Techno-economical Analysis of Rooftop Grid-connected PV Dairy Farms; Case Study of Urmia University Dairy Farm

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Abstract. The global trends indicate a growing commitment to renewable energy development because of declining fossil fuels and environmental threats. Moreover, the global demographic growth coupled with rising demands for food has escalated the rate of energy consumption in food section. This study aims to investigate the techno-economic impacts of a grid-connected rooftop PV plan applied for an educational dairy farm in Urmia university, with total estimated annual electrical energy consumption of 18,283 kWh, located at the north west part of Iran. Based on the current feed-in tariff and tremendously low electricity price in agriculture section in Iran, the plants with size ranged from 14.4 to 19.7 kWp (initial investment ranged from 26,000 to 36,000 USD) would be satisfied economically.

1. Introduction

Distributed photovoltaic electricity generation can provide electricity for using up locally, as well as, feeding surplus amount in local distribution grid. Distributed renewable energy systems can serve as a complement to centralized energy generation systems, or even as a substitute [1]. The global demographic growth coupled with rising demands for food has escalated the rate of energy consumption in food section. At the same time, the tremendous threat of climate change associated with the use of declining fossil fuels makes supplying this energy source increasingly unpleasant from the standpoint of environmental impacts. Hence, the agricultural sector faces a great balancing act on the choice of its energy sources. Increasing attention is being focused on the renewable energy sources employment in the agricultural sector in several countries of the world purposely to contribute to global reduction in greenhouse gas emissions and sustainable food production. Furthermore, it might seem intuitively reasonable to explain the emergence of new energy policies driving transition to a sustainable energy systems even in agriculture sectors. Decentralized small scale renewable energy plants at the agricultural farms may be a good energy policy [2]. The assessment of small scale rooftop PV plants regarding their techno-economic feasibility is of utmost importance. Farmers wish to know what options offer them the most beneficial investment and potential for reducing operating costs and energy use, while providing the greatest return on investment. This paper presents an investigation of techno-economic impacts of a grid-connected rooftop PV plan applied for a educational dairy farm.

The site selected for the study is an educational dairy farm located in Urmia university with large space available on rooftop area (roughly 1000 m2). The geographic and climatic conditions in Urmia are very favorable for renewable solar energy (Figure 1). The country exposes by an outstanding direct normal radiation of up to 5.5 kWh/m2/day and an average of 300 sunny days per year. The geographic site location and meteorological properties of Urmia city was depicted in Figure 1. Moreover, the herd size up to 50 lactating cow is expected to be kept in this farm which is demonstrated in Figure 2.
Temperature: -7°C to 32°C (min -13°C - max 35°C)
Precipitation falls: 386 mm
Length of the day: 9:34 h at Dec 14:46 h at June
Cloud cover: 16% (mostly clear) to 82% (partly cloudy)
Relative Humidity: 26% to 94% (min 16% - max 100%)
Wind speeds: 0 - 7 m/s
Precipitation: 15% average chance (Mar-May, Aug-Sep)
Global Solar Radiation: 1800 - 1900 kWh/m² annually

Figure 1. Case Study; Site location and meteorological properties [3], Iran solar resources map [4].

2. Material and methods
Software simulation is a commonly used approach to design, examine and make decisions about application of PV systems configurations. All grid connected systems can meet the load demand at any time making the technical feasibility assured for all grid connected configurations. The assessment structure in the present study is based on the simultaneously interaction between farm load demand profile and PV system configuration as the electricity flow between the system and the grid. TRNSYS software was adopted to develop dairy farm GRPV plant model. MATLAB and EXCEL were also used to post process the TRNSYS results, specifically the economic analysis. The technical performance parameters are also needed to define an overall performance evaluation of RGPV systems with respect to the energy production under the operating conditions. Two important indicators were implemented to provide judgment of plant performance in technical point of view; Capacity Factor (CF) defined by equation (1) and Capacity Value (CV) defined by equation (2). CV refers to the contribution of a power plant to reliably meet demand. Solar plants can be designed and operated to increase their capacity value either capacity factor.

\[ CF = \frac{\text{Final a.c Output Electricity (kWh)}}{\text{Nominal d.c Power (kW)}} \]  
\[ CV = \frac{\text{Met Demand Load by PV (kWh)}}{\text{Demand Load (kWh)}} \]  

