Mansoura Engineering Journal

Volume 39 | Issue 4 Article 13

10-10-2021

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Recommended Citation

Rashed, Ibrahim; Abdel-Mageed, Hesham; and Matouk, Rabab (2021) "Biogas Utilization Model Using Linear Programming for Layer Farms.," *Mansoura Engineering Journal*: Vol. 39 : Iss. 4 , Article 13.
Available at: https://doi.org/10.21608/bfemu.2021.201585

Biogas Utilization Model Using Linear Programming for Layer Farms

نموذج إستغلال طاقة الغاز الحيوي بإستخدام البرمجة الخطية لمزارع الدواجن

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ملخص البحث:

تعانى كثير من القطاعات الإنتاجية والخدمية في مصر من مشكلة نقص الطاقة بجانب سوء إدارتها ولما كان الإتجاه الجديد هو السعى وراء إنتاج طاقة بديلة فإن الإدارة الجيدة تفتح بابا لحل هذه المشكلة مما يفرض علينا إضافة مفهوم جديد لإدارة الطاقة الناتجة من تخمر المخلفات العضوية لاهوائيا و توجيهها إلى نحو أمثل. لذا كان هدف البحث هو تقييم مسارين لإستغلال طاقة الغاز الحيوى التى يمكن إنتاجها من مخلفات مزارع الدجاج البياض بإستخدام نموذج رياضى تم تطويره ليساعد فى الوصول للحل الأمثل بإستخدام أحد البرامج الجاهزة (LINDO) التى توفر الكثير من الوقت و الجهد لمتخذى القرار لا سيما عند تخطيط إنتاج الطاقة بكميات كبيرة لمعرفة التغيرات االتى تطرأ على هذا الحل عن طريق استخدام الحاسوب . وقد تم تغذية البرنامج بالبيانات المطلوبة والتى تم تجميعها من المزرعة مباشرة بجانب البيانات الإقتصادية والإحصاءات المنشورة فى المراكز البحثية والمؤسسات الحكومية والدوريات العلمية وهى بيانات إستهلاك المزرعة من الطاقة الكهربائية على مدار ثلاث أعوام متتالية وكذلك إستهلاك المزرعة من الوقود اللازم للتدفئة. وقد تم إستخدام أحد طرق التأكد من سلامة الحل الرياضى بإختبار حساسية بعض المعاملات الأساسية التى يعتقد أنها تؤثر ليس فقط على المسار الأمثل لتوزيع طاقة الغاز الكامنة والكمية الواجب إستغلالها ولكن أيضا على خفض أو زيادة تكلفة تحويل طاقة الغاز إلى طاقة حرارية وكهربائية. وبناء على نتائج النموذج الرياضى فإن البرمجة الخطية هى الأفضل لأنها تساهم فى التوصل إلى الحلول ذات القرارات البديلة مما يتيح فرصة لصاحب المزرعة فى إختيار الحل الأمثل وفق البدائل المتاحة بعكس الإستغلال وفق الأساليب التقليدية التى تقدم حلا واحدا وبالتالى يكون هناك قرار واحد وليس عدة قرارات. كما أن المرحلة المقبلة من تطوير البرنامج تشمل إدخال الأحمال المختلفة على مدار اليوم و إستمرارية التشغيل.

Abstract:

The gap in demand and supply of energy can be met by optimal allocation of available energy resources. For farmers throughout the world, energy inputs represent a major and rapidly increasing cost. The energy production planning problem starts with a specification of farm demand that is to be met by the energy production plan. In this paper the mismatch between the biogas potential contribution levels and optimal energy allocation for two end-uses has been deduced. As such energy planning problem is inherently optimization problem. The model has been optimized using LINGO software version 12.0. The optimization problem of biogas energy produced on-site has been executed from the economic point of view. The analysis assumed no thermal energy storage capacity is available to address generation/load mismatch. Based on the optimal solution biogas energy can be utilized to cover great portion of the annual electricity and heat demands by about 95 % and 99 %, respectively. This model is considered a powerful tool for analyzing competition between two routes of the rational use of "*chemical potential energy"* with independent demand, which can be used in a small-scale rural poultry farm. In addition, sensitivity analyses have been elaborated in order to show how the optimal solution would vary due to some key parameters including energy demands, conversion efficiencies and relevant costs. The results also, demonstrate that the optimized model has been found as the best choice for meeting the energy needs of the farm.

Keywords: Biogas Utilization Model, Linear Programming, Energy Demand, Poultry Farms.

Received: 27 October, 2014 – Revised: 9 December 2014 - Accepted: 9 December 2014

1.Introduction

The problem of energy shortages is aggravated by the fact that the available fossil fuels are limited and exhaustible and there is a strong need to initiate the search for non-conventional/renewable energy source, which are not only the abundantly available but are also eco-friendly [18]. In developing countries like Egypt, demand for energy is constantly rising. Conventional energy supply options have failed to cope up with this increase. The basic impact of this scenario can be seen in rural areas facing the shortages of fossil fuel as well as electricity due to their remoteness. Therefore, it is required to utilize the farm waste for producing renewable energy and planning at optimal allocation thereby reducing dependence on commercial energy and reducing associated environmental hazards.

In order to overcome these problems, many studies have presented and suggested to use farm wastes for renewable energy production [14]. In recent years, anaerobic digestion (AD) has been developed as one of the most attractive renewable energy resources especially in developing countries. Renewable energy production, in the form of biogas, is an important objective of this process [11,32,37]. A digester is often described as an extension of the digestive system of herd itself. Biogas produced via AD is a mixture of methane (CH_4) and carbon dioxide (CO_2), in a ratio of about (60:40) to (70:30). Biogas can then be burned in stationary engines to produce electrical and thermal energy or to fuel vehicles [1]. The biogas produced through the AD has a heating value of 20-25 MJ/m^3 [20,24,25,30]. Since biogas energy can be produced in-situ, it can alleviate the problems of the energy provided with conventional sources of energy, especially in rural areas. One of the most noticeable problems in the field of biogas technology is regarded to the produced gas which cannot be stored from period to period. The design and operation of electrical and thermal power units are greatly dependent upon climatic conditions [33], both electricity and thermal energy demands fluctuate seasonally and daily, so it is very difficult to solve the problem since it is necessary to take account of the plant's annual strategies for the variations of demands [3]. The biogas energy production planning entails the evaluation and allocation of limited resource to farm so as to satisfy activity demand in the most efficient and effective way over a certain period. [4] formulates this problem as a transportation problem, when there are multiple time periods and multiple production options, but only one item and one resource type. As such energy planning problem is inherently optimization problem, where the objective is to develop a plan that meets demand at minimum cost or that fills the demand that maximizes profit. Optimization models are widely applicable for providing decision support. Models based on optimization methodologies are deployed to optimize energy investment decisions endogenously, meeting a specific target under some constraints. They are often used by utilities or municipalities to derive their optimal investment strategies and by national energy planning to analyze the prospects of the energy system. These models require a relatively high level of mathematical knowledge and the included process must be analytically defined [10]. The mathematical approach used in most of these models is linear programming (LP). The majority of optimization models use this approach and it is also applied in national energy planning as well as in studies related to selection of energy technologies in the long term. LP is a practical technique for finding the arrangement of activities which maximizes or minimizes a defined criterion, subject to operative constraints [34]. All mathematical relations in this approach must be expressed in terms of linear functions, and all coefficients remain constant. Mixed integer programming

