International Journal of Smart Grid and Clean Energy

# Optimizations of integrated energy systems for animal farms in Vietnam

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**Abstract**

This paper presents an optimization of energy systems for animal farms in Vietnam considering availability of energy resources within the farm such as biogas, solar, etc. It is proposed to combine two energy carriers together: biogas, and electricity into an aggregate system to improve the energy efficiency in the farm. Particularly nowadays in Vietnam, the local renewable power source can supply electricity back to the grid at a special price, making the investment of on-site generation is more reasonable. The optimal design of the energy system is formulated considering biogas generator, photovoltaics, battery, converter and the grid feeder, etc. The problem is then examined in a case study of a typical pig farm in Vietnam. In both case of within or without the ability to sell electricity back to the grid, the result shows the effectiveness of the proposed energy system.

*Keywords: Integrated energy system, biogas engine generator, photovoltaics, optimal planning*

## 1. Introduction

In Vietnam, the agriculture sector is an important part of the national economy which uses more than 70% of population and 82.4% area of lands [1-2]. In the country, there are more than 10.9 million poultry, 4 million pig and about 2.5 cattle farms. In average, the waste produced by each cow is 10-15kg feces/day, by pig is 2.5-3.5kg feces/day, and by poultry is 90g feces/day. The pollution caused by the waste from these animal farms become more and more critical. Recently, the law of environment protections was reinforced which requires all farms to have biogas digesters to process the organic wastes before injected to environments. In this case, a significant amount of biogas is produced, but only small parts of them are used for cooking in the farm while the rest is burned out [3].

In the past, most of energy systems were planned and managed independently. Nowadays, many new energy resources have been found for substitutions of traditional fossil fuels, such as solar, wind, biomass, etc. They can be located near the consumption site. It came to the idea of integrating various energy infrastructures such as electricity, heat and gas, etc. in an aggregate system called energy hub. By this means, the quality, reliability and efficiency of energy supply can be improved [4-5]. Many researches on energy systems have been conducted all over the world. The integration of distributed generation (DG) into the existing electric grid with multiple energy carries is studied in [6-8]. The uncertainty of renewable DG such as wind, solar power as well as loads is treated by adding an appropriate battery bank or demand response (DR) which are solved by stochastic models [9-10].

In this paper, we propose a new structure of energy systems particularly for animal farms with biogas in Vietnam. It is to cooperate three different types of energy carriers including electricity, biogas and heat to supply the energy demand of the farm. Biogas from digesters after filtering can be used to for cooking, heating and also running biogas generators to provide electricity; if shorted, natural gas can be purchased from markets. Electric loads can be supplied by the grid feeder, biogas generators and photovoltaics (PV)

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doi: 10.12720/sgce.9.2.448-457

in coordination with battery banks; the excess of electricity can be sold back to the grid. In Vietnam, the utility is required to purchase electricity from renewable source at a special price (0.1 $/kWh) which is much higher than the normal market price (0.075 $/kWh).

The remainder of the paper is organized as follows. Section II introduces the proposed energy system for animal farms in Vietnam, the potential of on-site power sources and energy consumption. Section III presents the mathematical formulation to determine the optimal design of energy systems with the objective function of minimizing the net present cost (NPC) and the constraint of heat, gas and electricity. Section IV is to examine the proposed energy system in a case study. Finally, the remarkable and finding points are summarized in Conclusion.

## 2. The Integrated Energy System

The proposed energy system consists of biogas and electricity carriers to supply the energy demand of animal farms [Fig. 1]. Initially, the waste of animals (chicken, pig, cow, etc.) is fed to biogas plants (digesters) where it is decomposed by bacteria to produce biogas. Then, the biogas is led through a filter to remove its contaminants such as $H_2S$, $C0_2$, etc. before usage. The clean biogas can be used either for cooking or producing electricity by biogas generators. The electrical load including lighting, pumping, heating, ventilation and cooking, etc. can be supplied from the on-site sources: biogas generators, photovoltaics or from the electric grid.