Cash flows were calculated at the end of each year. Net Present Value (NPV) was calculated as equation (3) at the end life of project (20 years), the same period of guaranteed power purchase agreement. However the usual life time of PV plats is 25 years, this under estimation of life time would cause to better confidence level of modeling results. Where " Se " is annual PV electricity selling income, " Sa " is annual saving in electricity bill, " OM " is annual operation and maintenance cost, and " i " is the year index. Moreover, Internal rate of return (IRR) is defined as a discount rate that makes the NPV of all cash flows equal to zero. IRR calculations rely on the same formula as NPV does.
2.1. Load profile modelling

Dairy farm energy consumption modelling is the first step in exploring the possible demand response and load compensation opportunities under the grid connected rooftop PV initiative. Generally, dairy farms use between 800 and 1200 kWh/cow-yr.

\[
NPV_{20y} = \sum_{i=1}^{20} \frac{Se_i + Sa_i - OM_i}{(1 + DR)^i} - II
\]  

(3)

Moreover, Kythreotou et al. reviewed several researches which have been conducted in different countries and reported the annual energy consumption of dairy farms put in the wide range of 281-2900 kWh/cow/year [5]. Electrical energy consumption in dairy farms varies largely because of machinery, production systems, working habits and maintenance [6]. Other factors such as herd size, milk production capacity, management practices, and ambient conditions, can also have significant
effects on overall system performance. This study is aimed to establish a mathematical model to represent and model the load profile of dairy farm based on the farm herd size, farm milking capacity and farm location. Farm electricity load profiling includes the details on the electrical appliances, its energy requirement, and consumption pattern. The model is generated based on the activity time scheduling depicted in Figure 3. Regarding the technical specification of farm equipments, presented in Table 1, the TRNSYS transient system simulation program was used to develop a model to overcome these limitations.

**Table 1.** Technical specification of electrical appliances demonstrated in Figure 2-c

| Farm Activity | Electrical Appliance     | Commercial Brand | Technical Specification               |
|---------------|--------------------------|------------------|---------------------------------------|
| Milking Milk  | Vacuum Pump              | CAMAK-AGM112M    | 4 kW - 1425 rpm                       |
| Cooling       | Compressor & Fan         | Paykan           | 4.75 kW, Scroll Compressor            |
| Pumping       | Agitator                 | SYN MOTOR+Gearbox| 0.75 kW - 1440 rpm                   |
|               | Milk Pump                | LOWARA-CEAM70/5/A| 0.55 kW - 30-80 lit/min - 28.8-20.2 m|
| Artificial    | Barn                     | Fluorescent      | 25× (2× *32 W) - supplying about 100 lux|
| Lighting      | Milking Parlor           | Incandescent light bulb | 8 × 100 W - supplying more than 500 lux |
|               | Office                   | Incandescent light bulb | 2 × 100 W - supplying about 500 lux     |

* Based on the regulation [7], not the current lighting system

TRNSYS modules were developed for all major milking center equipment components, including the milking unit, refrigeration unit, artificial lighting and pumping. Models were verified by comparing predicted results to monitored data. Simulation is performed by hourly solar resource and meteorological parameters profiles based on the Typical Meteorological Year (TMY) data set of Urmia. The simulated load profile is successfully validated against the EUI reported by literature.

![Figure 3. Dairy farm demand load profile modelling](image)

### 2.2. Grid-connected rooftop PV system

Rooftops provide a large expanse of untapped area for solar energy generation, and onsite distributed generation could potentially reduce the costs and losses associated with the transmission and distribution of electricity [8]. The size of the RPV installation can vary dramatically and is dependent on the plant design purpose, which can be based on either of the following: attainable roof area, electricity demand, available funding, and the grid operator feed-in capacity. The variety of solar PV...
technologies are available running on a scale of efficiency, price, durability and flexibility, depending upon the need of projects. For most applications, a mono or polycrystalline solar PV solution is usually the best option, as these established technologies generally provide the right balance of price, efficiency and reliability.

Table 2. Techno-economic properties of the PV panels

| Type        | Model | Size (mm*mm*mm) | Efficiency (%) | Power (Wp) | Initial Cost ($/Wp) | BoS Cost ($/Wp) | O&M Cost ($/Wp) | Life Time (year) |
|-------------|-------|-----------------|----------------|------------|---------------------|----------------|----------------|-----------------|
| Poly Crystalline cell | JAP6-240 | 1650×991×4 (1.64 m²) | 16 | 240 | 0.68 | 1.14 | 0.0053 | 25 |