(MIP) is an extension of LP which allows the variables considered in the model to take discrete values. Decision variables are used to describe key discrete points of an energy management system. The objective function is referred as goal for the optimization. The main constraints include: (a) demand constraints (energy output from demand technology is greater than or equal to the amount of end-use demands), (b) balance constraints (balance equation for energy carriers of fossil, heat, electricity, and renewable energy and technologies), (c) technology constraints, and (d) bound constraints. Also, emission limitations of greenhouse gases (GHG) and pollutants can be included as additional constraints [5]. In this research, we used the classical multi-item lot-sizing problem (CLSP) in inventory theory that has been studied by several researchers throughout the years [13,22,31], the approach is based on an immense amount of work production planning. The classical capacitated lot sizing problem (CLSP), consists of determining the amount and the timing of the production of the products in the planning horizon or the time interval as well as capacity restrictions constrain the production quantity in each period, while tacking into consideration two exact approaches in order to strength the LP feasible solutions. The objective of CLSP is to determine a production plan with minimum cost. One is called cut-generation techniques [2,21], while the other is the variable redefinition technique of Eppen and Martin (1987), these are used as an additional constrains to ensure the operating of each time interval.

Based upon the biogas energy assessed for the fulfillment of the demand, two routes of utilization have been considered. Linear Programming (LP) using LINDO software [38] has been used for the optimization of biogas energy utilization model. The electrical and thermal energy productions have been indeed the specific routes of extensively studied and exploited in this paper. Typical decisions include production lot sizes and sequencing of production runs. A key choice is what planning decisions of energy production to include in the model. The objective function is set from the economic viewpoint by minimize the total annual energy cost.

2. Materials and Methods

2.1 Basic assumptions of model

The structure of every model subdues to a number of assumptions which can simplify the real fact and they suffice by what is primary and leaves what is secondary for the attributes have the same dependent aspects and conditions. The first assumes a linear relationship between the expected quantity of biogas energy production and the resource consumption which is considered a type of production functions [17]. The second also assumes one operation mode of utilization methods is analyzed, on continuously. For continuous operation, biogas-based electrical and thermal energy supply units are matched to demand scenario. The electrical and thermal energy productions have been indeed the specific routes of extensively studied and exploited in this paper. All subsequent analysis is based on the optimum operating conditions for each system. The analysis assumed no thermal energy storage capacity is available to address generation/load mismatch may appear economically attractive may not be technically feasible.

2.2 Model Formulation

The approach that was used for this analysis based on the specific scenario assumption by considering the amount of energy in the form of biogas it could produce continuously. An optimization model based on linear programming technique has been developed for evaluating on-farm energy supply system considering conversion technologies using biogas energy. In order to reach an overall optimum of the structure of the energy model, the evaluation problem is formulated here as a MILP model. Fig.1 is a flow chart illustrating the structure of the model. This model is considered a tool for analyzing competition between two routes of the rational use of biogas energy with independent demand, which can be used in a small-scale rural poultry farm. As we already mentioned, a key choice is what planning decisions to include in the model. Therefore, choices must be made as to which energy carrier to include and how to model their capacity, and their costs. Related to these choices is the selection of the time period. The identification of the *relevant costs* is also an important issue. For energy production planning, one typically needs to determine the variable production costs, including setup related costs, inventory holding costs, and any relevant resource acquisition costs.

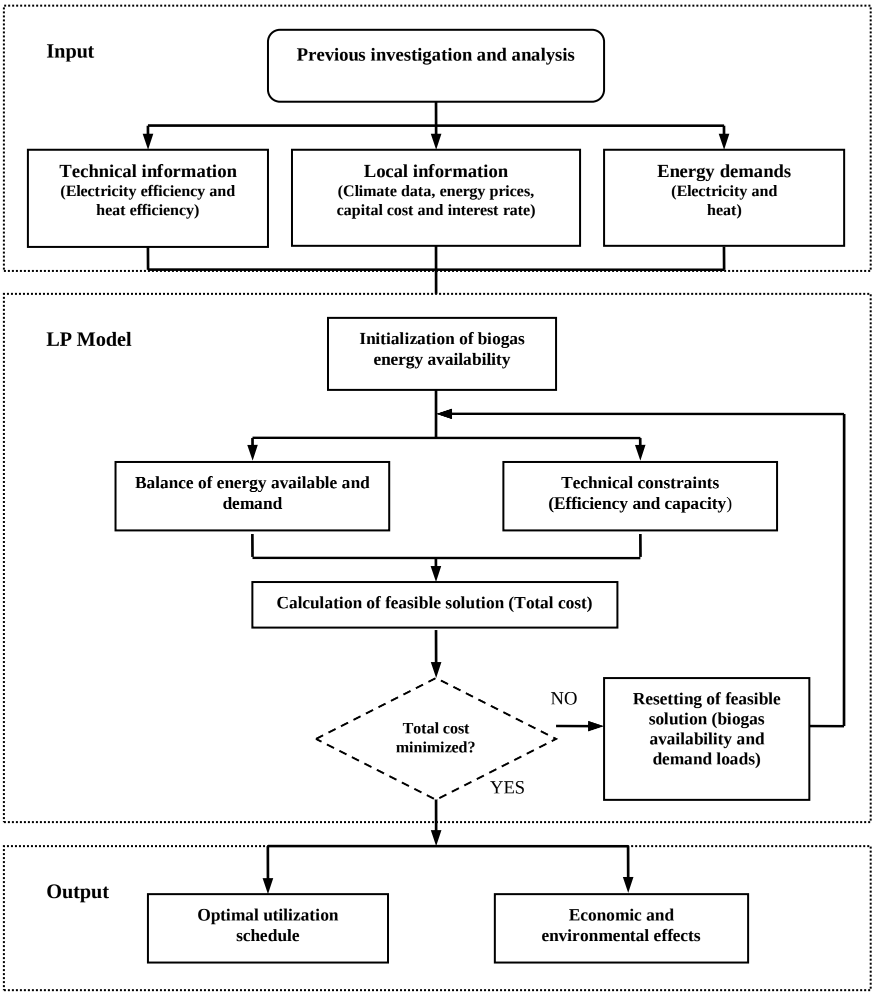


Fig. (1) Model Flow chart.

2.2.1 Decision variables: The decision variables are those quantities that represent the decisions to be taken, and are necessary to formalize the objective function and the constraints by mathematical representation. In particular, the decisions concern two choices. For these two choices, two types of decision variables are defined respectively:

- Decision variable to reflect the allocation schedule (energy flows) of the energy conversion systems every time (month) to all the year.
- Decision variable to reflect the existence of energy conversion equipment will be chosen to be operated or not, as well as on-off operation system.