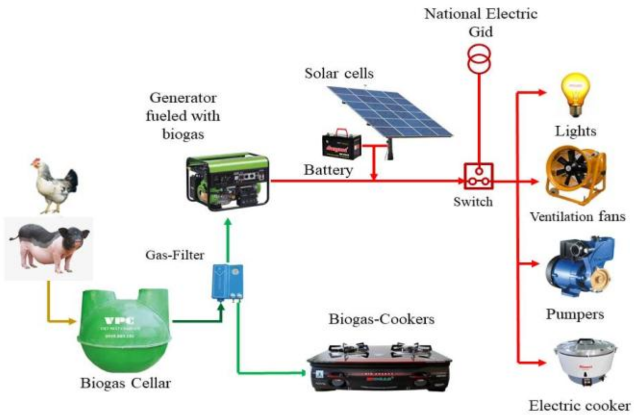


Fig. 1. The proposed energy system for animal farms.

### *2.1. Biogas systems*

The biogas system consists of biogas plants, filters, storage and pipelines. The biogas plant or biogas digester is a large tank which can be made by polyethylene, composites or cements. The organic matter of animal feces is decomposed by bacteria to produce biogas, called anaerobic digestion. The volume of biogas plants can be estimated according to the size of animal farms as follows.

$$V_{Plant} = f \times N \times T \tag{1}$$

where f is the mass of fresh feces per day (kg), N is the number of animals and T is the storage time (day). In industrial farms, the feces are stored in plants for about 30 days while in household farms, it is for 60 days.

The digestion process consists of four stages:

- The feces of animals are mixed with an appropriate quantity of water to make slurry in the mixing tank and then fed into the digester via the inlet chamber. After partially filled, the digester is left for about two months for the decomposition process takes place.
- In the digester, the organic matter of slurry is decomposed and fermented by bacteria to produce

biogas. As results, the amount of biogas and the pressure increase, the waste of digestion will be pushed out via the outlet chamber. It can be used as manures for plants. The process can be described by a chemical reaction as follows.

$$C_6H_{12}O_6 \longrightarrow 3CO_2 + 3CH_4 \tag{2}$$

- The gas outlet is concentrated on the top of the digester which can be fed to the demand through the outlet with a controllable valve. The surplus biogas will be stored in the tank for future usage. The storage tank can be integrated inside or outside the digester, i.e., internal and external biogas holder, respectively. The cheapest and simplest method to store biogas is at low-pressure (below 2 psi) using floating biogas holder which can be made from high-density polyethylene (HDPE), low-density polyethylene (LDPE) or linear low-density polyethylene (LLDPE). The thickness of the cover is often from 0.5 to 2.5 millimeters. The medium- (2–200 psi) and high-pressure (above 200 psi) biogas storage usually employ external biogas holders to reduce the size of the tank, but with much higher cost. Moreover, the quality of biogas need to be ensured for safety with $H_2S$, $H_20$, $CO_2$ removed, it is called compressed biomethane (CBM) or liquefied biomethane (LBM).

Table 1. Estimation of the waste and biogas of pig farms.

| The number of pigs | 100 | 200 | 500 | 1000 | 10000 | 30000 | 60000 |
|---|---|---|---|---|---|---|---|
| Waste water ($m^3$) | 3 | 9 | 15 | 30 | 300 | 900 | 1800 |
| Feces (kg) | 200 | 400 | 1000 | 2000 | 20000 | 60000 | 120000 |
| $CH_4$ ($m^3$) | 23 | 70 | 117 | 234 | 2340 | 7020 | 14040 |
| Biogas ($m^3$) | 36 | 108 | 180 | 360 | 3600 | 10800 | 21600 |

