010

[25] Kaldellis JK. An integrated model for performance simulation of hybrid wind-diesel systems. Renewable Energy. 2007;**32**:1544-1564. DOI: 10.1016/j.renene.2006.07.004

[26] Li-qun L, Zhi-xin W. The development and application practice of wind-solar energy hybrid generation systems in China. Renewable and Sustainable Energy Reviews. 2009;**13**: 1504-1512. DOI: 10.1016/j.rser.2008.09.021

[27] Perez-Navarro A, Alfonso D, Alvarez F, Ibanez C, Sanchez I, Segura C. Hybrid biomass-wind power plant for reliable energy generation. Renewable Energy. 2010;**35**:1436-1443. DOI: 10.1016/j.renene.2009.12.018

[28] Fantidis JG, Mantzari VC, Kalkani E, Bandekas DV, Vordos N. A hybrid wind and hydroelectric power production system in Plaka, Alexandroupolis, Greece. International Journal of Advances in Engineering, Science and Technology. 2013;**2**(4): 376-385

[29] Lal DK, Dash BB, Akella AK. Optimization of PV/wind/micro-hydro/diesel hybrid power system in HOMER for the study area. International Journal on Electrical Engineering and Informatics. 2011;**3**(3):307-325

[30] Maherchandani JK, Agarwal C, Sahi M. Economic feasibility of hybrid biomass/PV/wind system for remote villages using HOMER. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering. 2012;**1**(2): 49-53

[31] Nahid-ur-Rahman C, Syed ER, Tofaeel AN, Mahabub A-A-F-I. Present scenario of renewable energy in Bangladesh and a proposed hybrid system to minimize power crisis in

remote areas. International Journal of Renewable Energy Research. 2012;**2**(2): 280-288

[32] Gupta A, Saini RP, Sharma MP. Steady-state modelling of hybrid energy system for off grid electrification of cluster of villages. Renewable Energy. 2010;**35**:520-535. DOI: 10.1016/j.renene.2009.06.014

[33] Gupta A, Saini RP, Sharma MP. Modelling of hybrid energy system-part I: Problem formulation and model development. Renewable Energy. 2011; **36**:459-465. DOI: 10.1016/j.renene.2010.06.035

[34] Gupta A, Saini RP, Sharma MP. Modelling of hybrid energy system-part II: Combined dispatch strategies and solution algorithm. Renewable Energy. 2011;**36**:466-473. DOI: 10.1016/j.renene.2009.04.035

[35] Gupta A, Saini RP, Sharma MP. Modelling of hybrid energy system-part III: Case study with simulation results. Renewable Energy. 2011;**36**:474-481. DOI: 10.1016/j.renene.2009.04.036

[36] Carrie H, Samuel G, Jonathan W. Evaluation of energy efficiency and renewable energy generation opportunities for small scale dairy farms: A case study in Prince Edward Island, Canada. Renewable Energy. 2014;**67**:20-29. DOI: 10.1016/j.renene.2013.11.040

[37] Zehetmeier M, Baudracco J, Hoffmann H, Hei Benhuber A. Does increasing milk yield per cow reduce greenhouse gas emissions? A system approach. Animal. 2012;**6**(1):154-166. DOI: 10.1017/S1751731111001467

[38] McSweeney PLH, Fox PF. Advanced Dairy Chemistry. New York: Springer; 2009

[39] Le Lostec B, Galanis N, Millette J. Experimental study of an ammonia-water absorption chiller. International Journal of Refrigeration. 2012;**35**: 2275-2286. DOI: 10.1016/j.ijrefrig.2012.05.012

[40] Koop K, Koper M, Bijsma R, Wonink S, Ouwens JD. Evaluation of Improvements in End-Conversion Efficiency for Bioenergy Production; Ecofys. 2010