2.2.2 Objective function. The objective function of the model is to minimize the annual total generation cost of supplying energy to a specific poultry farm by using on-site generation systems, is used biogas energy potential, to meet part or all of its electrical and thermal energy requirements in the whole year. This may drive only from the net energy gained which can be counted, i.e. the process energy fraction (for agitators, pump, heating and any outside energy input) must be subtracted from the total gas yield. In a simplified form the objective function can be written as:

$$Min\{C_{Total} = C_{Inv} + C_{OM} + C_{Ctax}\} \quad (1)$$

The annualized investment (L.E/year) is described in Equation (2). It is calculated by spreading the initial cost across the lifetime of the hypothetical conversion technologies while accounting for the time value of money [35].

$$C_{Inv} = \sum_u F_{MCap}(u) \cdot P_{equ}(u) \cdot \frac{R}{\left(1 - \frac{1}{(1+R)^{T_{equ}(u)}}\right)} \quad (2)$$

Where, F_{Mcap}, P_{equ}, R, and T_{equ} denote the maximum capacity (kW) of each conversion technology (both biogas engine-generator and firing system), the capital investment costs (L.E/kW) associated with kW of capacity plant, interest rate (%), and life time period of each equipment (year), respectively. The index (u) illustrates the index of end uses, including energy carriers (electricity and heat).

The operational and management (O&M) cost is composed of fixed and variable ones. The fixed (setup) O&M cost is calculated with the installed energy conversion equipment capacity multiplied by a unit cost coefficient. The variable O&M cost is calculated with cumulative power generation during the calculation period multiplied by a unit cost coefficient. The (O&M) cost can be calculated as a modification of the models presented by [8,15].

$$C_{OM} = \sum_t \sum_u \left(F_{Cap}(u) \cdot P_{omf}(u) \cdot Y(u) + E_{Gen}(u,t) \cdot P_{omv}(u) \cdot X(u,t)\right) \quad (3)$$

Wherein, the variable E_{Gen} (kWh/year) denotes the amount of energy (including electricity and heat) for future generation. F_{cap}, t and u are the rated capacity or production operating limit (kW), index of time interval (month) and end-uses, respectively. The parameters P_{omf} and P_{omv} mean the cost coefficient matrix off the entire known energy demand vector. Two types of binary variables were also introduced in the model. These include Y (u) (The integer variable to decide whether the uth end-use will produce, as well as the existence of energy conversion equipment, e.g. engine-generator and firing system) and X(u,t) (the continuous variable to express the input and output energy flows of the system components in each period (t).

The carbon tax cost is described as the cost for carbon emissions from on-site power generation, as well as equipment operation, it is defined as bellow:

$$C_{Tax} = \sum_u C_{TRate} \cdot I_C(u) \cdot E_{Gen}(u,t) \quad (4)$$

Where, C_{TRate} and I_C denote the value of carbon tax (L.E. /kg CO_2) and CO_2 intensities (kg/kWh) or emissions for each conversion technology that can produce electrical and thermal energy [23].

Notably, stoichiometrically combusting one cubic meter of biogas yields 1.8 kg of CO_2 after combustion no matter what portion is comprised of methane. From this result it can be concluded that, theoretically, the emissions of CO_2 from the combustion of biogas are constant in spite of changes in its composition. The energy content of the gas is the only factor that varies with methane content. That is, even though the CO_2 emissions from biogas combustion are dependent only on the volume of gas burned, the amount of useful energy that can be extracted depends on the methane mole fraction of the fuel. The method of [25] was followed to determine the emissions that would result from the combustion of biogas with a methane volume percentage of 60–70% and carbon dioxide content of 30%– 40%, which is the typical composition of biogas [19,25].

$$I_C = 1 m^3_{biogas} \left(\frac{(1.7875)\%CH_4 + (1.8)(1 - \%CH_4)}{E\%CH_4 \times \eta} \right) \quad (5)$$

This energy content information can be combined with the emissions results to find the carbon dioxide produced per kilowatt hour of energy generated, which is a function both of the methane molefraction and the conversion efficiency. Equation (5) was used to find the emissions factors. In this equation, $E\ \%\ CH_4$ is the energy density of biogas as a function of methane mole fraction and expressed in kWh/m^3 of biogas. These values can be converted to kilowatt hours by using the conversion factor of 3.6 million joules per kilowatt hour. The resulting emissions factors (I_C, in kg of CO_2 per kWh of energy produced).

2.2.3 Constraints: There are also a number of main constraints incorporated into the model to restrict the set of feasible solutions. The first of these requires that the terminal energy supply shall be at least equal to the demand. It also means that the total amount of generated electricity and/or heat, in terms of MWh/year, must meet or exceed total demand.

$$\sum_{u=1}^{2} E_{Gen}(u,s) \geq D(u,s)/\eta(u) \quad (\forall u;\ s=1) \quad (6)$$

Wherein,

E_{Gen}: Unknown energy vector of all links present at the flow from primary energy product to terminal energy demand.

D: Terminal energy demand vector,

η: Energy conversion efficiency matrix,

s: Setup times of conversion.

Another key constraint for the available energy limit is that the energy yield (E_{Gen}) shall not be beyond the net power available on-site use (M_{cap}). Quite the power generated in each period (t) may not exceed the rated capacity of the generator and firing systems. Thus constraints sets (7) guarantee that the capacity of every order or link is not exceeded [36].

$$\sum_{u=1}^{2} E_{Gen}(u,t) \cdot X(u,t) \leq M_{Cap} \quad (\forall s;\ t=1,\ldots,T) \quad (7)$$

At the beginning of each period $s = 1,\ldots,T$, it is possible to place an order for any subsets of energy carriers (electricity and heat), and this incurs a fixed ordering cost $P_{omf}(s)$ regardless of the subsets of energy- carriers or possibly fractional number of units ordered from each energy carrier. However, the overall quantity (energy yield) of units ordered in period s cannot exceed a certain capacity limit $M_{cap} \geq 0$. These are usually called uniform capacity constraints, where in each period s, the order is placed in batches, each of which has capacity $F_{cap}(s)$ and incurs an additional fixed ordering cost $P_{omf}(s)$. The energy units ordered in period s are assumed to arrive instantaneously, and can be used to satisfy demands in that period and subsequent periods. For each demand u and period t, there is a variable cost P_{omv} or the per unit cost to carry one unit of energy (both electricity and heat) carrier from t to period $t+1$. For each demand point (u,t) and a potential order $s<t$, let X=1 from s to period t. Most of demands will arrive in the period T, that is, at the end of the planning horizon.

Constraints set (8) guarantee that any positive demand is fully satisfied on time. The demand of end-use u in period t is denoted by $D(u,t)$. The demands of energy are known in advance but can vary from period to period. Moreover, all of the demands must be fully satisfied on time. So the constraints set (7) guarantee that any positive demand is fully satisfied on time.

$$\sum_{t>s} x(u,s,t)=1 \quad (\forall u \,;\, t=1,\ldots,T;\, E_{Gen}>0) \qquad (8)$$

The constraint set (9) is for the so-called forcing constraints. These constraints relate the production variables to setup variables. It states that an order cannot be used to satisfy a demand if it is not placed. For each energy carrier and time period, if there is no setup {*Y* (u, t) =0}, then this constraint assures that there can be no production {E (u, t) =0}. Conversely, if there is production in a period {E (u, t)>0}, then there must also be a setup {*Y* (u, t) =1}.

$$X(s,t)=Y(s) \quad (\forall u;\, s=1,\ldots,T;\, t>s) \qquad (9)$$

Additional constraints are needed to ensure the operation of energy conversion units (both electricity and heat). The corresponding constraint of the energy inventory balance is described in Equation (10). It states that the total amount of energy converted at the beginning of each time interval is equal to the non-converted energy at the beginning of previous time interval plus demand to meet end-use loads, while constraints set (11) ensure the non-negativity variables.

$$E_{Gen}(u,t)=E_{Gen}(u,t-1)+D(u,t) \quad (\forall s,t>s) \qquad (10)$$

$$Y(u,s)\in(0,1), \qquad X(u,s,t)\geq 0, \qquad (\forall u,s,t)$$

(11)

This problem is now a mixed-integer linear programming (MILP), with two binary decision variables. It can be reliably solved by commercial optimization packages. The corresponding MILP formulation has been optimized using LINGO software version 12.0 [38], based on objective function and various constraints.