- Biogas from digesters consists of about 55-70% of methane ($CH_4$), 30-40% of carbon dioxide ($CO_2$), ammoniac (NH3, 80-100 ppm), water ($H_2O$, 1000-3000 ppm), hydrogen sulfide (H2S) and some others. Among those, CH4 is only the matter to bring useful energy thus high-quality biogas should contain a large quantity of CH4 and less the others. $CO_2$ can be removed by the absorption of water, polyethylene glycol or carbon molecular sieve at high pressure. H2S is even in small amount but causing unpleasant smells, corrosions in the metal and health problem for human. Thus, the removal of H2S is usually done in two stages: (1) biological desulphurization by bacteria within the digester and (2) chemical reaction with iron oxides and iron hydroxides. The first stage is performed by injecting a small air (2-5%) into the top of the digester, the decomposition can be done with the assistance of bacteria:

$$H_2S + 2O_2 \xrightarrow{\text{Bacteria}} H_2SO_4 \tag{3}$$

or

$$2H_2S + CO_2 \xrightarrow[\text{Bacteria}]{\text{Light}} 2S + (CHO) + H_2O \tag{4}$$

The second stage takes place within the biogas filter where the reaction to remove $H_2S$ is as follows.

$$H_2S + \frac{1}{3}Fe_2O_3 \longrightarrow \frac{1}{3}Fe_2S_3 + H_2O \tag{5}$$

Then the reaction of regenerations happens as:

$$\frac{1}{3}Fe_2S_3 + \frac{1}{2}O_2 \longrightarrow \frac{1}{3}Fe_2O_3 + S \tag{6}$$

Biogas from filters is increased by 30% of $CH_4$ and decreased by 95% of $H_2S$ compared to its originality: "clean biogas". It can be fed directly to biogas generator, cooker or storage tank through pipelines. The pipeline would be designed properly with accessories such as sections, values, conjunctions. Particularly, it needs to be installed with appropriate slope so thus condensed water can be collected and removed from the pipeline (water traps).

Compared to fossil fuels, biogas has the following pros and cons:

- It is renewable by the digestion process of organic materials from farming activity.
- It is neutral in carbon footprint if considering the whole carbon cycles.
- It is widely available in animal farms with biogas digesters.
- It is cheap and free; in some cases, it is burned out without any purposes.
- It is to reduce the dependency on fossil fuels which become shorted nowadays.
- It is to mitigate the environmental problem caused by the waste of animal farms.
- However, it is caused other harmful gas emission such as $CH_4$, $H_2S$, etc.
- It is required a large amount of water which is also important resource for human.
- It is not so efficient, thus in some cases it needs to combine with fossil fuels in usage.

*2.2. Biogas engine generators*

Biogas generators employ an internal combustion engines (ICE) which can use both biogas or gasoline to drive an electric generator. Currently, one of the popular biogas/gasoline conversion kits is developed based on GA5 LPG/gasoline engines, rated from 3 to 5 horse power (HP). The fuel consumption of biogas engine-generator (BEG) is about 0.9 ($m^3$/kWh).

Compared to gasoline, BEG causes less than 50-90% of emissions. However, one problem of BEG is its continuity when the load increases suddenly, e.g., starting water pumps, switching on water heaters, etc. In this case, although the governor would respond to open the gas-intake valve more, it does not create enough pressure differences for the suction of biogas. As results, BEG probably stops unintentionally. The loading problem of 2-HP BEG is shown in Fig. 2.

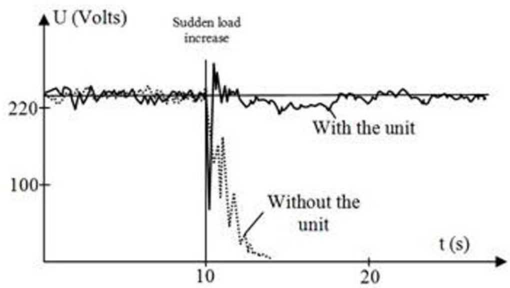


Fig. 2. The voltage output of 2-HP BEG with 100-W loading at t = 10 seconds.

To overcome this problem, an electronic speed control unit is employed. When the load increases suddenly, the drag torque causes the speed of BEG to decrease and the output voltage drops. If the voltage is below a threshold (200 volts), the control circuit is activated to adjust the valve of an extra biogas inlet. As results, an additional amount of biogas is sucked into the engine to create more torque driving up the BEG to its normal speed and voltage. When the speed and voltage of BEG are stable, the control circuit and the extra biogas inlet will be restored to idle modes; biogas is taken from the main inlet. The response of the speed control unit is expressed at t = 10 seconds in Figure 2.