PV modules market is still relatively small and non maturated in Iran compared to global market. Most PV panels range in efficiencies of 13 to 16%, though some high-end model modules can reach percentages as high as 20%. Most of inverters receive benefit of the maximum power point tracker (MPPT) technology, making sure the solar PV modules generated DC power at their best power output at any given time during sunshine hours. The inverter efficiency value almost remained at the range of 0.8-0.9. According to the information gathered from Iran market and quote from informed opinion by screening the experience of local experts, the basic technical specification of PV module and inverter was selected to run simulation as presented in Table 2. The overall DC/AC de-rate factor of 0.83 was selected based on existing literature on the optimal sizing of inverters to minimize the cost of PV-generated electricity [9] [10] [11]. The long axis of the dairy barn is set in the north-south direction to have the maximum benefit of the sun as illustrated in Figure 2-a and Figure 2-b, imposing an azimuth angle of 95 degrees for PV panels. Buildings should be placed so that direct sunlight can reach the platforms, gutters and mangers in the cattle shed. Moreover, based on the pitch angle of 15 degrees for barn roof, it has been selected for tilt angle of PV panels.

2.3. Local grid tariffs
The electricity bill tariffs of the agriculture and livestock section in Iran are levelized with respect to the consumption seasons and day time. Two seasons of Cold (23September-19March) and Warm (20March-22September) are considered during the year, and three levels of Low, Mean and Peak Consumption were considered during the day as well, respectively with the tariffs of 0.391, 0.782 and 1.515 USD cent/kWh for small scale consumers (less than 30 kW). For warm season low, mean and peak levels put into 24:00-7:00, 8:00-19:00 and 20:00-23:00, respectively. For cold season the low, mean and peak levels put into 22:00-5:00, 6:00-17:00 and 17:00-21:00, respectively. Moreover, in summer months (21 June to 21 September) these prices will increase by 20%. Most recently guaranteed electricity purchase FiT allocated to the end user consumers and limited to the connection capacity are 22.332 USD cents and 26.067 USD cents per each purchased kWh respectively for PV plants size up to 100kW and up to 20 kW for guaranteed period of 20 years.

3. Results and discussion
Cash flow and energy flow diagrams of the dairy farm is illustrated in Figure 4. January and August represent the cold and warm periods of the year, respectively. In top diagrams of Figure 4, income and bill as a function of day hours are monitored.

1 With exchange rate of 1 USD=37,480 IRR in free markets on April 2017
Regarding high tariffs and incentives for PV electricity in Iran, incomes surplus the bills wherein, regardless of RGPV, in January and August, 8 and 11 percent of the bills are covered by PV, respectively. This may be because of subsidies for the electricity in the country. However, the CV values for January and August are 8 % and 21 %, respectively. The different amounts of CV and bill coverage originated from the dependency of electricity price on time of use in Iran. On the other hand, income as a result of guaranteed PV buying, is calculated to be 584 $ and 2317 $ for January and August, respectively. Therefore, a farmer in Iran would prefer to sell the produced PV electricity rather than simply consuming it which endangers the policy of renewable energy strategy toward self sufficiency plans. Three major economical features, IRR, NPV and PP are analyzed in Figure 5. To get a more comprehensive perception of the problem, horizontal axis is segmented and scaled on both plant size and capital cost. The influence of incentive policy is now highlighted in the sense that the trends of economical features in plant sizes of less than 20 kWp are quite distinct from that of larger sizes.

Base year is 2017 and calculations are based on 20-year life-time of the technology. Regarding 18% discount rate, in plant sizes of the range 14.4 kWp to 20 kWp, the utilization of PV would meet
economic justification on the basis of IRR (Figure 5, red line). As shown in the figure, NPV is in accordance with IRR and corroborates the fact that up to 20 kWp plant size, the utilization of PV would be rational but as the plant size grows, there is no reason to invest on solar PVs in a dairy farm. The main point to be noticed in the results is that payback period (PP) is not attractive for an investor unless more incentive are employed.

4. Conclusion
The current study analyses the techno-economic impacts of grid connected rooftop PV system on the balance of a educational dairy farm located in cold climate north west of Iran. By means of TRNSYS simulation software, it has been shown that the GRPV plant with 89 PV modules of the nominal plant size of 20 kWp is the economically optimal solution. Up to 20 kWp plant sizes, economical feature including IRR, NPV and PP prove the reasonability of implementation of PV in dairy farms. Different size of PV plants with capacity factor of 1321 kWh/kWp, corresponding to the farmer initial investment was adopted to find the economical characteristics of net present value and payback period of investment after 20 years. Economical evaluation was carried out based on the year 2017, considering 18% discount rate and recent incentive renewable energy policies. Due to approved incentives already employed in Iran, justification of the renewable energy installation in dairy farms require meticulous and further investigations on policies.

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