2.3 Case study farm

Keeping in view, the present study was proposed to optimally energize poultry farms through biogas is generated from droppings, and is converted to electricity or heat. The model is based on the interaction between literature information and numerical databases, derived from the Agricultural Research Institute. Data however, was directly collected and interviews carried out by the researcher with breeders and from Agriculture Ministry Information Center in Egypt. Hence, survey was conducted for one layer farm energy needs during October 2009–February 2012, which the year (2010) is considered the base year for this study. Considering the feasibility of upgrade and promotion serves in poultry farms, it has been examined how biogas energy potential could be preferentially used for meeting the energy needs of the farm. Especially, options for energy supply are paid the most attention for overall farm area. As an environmentally friendly technology with high efficiency and low CO_2 emissions, biogas based energy conversion systems are selected and analyzed in a detailed way. The farm that has been selected to apply biogas technology is located at Zayan village, Belkas centre, Egypt. The farm has 4 houses, each of which is occupied by 18700 birds which have an average 1.6 kg of weight. Breeding area of farm studied in this paper is typically closed building for which artificial lighting and ventilation is required throughout the year and has a total floor area of 6236 m^2. In order to assess biogas production and its use in the poultry farm, the equation was based on the assumption that daily manure yield is equal ten percent of birds live weight [16]. It is possible to calculate roughly the biogas production from an AD system in relation to the composition of the dung. Therefore, such calculations are based on average values and they do not take the process parameters into account (digester efficiency, the loading rate of waste and its temperature and dilution). This is mostly because the expected biogas yield used in the analysis is the default value. The net thermal energy was calculated as a difference between the energy output from total gas yield and the energy needed to heat the influent and to compensate the energy losses from digester to the environment and any process energy fraction (for agitators and pumps).

2.3.1 Energy demands.

Heating is only used during winter and cooling is used during some days of the summer when temperatures are above 35 °C. Furthermore, data regarding several aspects having an important bearing on farm energy planning are not readily available in published statistics. Hence, the daily load values of the energy used for space heating of the farm building were assessed according to the Intensity data of [29] around the whole year under Egyptian weather conditions and based on the climatic data corresponds to the base year for this study (2010). The entire values of average climatic (outdoor temperature and air relative humidity) were taken according to published documents concomitantly studying year to estimate the energy consumption for space heating which typically accounts for several equations can be calculated based on [7]and [9]. The annual average temperature is about 25 °C. The coldest month is January with monthly average temperature of about 13 °C, and the hottest month occurs usually in July with monthly average temperature of 37 °C. For the analysis, the year is divided into two seasonal periods. Period 1 (November to April) is considered to be a winter period with only a heating demand. Period 2 (May to October) is considered to be a summer period.

2.4 Other assumptions.

As mentioned earlier, biogas is assumed to be comprised of 60% CH_4 and 40%CO_2 by volume. The calorific value of methane was used in these calculations is assumed to be 37 MJ/m^3. Depending on the size of the farm to which the model is applied, more accurate and technical specific information may be available for some of the parameters' values. It was assumed that all the biogas will be consumed for heat and/or electricity generation. It was also assumed that all the heat and/or electricity will be produced on-site and will be consumed by the farm itself and digester. The supposed engine-generator as an electric power unit is of 59.5 kW scale operating at 85% of the total capacity and has electric generation efficiency of 23 %. On the other hand, a heat power unit using biogas as a fuel to cover the heat (space heating and hot water) load was assumed at an efficiency of 90 % and is assumed to be operated at full capacity.

The calculations for cost and generation require a number of parameters that are specific to the source being analyzed. Many of these parameters are subject to variability. For example, the cost of a ton of fossil fuel has fluctuated greatly in the past few years, and the average cost per ton increased more than 20% between 2009 and 2014. Due to the changing cost structure of traditional fossil fuel sources, therefore, the model supports user inputs for specifying the last cost is 1 L.E./liter. Capital costs used in the calculations for the assumed conversion technologies are drawn from the market survey data. The capital costs are 1100 L.E./kW of the system that producing electricity from biogas and 66 L.E./kW of the system that producing thermal energy from biogas. For economic evaluation a discount rate of 10 % and 15 and 20 years operation times have been assumed for electrical and thermal power units respectively. Only CO_2 emissions embedded in electricity and heat from generator and direct combustion system are considered and the estimated CO_2 emissions factors of two systems are 1.26 kg/kWh and 0.323 kg/kWh respectively. Moreover, the value of carbon tax or emission cost is 0.108 L.E./kg CO_2 as reported in [12]. While the variable costs include operation and maintenance costs at 5% of capital cost and fossil fuel only to start generator is 0.088 L.E per MWh power produced and cleaning biogas is 0.12 L.E per MWh power produced. Finally, biogas cleaning system capital cost which is considered as additional variable cost items was assumed to be 2 % of capital cost and labor cost as fixed cost is 10 L.E./day.

Applying sensitivity analysis, optimal solution could be examined on the utilization rate of biogas energy availability of each conversion unit in the model. These changes will affect the whole biogas utilization schedule, meaning e.g. that when the biogas products is not in a position to contribute at its highest potential then conventional sources will be chosen to cover this default by the biogas facility.

3. Results and discussions

The application of the LP model provided the optimal allocation of the biogas energy for the scenario considered. As the base scenario for evaluation of two utilization routes of biogas energy on-site, were assumed. The electricity is served by assumed generator that has a net generation capacity of 59.5 kW and biogas fired furnace is employed for heating (both space heating and hot water). On the basis of the information related to surveyed farm, the expected biogas yield from the farm waste is 920.11 m^3/day and has a potential contribution of 20426 MJ/day. The Data of heat and electricity demands used in the analysis and optimal generation are shown in Table 1. Taking the whole year as an example, the potential of dung power for electricity and heat generation has been estimated as 2042.4 MWh/yr. In order to gauge the annual energy requirements, heat and electricity demands were calculated as approximately 359.78 MWh/yr and 364.95 MWh/yr, respectively. In the following, the optimal allocation strategy of the biogas energy and the economic and environmental effects of the energy routes are discussed.