*2.3. Photovoltaics*

Nowadays, photovoltaics (PV) is ubiquitous to be an important substitution for the traditional power source. It is thanks to the advances of semiconductor technologies the efficiency of PV is increased while the cost is decreased constantly. In practice, PV systems include of PV panels, power electronic converters, energy storage and control units. PV panels are comprised of many cells connected in series and parallel to provide an adequate amount of voltages and currents. Each cell is a semiconductor with two layers: P type and N type, called P-N junction. When exposed to sun lights, the photon knocks off electrons from its position, making pairs of electron - hole. Then, they are separated to opposite layer: P type becomes positive while N type becomes negative. The current is formed when connecting to an external circuit:

$$I_{PV} = I_0 - I_S \left( e^{\frac{q(V_{PV} + I_{PV} R_S)}{kT}} - 1 \right) - \frac{V_{PV} + I_{PV} R_S}{R_{Sh}} \tag{7}$$

where $I_{PV}$ and $V_{PV}$ are the current and voltage of PV; $I_0$ is the photon-electric generated current; $I_S$ is the saturation current of the diode; q is the charge of election (1.6x10$^{-19}$ C), k is Boltzmann's constant (1.38x10$^{-23}$ J/K); T is the temperature of the cell; $R_S$ and $R_{Sh}$ are the series and parallel resistors. Three types of PV cells common in markets are polycrystalline, monocrystalline and thin film.

The power provided by PV panels is DC at low voltage levels in nature, thus it needs to be converted into AC at desired voltage: DC/DC converter, DC/AC inverter. More importantly, the I-V characteristic of PV cells in Eq. (7) shows that the power generated by PV varies with the output voltage: At a voltage, PV delivers the greatest quantity of power for a given condition (solar radiation, temperature, etc.), called maximum power point (MPP). Therefore, controlling the duty cycle of pulse width modulation (PWM) of DC/DC converters, we can keep PV operating at the MMP when the condition changes. This well-known control algorithm is called MPP tracking (MPPT). Then, inverters are used to supply its AC loads in the stand-alone mode or, if surplus, the utility in the grid-connected mode. To increase the reliability and economics of PV, battery banks can be installed. In normal operations, the surplus power from PV in day-time, if any, is stored (charged) in battery and used in future (discharged). In case of interruptions in the feeder, battery will be used as backup power to supply for the local load in coordination with others. Additionally, battery can be considered to address the loading problem of BEG, making the loads of BEG changes slowly as its ability to respond. However, the use of battery is costly since it needs replacement quite frequently (800-1000 cycles). Thus, the installation and replacement cost of battery need to consider carefully in planning of the system.

### *2.4. Energy consumption*

The energy consumptions of animal farms are in three forms: biogas, electricity and heat. Biogas from digesters is mainly used for cooking, heating and running BEG to produce electricity. Electricity is consumed for various purposes: lighting, heating, ventilation and pumping. Lighting used to be an important part when incandescent lamps were used (30-40%). But recently, LED technology was introduced which replaces most of incandescent lamps in the farm, reducing the lighting load as much as 10-20%.

Heating, ventilation and air conditioning (HVAC) is very important load in the farm to keep the thermal comfort and good air quality for livestock. It is designed and constructed according to the principle of thermodynamics, fluid mechanics, heat transfer and also the characteristic of occupied animals. Ventilation systems are to exchange the indoor and outdoor air to maintain a high-quality of the air. It can be done periodically or through a sensor network which will activate HVAC systems when air-quality indices fall out of thresholds: Temperature, oxygen, moisture, odor, smoke, dust, airborne bacteria, unpleasant smell, etc.

Pumping is another important load in animal farms. It is used to manage the water supply to many purposes such as drinking, washing, cleaning, etc. In addition, a large amount of water is used to mix with animal feces (slurry) before feeding into digesters.

## 3. Mathematic Formulation

The problem is to design the proposed energy system for animal farms with both biogas and electricity carriers [Fig. 3].