3.1 Optimal allocation schedule

In this study, the optimal allocation strategy has been executed from the economic point of view. The study assessed the biogas potential, demand estimation and evaluation of unit cost of energy. The potential use of the biogas has been done using the standard methods. The success of energy utilizing depends on accurate estimation of energy demand and energy availability. Thereby, the quantum of utilized energy will make the plan successful. The solution strategy is to create feasible production plans through generation-demand optimization from single resource of fuel is biogas product. This generates a set of possible solution routes. Integer variables (decision variables) conducted the selection generation route and gave the ability to exclude a previous integer solution that may be implemented. They try to build a feasible solution for the problem by a number of iterations on the linear programming solution. At each iteration, capacity constraints and objective function coefficients are modified in the linear program to account for the energy converted and the costs incurred by the setups on energy conversion units. Then a combinatory optimization was performed to select the set of quantities that yields the lowest total cost with the time vector constraints. The iterative analysis of optimal utilization routes for each conversion unit was conducted in which a sequence of improving approximation solutions (i.e. improved energy unit cost) were analyzed in conjunction with technical aspects, as a scenario that may appear economically attractive may not be technically feasible.

From the optimal utilization point of view, the results of the model are that answer of how much of each product should the farmer produce in each period at minimum total cost (suiting the objective function and constraints). The Model wants to attain the optimum distribution in order to perform the final demands for heat and electricity. In other words the model tries to convert all the available energy for energy purpose in the solution. Therefore, we assumed that the losses associated with converting biogas energy is neglected and no changing in net available power through process.

According to the Table 1, It is obvious that the model converts large amounts of biogas energy to electrical power unit when demand is relatively high and not exceeded the limit of available power, while it converts relatively small amounts of biogas energy to heat power unit when demand is relatively small and not exceeded the limit during the same period of time. So, the heat and electricity productions represent 19.32 and 73.75 % of the yearly available energy, respectively.

As shown in Fig. 2, the energy required for electricity generation is increased in hot months rather than required in cold months. For hot months it can be found that most of the available energy is converted to electricity and the amount of electricity produced is uniform. Thus, a fraction of this yield, in this case, amount of biogas energy, has to be shipped to other equipment is electrical power unit in order to use it completely in heat needs.

Even with a highly conversion coefficient of heat power unit rather than electric unit, for hot and cold months most of the energy supply is allocated into two end-uses are close to the demand of each.

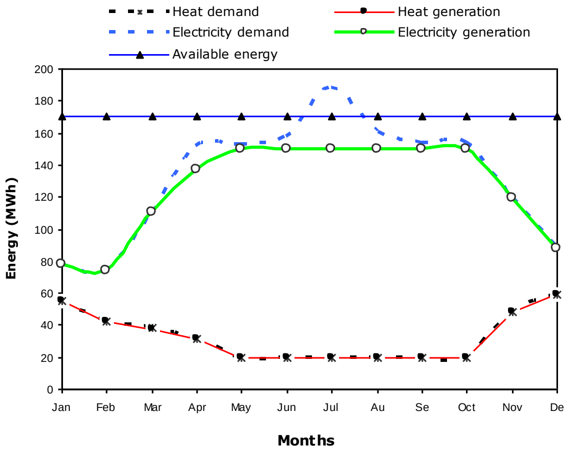
Although electricity supplied by electric power unit is more expensive than combustion system, the lower conversion efficiency of this power unit results in an allocation of biogas energy within the year. Whereas the rest is supplied in equal proportions to heat power system for operating digester because the heat demands in this period have similar running schedules. Thus, reducing the need for grid electricity to operate digester or parasitic load.

Although the result shown above is determined optimally from the viewpoint of economics, it is not satisfactory from the energy saving viewpoint because unutilized biogas energy may be disposed of sometimes. As it is apparent that both electricity and thermal energy demands fluctuate seasonally and the demand in electricity was varied independently from hot to cold months. Both heat and electricity outputs in hot months are found to be equivalent 119.88 and 900.45 MWh and correspond to 11.74 and 88.18 % of the available energy used, respectively. On the other hand, the heat and electricity outputs in cold months are found to be equivalent 274.75 and 605.81 MWh and correspond

Table (1): Comparison of demand and generated energy in cold and hot periods.

Period	***Month***	***Heat (MWh)***			***Electricity (MWh)***		
		Demand	***Generated***	***Utilized Power %***	***Demand***	***Generated***	***Utilized Power %***
Winter (1)	**NOV**	*43.43*	*43.39*	*28.30*	*27.51*	*27.52*	*70.31*
	DEC	*53.63*	*53.58*	*34.98*	*20.27*	*20.28*	*50.81*
	JAN	*49.49*	*49.44*	*32.28*	*17.91*	*17.91*	*45.75*
	FEB	*38.15*	*38.11*	*24.88*	*16.91*	*19.92*	*50.88*
	MAR	*34.15*	*34.12*	*22.27*	*25.31*	*25.32*	*64.69*
	APR	*28.67*	*28.64*	*18.70*	*34.87*	*31.56*	*80.61*
	Total	***247.52***	***247.27***	***26.90***	***142.77***	***139.4***	***59.32***
Summer (2)	**MAY**	*18.71*	*17.98*	*11.74*	*35.19*	*34.52*	*88.18*
	JUN	*18.71*	*17.98*	*11.74*	*36.15*	*34.52*	*88.18*
	JUL	*18.71*	*17.98*	*11.74*	*43.23*	*34.52*	*88.18*
	AUG	*18.71*	*17.98*	*11.74*	*36.91*	*34.52*	*88.18*
	SEP	*18.71*	*17.98*	*11.74*	*35.31*	*34.52*	*88.18*
	OCT	*18.71*	*17.98*	*11.74*	*35.39*	*34.52*	*88.18*
	Total	***112.26***	***107.89***	***11.74***	***222.81***	***207.1***	***88.18***
Aggregation Power		***359.78***	***355.16***	***19.32***	***364.9***	***346.4***	***73.75***

Fig. (2): The available and generated energy balance for heat and electricity every month.



to 26.90 and 59.32 % of the available energy used, respectively. As mentioned previously, the model was formulated using demand and available constraints.

Although occupying a large conversion efficiency to produce thermal energy rather than electrical energy in hot and cold months, model commits portions from available energy only to satisfy demands and guarantees that the capacity of every order each month is not exceeded. Based on the results, the electricity generated by the optimal solution is sufficient to meet 93.2 and 97.6 % of the demand electricity in hot and cold months, respectively. Also, the heat generated by the optimal solution is sufficient to meet 96.1 and 99.9 % of the heat demand in hot and cold months, respectively. This behavior is excluded only 6.93 % of the total available energy which equivalent to 141.54 MWh is not exploited in cold months. On the other hand, the deficiency in energy demand for producing electricity and heat together is equivalent to 85.63 MWh/yr corresponds to 4.2 % of the total available energy. It now appears certain that the solution has gone to the most attractive operational mode that is found to be running continuously in all year. This is because the optimum solution for the energy system as described above gives the best allocation from an economic perspective assuming that generated energy from biogas cannot be stored in the long term. Finally, the optimal solution only from the economic viewpoint conflicts with the energy saving perspectives to some extent. This result is in harmony with that characterized by [3].

3.2 Economic and environmental effects

The objective is to minimize the cost of producing electricity and heat according to the demand without explicitly considering emissions. Moving close to this scenario, Fig. 3 shows overall trends in total annual cost of the energy utilization system when normalized by total final energy demand (total system cost includes the annualized capital and operating costs, as well as the cost of imported fuels and maintenance for the conversion equipment). The annual cost associated with optimal solution is 29 695 L.E. per year involved the cost of carbon dioxide emissions and the associated annual emission of CO_2 is 553 ton per year. As to the environmental merit, CO_2 emission costs were also estimated independently from the cost objective. This scenario resulted in 115 and 438 ton per year of CO_2 emissions from converting biogas to heat and electrical energy, respectively.

Based on the model outputs, the reduction ratio of CO_2 emissions illustrates certain trend as the increase of demand scale. However, the reduction ratio of CO_2 emissions will be increased to 30 % if electricity is generated and to 82 % if heat is generated. The indicated reduction in CO_2 emissions comes at an annual generation cost of 7710 L.E./year for electricity and 146 L.E./year for heat, respectively. Therefore, converting biogas to electricity is not always better than heat at any month because that will contribute to a rather negative environmental impact achieved due to the reduction of CO_2 emissions. For example, as to electricity production case, the results have more emissions than heat production case which has larger conversion efficiency and higher energy demand. This is partly because the relatively larger electrical demand and lower conversion efficiency are included and combustion fuel at the start of operation is considered. Unreasonable supplying of biogas energy and poor operational strategy emissions. The environmental merit is also increased due to excessive

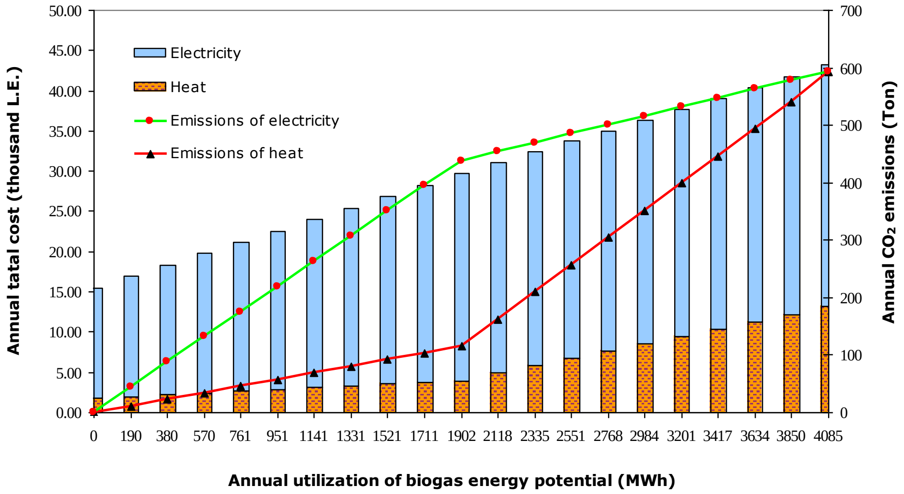


Fig. (3): Economic and environmental effects at different rates of outputs.

generation of heat and electricity from biogas energy compared to the conventional resources.

Furthermore, from this figure, it can be found that the economic merit is always larger than the environmental one at various scales. This is partly because of the economic objective which has been assumed in this study. Compared with the scenario of conventional systems which are being certified in operating farm in reality, the cost reduction ratio regarded to supply farm by energy is increased by about 84 %. This is because the converted energy is sufficient to meet 94.93 and 98.72 % of the total annual electrical and thermal energy requirements, respectively, in place of conventional resources. If the installation of anaerobic digestion facility was taken into consideration in economic performance analysis with the biogas utilization model, the total annual cost reduction ratio would be increased to 7 %. Along with the increased consumption of energy resources especially fossil fuel, the energy prices (e.g. electricity, gas, etc.) are expected to have a continue increase in the following years. Under this consideration, the generation cost is the most important factor affecting the total annual system cost, is analyzed by increasing the rate of annual production until twice of current quantity.

3.3 Results of sensitivity analysis

A sensitivity analysis has been conducted in order to explore the changes in the energy generation cost and to understand the influence of key parameters on the decision to accept the proposed solution related to the model outputs or not and obtaining further results. In particular, the results of sensitivity analysis indicated the impact of changes in capital costs, annual O&M costs, the interest rate, lifetime, conversion efficiency and equipment capacity. The sensitivity analysis has been solved by fixing a value for the unit cost of energy on yearly basis for each conversion unit. The evaluation of unit cost of energy has been done using the standard methods. Unit cost of energy sharply responds to changes in capital costs. This indicates that in evaluating the system proposals, attention should be focused on ensuring that the estimation of capital costs is properly done. As for the other parameters (i.e. annual O&M costs, interest rate and lifetime) their impact is relatively minor. The results indicated that the level annual cost of energy has been computed as approximated 0.0375 L.E./kWh of generated electricity and 0.001 L.E. /kWh of generated heat.

According to the optimal value illustrated above, the biogas utilization model supplies about 94.93 % of the total electricity demand as well as supplies about 98.72% of the total heat demand. In the following, by changing the quantity of generated electricity, its effects on the optimal electric power unit size and corresponding economic and environmental performances are analyzed. The variation of the unit cost of energy with respect to the quantity of generated electricity is shown in Fig. 4. It can be observed that all the key parameters are sensitive to generation cost. The slope of the lines associated with different values examined; represent sensitivity of cost of energy with respect to the capital cost, electricity generation, capacity factor, and conversion efficiency. High value slope line for analysis indicates that cost of energy increases/decreases sharply with variation in the size of conversion system and vice-versa.

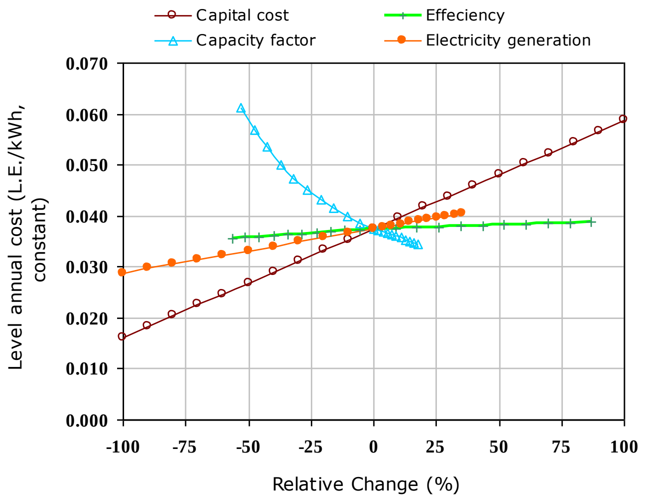


Fig. (4): Effect of some electric power system characteristics on unit cost of energy.

According to the Fig. 4, the sensitivity of the capacity factor is examined and compared for various demands of electricity. Along with the increase of the rated capacity, unit cost of energy illustrates a trend of shift from increase to decrease one for optimum point. The unit cost of energy does not show a linear decrease to the rated capacity scales. An increased in capacity level by 18 % means a decreased in unit cost of energy to 8 %. It is interesting to notice that the increasing of the size of electric power unit up to 70 kW is only introduced from the sensitivity analysis resulted in reduction in unit cost of energy equivalent to 0.0345 L.E. /kWh. Moreover, the amount of electricity produced is not uniform over the life of the equipment. The effect of the capacity factor of heat power unit have not been included in the analysis; however its potential impact can be assessed by assumed the firing system of heat power unit is able to convert all biogas energy availability.