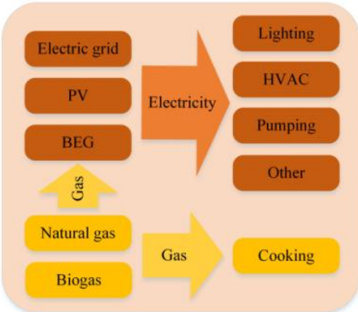


Fig. 3. Energy conversion in the proposed energy system.

Depending on the characteristic and size of the farm, the capacity of each component in the energy system is determined with the objective function of minimizing the NPC. The problem is formulated as follows.

- Objective function:

$$\min_{P_0}\left[C_0+\sum_{t=1}^{T}\frac{1}{(1+r)^t}(C_t-R_t)\right] \tag{8}$$

Where t is the index of time (year), T is the lifetime of the project; r is the interest rate or discount rate; $P_0$ is the installed capacity; $C_0$ is the capital cost, $C_t$ and $R_t$ are the annual cost and revenue at t-th year. The capital cost is:

$$C_0=c^0_{BEG}P_{BEG}+c^0_{PV}P_{PV}+c^0_{Bat}P_{Bat}+c^0_{Conv}P_{Conv}+c^0_{Grid}P_{Grid} \tag{9}$$

Where $c^0_{BEG}$, $c^0_{PV}$, $c^0_{Bat}$, $c^0_{Conv}$, $c^0_{Grid}$ are the rate of capital cost; $P_0$ = [$P_{BEG}$, $P_{PV}$, $P_{Bat}$, $P_{Conv}$, $P_{Grid}$] are the installed capacity of EBG, PV, batteries, converters and the grid. The annual cost includes fuel cost, operation and maintenance cost, replacement cost and the cost to purchase electricity and natural gas from markets:

$$C_t=\left\{\begin{matrix} c^{OM}_{BEG}P_{BEG}+c^{OM}_{PV}P_{PV}+c^{OM}_{Bat}P_{Bat}+c^{OM}_{Conv}P_{Conv}+c^{OM}_{Grid}P_{Grid}+ \\ I\left(t>T^{lifetime}_{BEG}\right)c^{Rep}_{BEG}P_{BEG}+I\left(t>T^{lifetime}_{PV}\right)c^{Rep}_{PV}P_{PV}+ \\ I\left(t>T^{lifetime}_{Bat}\right)c^{Rep}_{Bat}P_{Bat}+I\left(t>T^{lifetime}_{Conv}\right)c^{Rep}_{Conv}P_{Conv}+ \\ I\left(t>T^{lifetime}_{Grid}\right)c^{Rep}_{Grid}P_{Grid}+\rho^{Elect}_t E^{Elect}_t+\rho^{Gas}_t E^{Gas}_t \end{matrix}\right\} \tag{10}$$

Where $c^{OM}_{BEG}$, $c^{OM}_{PV}$, $c^{OM}_{Bat}$, $c^{OM}_{Conv}$, $c^{OM}_{Grid}$ are the rate of operation and maintenance costs; $c^{Rep}_{BEG}$, $c^{Rep}_{PV}$, $c^{Rep}_{Bat}$, $c^{Rep}_{Conv}$, $c^{Rep}_{Grid}$ are the rate of replaced cost of batteries; $\rho^{Elect}_t$, $\rho^{Gas}_t$ are the electricity and gas price, $E^{Elect}_t$, $E^{Gas}_t$ are the quantity electricity and gas purchased from the market. Revenue is the monetary saving of the energy by the energy system (not being purchased from the market).

$$R_t=\rho^{Elect}_t E^{Elect}_{Savet}+\rho^{Gas}_t E^{Gas}_{Savet} \tag{11}$$

where $E^{Elect}_{Save}$, $E^{Gas}_{Save}$ is the energy saving which includes both electricity and biogas.

- Constraints:

- Energy balances: Electric and gas provided and purchased from the market need to fulfill the energy demand.

$$\left\{\begin{matrix} E^{Elect}_t+E^{Elect}_{BEGt}+E^{Elect}_{PVt}=E^{Elect}_{Dt} \\ E^{Gas}_t+E^{Gas}_{Biot}-E^{Gas}_{BEGt}=E^{Gas}_{Dt} \end{matrix}\right\} \tag{12}$$

where $E_D^{Elect} = E_D^{Light} + E_D^{HVAC} + E_D^{Pump} + E_D^{Other}$ is the electricity demand which includes lighting, HVAC, pumping and other loads; $E_D^{Gas}$ is the demand of (bio-) gas; $E_{Bio}^{Gas}, E_{BEG}^{Gas}$ are the biogas supplied by the biogas system and consumed by BEG, respectively.

- Capacity limits: Powers generated of BEG, PV, batteries, converters and the grid are subjected to its physical limits.

$$\begin{Bmatrix} P_{BEGt}^{Elect} \le P_{BEG}^{Max} \\ P_{PVt}^{Elect} \le P_{PV}^{Max} \\ P_{Bat}^{Elect} \le P_{Bat}^{Max} \\ P_{Conv}^{Elect} \le P_{Conv}^{Max} \\ P_{Grid}^{Elect} \le P_{Grid}^{Max} \end{Bmatrix} \tag{13}$$

- Energy storage limits: Electricity charged to batteries is subjected to its physical limits and the biogas stored is subjected to the size of the tank.

$$\begin{Bmatrix} E_{Bat}^{Min} \le E_{Bat}^{Elect} \le E_{Bat}^{Max} \\ E_{Store}^{Min} \le E_{Store}^{Gas} \le E_{Store}^{Max} \end{Bmatrix} \tag{14}$$

- Biogas supply limits: The biogas supplied to the system is subjected to the capability of the biogas digester.

$$\left\{ E_{Bio}^{Gas} \le E_{Digester}^{Gas} \right\} \tag{15}$$

## 4. Case Study

In this section, the proposed energy system is examined in a typical household pig farm in Thai Nguyen province, Vietnam. The size of the farm is for 2000 pigs with the area of about a hectare (ha) in the northern mountainous region. The farm has two parallel pigpens with the ventilation system driven 2-kW fans both on the top and the wall of the house. The temperature is controlled by a bunch of 100-W heating lamps to keep the temperature in winter within acceptable ranges. Two 5-kW pumps are employed to provide water and push slurry (the mix of feces and water) into the 22,000-m$^3$ digester. The average electricity consumption is 228.2 kWh per day. The load profile is given with the base load, maximum monthly load [Figure 4] and duration load in a year [Figure 5]. The simulation is run in HOMER Pro and MATLAB 2016a.

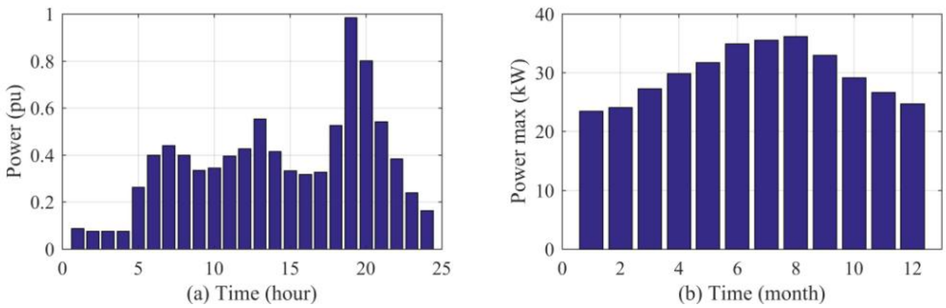


Fig. 4. The electrical loads: (a) Base load, (b) Monthly maximum load.