Furthermore, looking into the figure, it can be found that the unit cost of energy is greatly affected by the total capital cost. As the total capital cost is as high as twice of current value, the unit cost of energy is increased from 0.0375 L.E. /kWh to 0.0587 L.E. /kWh. As the variable costs is increased to twice of current value, the optimal level annual cost of producing electricity from 0.0375 L.E. /kWh to 0.0462 L.E. /kWh. This fact is due to the high installation cost: to contrast the higher costs, it is necessary to treat a large quantity of waste rather than that was suggested in the optimal solution. Moreover, the energy system itself is a barrier as it is not proven yet. Furthermore, the initial investment cost for the installation is also a barrier for the farmer.

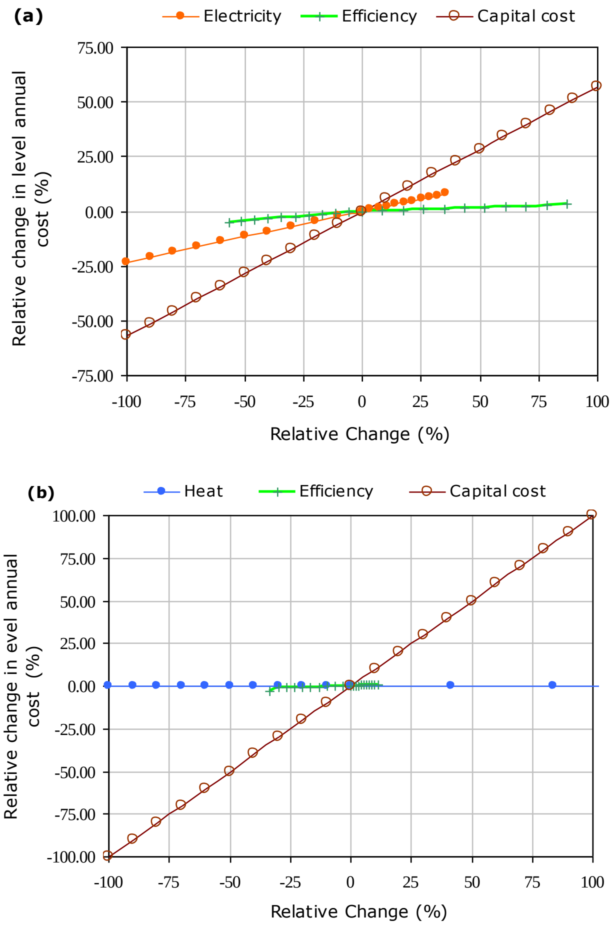


Fig. (5): Effect of efficiency on level annual cost of energy.

The analysis is optimistic as it is assumed that efficiency is constant at operational mode (continuously), whereas the energy conversion deficits were existed because of the small conversion efficiency of the electric power unit so the conversion was not matched to all electricity demand. The conversion efficiency is set of about 23 % is the turning point, which validates the analysis illustrated above. When estimating the level annual cost for producing electricity, conversion efficiency is not varied stepwise according to the rated capacity of electric power unit in analysis. The increasing in efficiency by 9% achieves the same level cost of energy so that it can be utilized excess quantity of biogas energy by selected other generator has an efficiency of 25%. The relative change in level annual cost increases from a negative value to appositive one. Thus the effect of which can be seen by referring to the sensitivity analysis in Fig. 5. Any increase in conversion efficiency of the heat power unit would not increase the unit cost of generation energy. It is concluded that the electricity generation cost are more affected by variation of capital cost, capacity factor and efficiency as compared to heat production cost.

4. Conclusion

The biogas utilization model was formulated for two end-uses to optimally energize layer farm through its wastes. Linear Programming (LP) using LINDO software has been used for the optimization of utilization model. The model is ensured to utilize biogas energy for operating digester instead of the auxiliary resource results in a lower system cost. Under this consideration, the generation cost is the most important factor affecting the total annual system cost. The model also considers the objective of minimizing annual system operating costs and allows a farmer to balance annual generation costs against the corresponding energy demands, and it provides significant support for the designer or operator of an energy conversion unit.

Through a numerical example about assumed electric and heat power units, the effectiveness of the proposed method has been proved. It has also proved that optimal rational operation and production capacity are very important to achieve the maximum economic merits of utilization system. By the optimal solution, in whole year biogas energy introduced as a part of the energy supply, mainly in winter and summer seasons for energy requirements. This result turns the reliability of model highly dependent on stable supply of biogas energy. The total utilized biogas energy was found to be equivalent to 1902 MWh/yr that corresponds to 93% of the available energy. Electricity and heat generation equivalent to 346.44 and 355.16 MWh/yr and will cover a great part of the electricity and heat consumption on farm correspond to 94.93 and 98.72 %, respectively. These quantities are enough to displace conventional sources. Furthermore, good waste handling will contribute to a rather positive environmental impact achieved due to reduction of CO_2 emissions. Therefore, it is expected that the biogas energy may play more and more important role in the future climate change programs.

The sensitivity analysis quantities the effects of some parameters to reduce unit cost of energy. Clearly, it is important to consider the impact of technical factors (such as electrical and heat generation efficiencies) when assessing the impact of specific electrical and thermal generation incentives schemes. These factors affect not only the feasibility of electricity and heat generation extensions, but also the scale of farm electrification. The sensitivity analysis of biogas utilization model also reveals that the multi-conversion can be more suitable to the poultry farm, even if the fuel price fluctuates with external circumstances. Furthermore, the optimal solution and corresponding economic and environmental effects are more or less sensitive to some key parameters including the scale of energy demand and the operational and management (O&M)

costs.

The model supposed some assumptions, which may bring obstacles in planning biogas energy in-situ. For instance, for data restrictions, only two representative conversion technology types are considered; and the capacity of the energy production are based on hypothesis. Besides, due to the complex situation of energy market, further improvements of the model are needed in order to optimize biogas producing rates using the hourly load values of electrical and thermal (electricity, cooling, space heating and hot water) loads for various types of poultry farms around the whole year in terms of the energy consumption intensity data. The model developed and applied in this research can be expanded beyond analysis of biogas supply with the inclusion of energy recovery. This will require a larger scope for the digestion process in order to include end-use devices and useful energy demands.

Acknowledgement

This research has been supported by the Agriculture Ministry Information Center, as well as the Electricity Ministry of Dakhlia Governorate. The authors are grateful to the reviewers for their insightful comments and suggestions.

References

[1]**Angelis-Dimakis. A. ; Biberacher, M. ; Dominguez, J. ; Fiorese, G. ; Gadocha, S. ; Gnansounou, E. ; Guariso, G. ; Kartalidis, A. ; Panichelli, L. ; Pinedo, I. and M. Robba (2011)**" Methods and tools to evaluate the availability of renewable energy sources" Renewable and Sustainable Energy Reviews,(15) 1182–1200.

[2]**Barany, I. ; Van Roy, T. J. and Wolsey, L. A. (1984)**" Strong formulations for multi-item capacitated lot sizing" Management science, 30(10):1255-61.

[3]**Beihong, Z. and Weiding, L. (2005)** "An optimal sizing method for cogeneration plants" Energy and Buildings, www.elsevier.com/locate/enbuild.