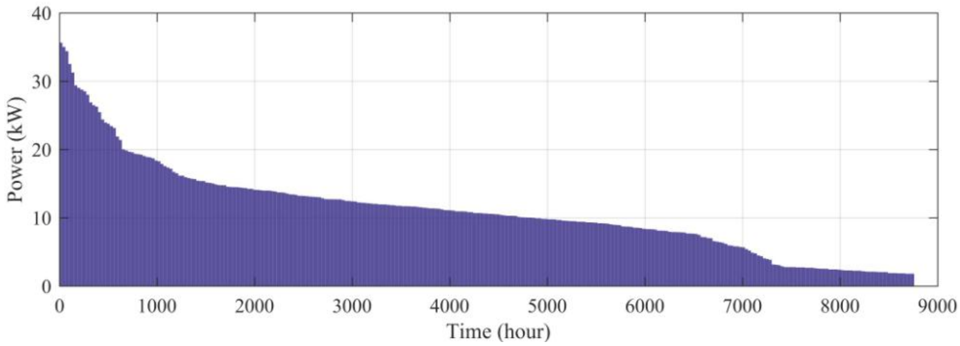


Fig. 5. The duration load of electricity demands.

Table 2. Parameters of the component in energy systems.

| | Capital cost ($/kW) | Operation and maintenance cost ($/kW) | Replacement cost ($/kW) | Fuel cost ($/kWh) | Time-life |
|---|---|---|---|---|---|
| BEG | 600 | 12 | 550 | 0 | 15000 hours |
| PV | 3000 | 30 | 2500 | 0 | 25 years |
| Battery | 300 | 3 | 280 | 0 | 800 cycles |
| Converter | 300 | 3 | 300 | 0 | 15 years |
| Grid | 500 | 10 | 400 | 0.1 | 15 years |

### *4.1. Case 1: Without electricity sellback*

In this case, it is assumed that the electricity is only purchased from the grid at the market price (0.1 $/kWh). The farm is unable to supply power back to the utility grid. Therefore, the surplus energy if any needs to be terminated (e.g., burning out the surplus biogas). The five best options of planning for energy systems are expressed in Table 3.

Table 3. Planning of energy system without electricity buyback.

| **No.** | **NPC ($)** | **BEG (kW)** | **PV (kW)** | **Battery (kWh)** | **Converter (kW)** | **Grid (kW)** |
|---|---|---|---|---|---|---|
| 1 | 64,122.6 | 12 | 0 | 0 | 0 | 25 |
| 2 | 66,714.7 | 15 | 0 | 0 | 0 | 25 |
| 3 | 68,905.4 | 12 | 2 | 0 | 0 | 25 |
| 4 | 69,255.7 | 18 | 0 | 0 | 0 | 20 |
| 5 | 69,850.6 | 9 | 0 | 0 | 0 | 30 |

In this case, the energy system should combine the on-site power source and the feeder from the grid. Significant amounts of BEG is considered in all options to take advantages of free biogas from digester which is far exceeding the consumption. But the electricity cannot be sold back to the grid and considering the load factor, an appropriate BEG is used to supply peak load while the base load is fulfilled by the grid feeder. PV can also be considered but it is not as economical as BEG due to high installation cost (PV and converters). Battery is not considered in all options because of high installation and replacement cost. The best planning option consists of 12 kW BEG (four 3-kW BEG modules) and 25 kW grid feeder with NPC of 64,122.6 ($). The result is more meaningful if we consider the electricity cost if only purchasing from the grid is 79,553,9 ($) excluding the installation cost of the grid feeder. The capital cost, fuel cost, operation and maintenance cost, and replacement cost in the best option of energy systems is displayed in Fig. 6.

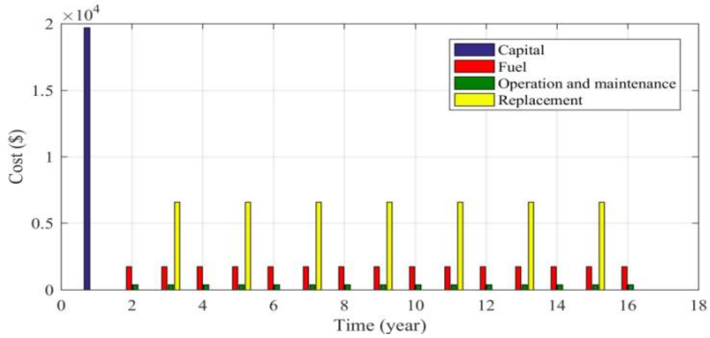


Fig. 6. The capital cost, fuel cost, operation and maintenance cost, and replacement cost of the proposed energy system in Case 1.