[4]**Bowman, E. H. (1956**) " Production Scheduling by the Transportation Method of Linear Programming," *Operations Research*, Vol. 4, No. 1, pp. 100-103.

[5]**Cai, Y.P. ; Huang G.H. ; Lin Q.G. ; Nie X.H. Tan Q. (2009)** "An optimization-model-based interactive decision support system for regional energy management systems planning under uncertainty" Expert Systems with Applications, (36) 3470–3482.

[6]**Casella, F. ; Maffezzoni, C. ; Piroddi, L. *et al.* (2001)** "Minimising production costs in generation and cogeneration plants" Control Engineering Practice, (9) 283–295.

[7]**Chepete, H. J. ; Xin H. ; Puma M. C., and Gates R. S. (2002)** "Heat and moisture production of poultry and their housing systems: Pullets and layers". Transactions of the ASHRAE (in review).

[8]**Chicco, G. and Mancarella, P. (2009)** "Matrix modelling of small-scale trigeneration systems and application to operational optimization". Energy, 34(3):261–73.

[9]**CIGR Handbook, 1999**. CIGR Handbook of Agricultural Engineering, Volume II. Animal Production & Aquacultural Engineering. Published by American Society of Agricultural Engineers. Swedish Standard SS 951050, 1992.

[10]**DHV Consulting Engineers (1984)** "The use of mathematical models for energy planning in developing countries" Report for the Asian Development Bank.

[11]**El-Hadidi, Y. M. and Seufort, H. (1997)** "Possibilities of increasing biogas production by using different mixtures of animal wastes. Misr. J. Agric. Eng. 14(1):17-26.

[12]**El-Kordy, M. N ; Badr, M. A. ; Abed K. A. and Ibrahim, S. M. A. (2002)**" Economical evaluation of electricity generation considerin externalities" Renewable Energy. 25: 317-328.

[13]**Eppen, G. D. and Martin, R. K.**

(1987) “Solving Multi-Item Capacitated Lot-Sizing Problems Using Variable Redefinition,” *Operations Research*, Vol. 35, No. 6, pp. 832-848.

[14]**Frombo, F. ; Minciardi, R. ; Robba, M. ; Rosso, F. ; Sacile, R. (2009)** "Planning woody biomass logistics for energy production: A strategic decision model" biomass and bioenergy, (33) 372 – 383.

[15]**Frombo, F. ; Minciardi, R. ; Robba M. and Sacile, R.(2009)** " A decision support system for planning biomass-based energy production" Energy 34: 362–369.

[16]**GTZ, (1989)** "Biogas plants in animal husbandry" OEKOTOP, Deutsche Gesellachaft fur Technische Zusammenarbeit (GTZ) GmbH. Berlin 33, Federal Republic of Germany.

[17]**Karimi, B. ; Fatemi Ghomi, S. M. T and Wilsonb J. M. (2003)**"The capacitated lot sizing problem: a review of models and algorithms" Omega, 31, 365 – 378.

[18]**Kythreotou, N. ; Florides, G. and Tassou, S. A. (2012)** "A proposed methodology for the calculation of direct consumption of fossil fuels and electricity for livestock breeding, and its application to Cyprus" Energy 40 ; 226e235.

[19]**Lansing, S. ; Botero, R. B. and Martin, J. F. (2008)** "Waste treatment and biogas quality in small-scale agricultural digesters" *Bioresource Technol.* 99 :5881–90.

[20]**Lee, S. ; Speight, J. G. and Loyalka, S. K. (2007)** "Handbook of alternative fuel technologies" Boca Raton: Taylor and Francis Group, CRC Press.

[21]**Leung, J. M. Y. ; Magnanti, T. L. and Vachani, R. (1989**) " Facets and algorithms for capacitated lot sizing". Mathematical Programming, 45:331-59.

[22]**Levi, R. ; Roundy, R. O. and Shmoys, D. B. (2006)** "Primal-dual algorithms for deterministic inventory problems. Mathematics of Operations Research, 31:267.284, 2006.

[23]**Liu, D. ; Yang, X. ; Tian, X. ; Wu, R. and Wang, L. (2011)**"Study on integrated simulation model of economic, energy and environment safety system under the low-carbon policy in Beijing" Procedia Environmental Sciences 5 :120–130.

[24]**Mata-Alvarez, J. ; Mace, S. ; Llabres, P. (2000)** "Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives" Bioresource Technology, 74:3-16.

[25]**Murphy, J. D. ; McKeogh, E. and Kiely, G. (2004)** "Technical/economic/ environmental analysis of biogas utilization" *Appl. Energy* **77 :**407–27.

[26]**Murphy, J. D. and Power, N. (2009)** "Technical and economic analysis of biogas production in Ireland utilizing three different crop rotations" Applied Energy, 86:25-36.

[27]**Nelson. R. (2006**) " Methane generation from anaerobic digesters: Considering different substrates" www.wikipedia.org

[28]**Nielsen, S. K. and Karlsson, K. (2007)** "Energy scenarios: a review of methods, uses and suggestions for improvement" International Journal of Global Energy Issues,27(3):302–322.

[29]**Obaia, A. R. ; Matouk, A. M. ; Elbanna, E. B ; and El-Hadidi, Y. M. (2001)** "Engineering consideration controlling the selection of poultry farms equipment and systems" Ph.D. Thesis, Dep. of Agric. Engineering, El-Mansoura Univ.

[30]**Orth, H. W. (1983**) "Various uses of gas and their influence on the design of an anaerobic digestion process" Biomethane Production and uses, Eng., Sec. 3-5: 177-191.

[31]**Pochet, Y.and Wolsey, L. A. (2006)** "Production Planning by Mixed Integer Programming.

[32]**Rashed, I. G.; El-Hadidy, Y. M.; (1992)** "A Techno economic Approach to Solid Waste Disposal and Handling in Dakhlia Governorate", Proceedings of The 1st Egyptian–Italian Symposium on Biotechnology, Assuit, Egypt .

[33]**Ren, H. ; Zhou, W. and Gao, W. (2012)**" Optimal option of distributed

energy systems for building complexes in different climate zones in China" Applied Energy 91 (2012) 156–165.

[34]**Slesser, M. (1982**) "Macmillan dictionary of energy". London: Macmillan Press.

[35]**White, J. A. ; Case, K. E. ; Pratt, D. B. and Agee, M. N. (1998**) "Principles of engineering economic Analysis, 4th ed (New York: Wiley, 1998).

[36]**William, H. M. (1980)**" Basic Theory of input-output analysis". *Beijing: China Social Sciences Press* ;9.

[37]**Zeeman, G. (1991)** " Mesophilic and psychrophilic digestion of liquid manure". Ph.D. Thesis, Wageningen university, Wgeningen, the Netherlands.

[38]**Lingo User's Guide**. **LINDO systems** Inc., (USA); **2005**
http:// www.lindo.com.

المراجع العربية

1- مشروع دعم التقييم والإدارة البيئية (سيم) التوصيف البيئي – محافظة الدقهلية- وزارة الدولة لشئون البيئة- جهاز شئون البيئة (1998).

2- الإدارة العامة للأمن الغذائي- محافظة الدقهلية- الجهاز المركزى للتعبئة العامة والإحصاء - مركز المعلومات بوزارة الزراعة.

4- مركز المعلومات بوزارة الكهرباء