### *4.2. Case 2: With electricity sellback*

In this case, it is assumed that the surplus electricity from the BEG, PV and battery can be sold back to the grid at the market price (0.1$/kWh). The five best options of planning for energy systems are expressed in Table 4.

Table 4. Planning of energy system with electricity sellback.

| No. | NPC ($) | BEG (kW) | PV (kW) | Battery (kWh) | Converter (kW) | Grid (kW) |
|---|---|---|---|---|---|---|
| 1 | -18,479.4 | 45 | 0 | 0 | 0 | 40 |
| 2 | -15,929.8 | 42 | 0 | 0 | 0 | 35 |
| 3 | -15,904.8 | 45 | 2 | 0 | 0 | 40 |
| 4 | -13,639.8 | 42 | 2 | 0 | 0 | 35 |
| 5 | -13,085.6 | 45 | 4 | 0 | 0 | 40 |

In this case, BEG is employed exclusively to take advantages of free biogas from digesters. Parts of it is to provide the load while the excess is sold back to the grid through the feeder. Thus, significant amount of feeders is installed for this reason. The best option consists of 45 kW BEG and 40 kW feeder with NPC of -18,479.4 $. The proposed energy system is not only able to supply its energy demand but also bring benefits to the farm owner by selling surplus electricity to the grid. The capital cost, fuel cost, operation and maintenance cost, and replacement cost in the best option of energy systems is displayed in Fig. 7.

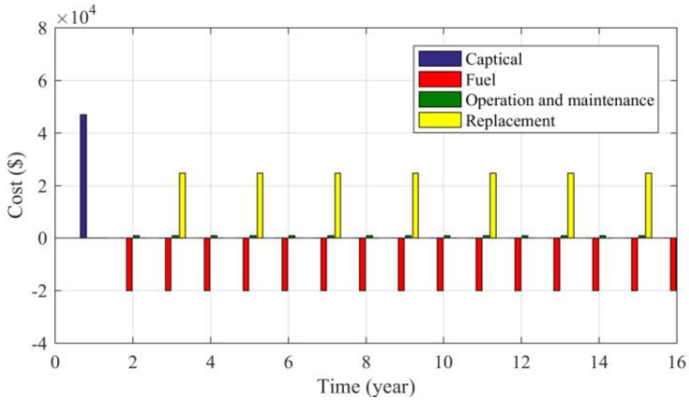


Fig. 7. The capital cost, fuel cost, operation and maintenance cost, and replacement cost of the proposed energy system in Case 2.

## 5. Conclusion

In this paper, we proposed a new structure of energy systems for animal farms in Vietnam which comprises the electrical and (bio-) gas systems. The optimal design of energy systems was formulated with the objective function of minimizing NPC. The problem is examined in case study with a typical pig farm in the northern mountainous region in Vietnam. Remarkable finding can be summarized as follows.

- The potential of biogas is high which far exceeds the demand of energy in animal farms (cooking, heating and electricity).
- It is economic to install BEG in the farm in both case: without and within capability of selling electricity back to the grid.
- The energy system should consist of BEG and the grid feeder with appropriate quantities depending on the load profile and the possibility of selling electricity back to the grid. PV can be considered but not so economical while battery should be excluded.

However, this work is subjected to addressing the technical detail of the energy system such as controls of BEG when the load changes or the biogas filter and storage, etc. Instead, it is assumed to be integrated into BEG module and the biogas system. The technical detail and operation of energy systems will be considered in the future work.

## Conflict of Interest

The authors declare no conflict of interest.

## Author Contributions

Nguyen M.Y. developed the concept, formulation, optimization algorithm and wrote the paper. Tran Q.S. investigated, analyzed the data and implemented the result. All authors had approved the final version.

## Acknowledgements

This work is supported by Thai Nguyen University of Technology as parts of its research project on Distributed Generation and Microgrid.

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