Reduction of Production Costs in Agribusiness Companies in the Western Region of the State of Paraná Using Photovoltaic Systems Connected to the Grid

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Abstract

This investigation was a case study of designs for grid-tie photovoltaic systems in agribusiness enterprises in the western region of the state of Paraná, in Brazil. Electricity consumption data of three grain storage enterprises and a complex with three aviaries was studied. Their monthly electricity consumption and production costs data were collected, and solar radiation data for the same locations were collected from the SunData database. Indices that related electricity costs and production expenses, and the photovoltaic system costs and production expenses were developed. The indices showed to be efficient tools of cost relation for systems of different installed powers and different agricultural productions. The study showed a cost reduction in production of up to 62.71% for the aviaries, and 76.87% for the grain storage enterprises, concluding that the use of grid-tie photovoltaic systems reduces the cost of production and increases the profit of the enterprises.

Keywords: grid-tie photovoltaic systems, agribusiness, aviaries, grain storage enterprises, cost reduction

1. Introduction

Brazil ranks third in corn production, with 9.12% of the world production; first in coffee, with 32.02%; and first in soybean, with 67.82%. Other highlights are: the leading orange juice and fresh oranges producer, with 66.46% and 35.19% of the world production, respectively; and in fourth position when it comes to sugar, soybean meal, soybean oil, and cottonseed production (FAS, 2018).

Brazil it is the second largest exporter of agricultural products to the European Union (Hubbard et al., 2017). For instance, exportation to the European Union in the year 2015/2016 generated US$18.3 billion (Alan Bojanic, 2017). According to the Ministry of Agriculture, Livestock and Food Supply, in the year 2015/2016, Brazil exported goods totaling US$52.9 billion, with the main markets being China, the European Union, the United States, Japan, Russia, and Saudi Arabia.

According to the National Energy Balance of 2018, the agricultural sector presented electricity consumption of 2 470 000 toe. In 2010, it was 1 629 000 toe, resulting, therefore, in an increase of 51.62% in seven years (EPE, 2018).

The solution of electricity generation through grid-tie photovoltaic systems is believed to be feasible in its implementation for some reasons: a) ease of project development, since the equipment for electric energy generation were all modular, thus facilitating implementation (Savazzi & Sobrinho, 2017); b) the small and micro rural producers or entrepreneurs of the agribusiness sector would not depend on the electric power transmission network and the logistics of the electric power supply companies (Priester et al., 2017), c) the environmental impact would be minimal, since it is a clean and renewable source (Lo & Mayumi, 2017), d) the project's financial return is short-term, in theory, depending on the size of the installed PV system (De Castro et

al., 2016); and e) there is the government's interest in implementing this type of systems, providing attractive funding lines and amortization time (Griebeler et al., 2016).

The hypothesis raised was that the greater the installed power of the grid-tie photovoltaic system, the greater the economic efficiency in agricultural production, thus increasing the profitability of the agribusiness enterprise.

2. Method

The work was developed in the state of Paraná, with its geographical coordinates S 24°57′21″ and W 51°27′19″, located in the southern region of Brazil. The region's climate can be classified as subtropical (Köppen & Geiger, 1928), and it presents an annual average solar radiation of 5.44 kWh m^{-2} (Tiepolo et al, 2017).

The agribusiness enterprises will be divided into two economic sectors: aviaries for broiler chickens and grain storage silos.

2.1 Aviaries

Average annual radiation of 4.83 kWh m^{-2} (CRESESB, 2018). The electric energy consumption was studied from November 2016 to January 2018, totaling 167 603 kWh, and the cost of R$45 562.87, with a capacity of 25 000 heads of chicken per batch, and 515 550 of them received during the period.

2.2 Small Silo

Average annual radiation of 4.70 kWh m^{-2} (CRESESB, 2018). The electric energy consumption was studied from June 2017 to May 2018, totaling 40 045 kWh, and a cost of R$ 17 388.86. There is a silo of 2 000 tons and four hoppers with 72 tons each, totaling a storage capacity of 2 288 tons.

2.3 Medium Silo

Average annual radiation of 4.81 kWh m^{-2} (CRESESB, 2018). The electric energy consumption was studied from July 2017 to June 2018, totaling 145 802 kWh, and a cost of R$ 61 275.67. There are two silos of 1 800 tons each, a lung silo of 1 800 tons, and four hoppers with 150 tons each, totaling a storage capacity of 6 000 tons.

2.4 Large Silo

Average annual radiation of 4.74 kWh m^{-2} (CRESESB, 2018). The electric energy consumption was studied from July 2017 to July 2018, totaling 593 190 kWh, and a cost of R$ 257 804.88. There are eight silos of 4 500 tons each, four lung silos of 600 tons each, a bulk carrier with 10 000 tons, and four hoppers with 240 tons each, totaling 49 360 tons.

2.5 Dimensioning Grid-Tie Photovoltaic Systems

2.5.1 Peak Power of the Photovoltaic System

The kWp was calculated using Equation 1, the average daily consumption, and the average annual monthly radiation of the enterprise location, by sizing the power generated per day (Pinho & Galdino, 2014).

$$S_{wp} = (E/FSH) \tag{1}$$

Where, Swp: the photovoltaic system's peak power (Wp); E: the average annual daily consumption (kWh day^{-1}); FSH: Full Sun Hours annual average (kWh m^2 day^{-1}).

2.5.2 Generation of Electricity at the End of the System's Useful Life

The photovoltaic system was calculated to generate the amount of electric energy to the 25 years of useful life. The solution of Equation 1 was used and it was divided by the decrease of 20% of generation the system suffers at the end of the useful life, as demonstrated by Equation 2 (Pinho & Galdino, 2014).

$$E_{real} = (E/0.80) \tag{2}$$

2.5.3 Number of Photovoltaic Modules

The number of photovoltaic modules is the ratio between the photovoltaic system's power, the chosen photovoltaic module's power, and the photovoltaic system's real installed power, calculated using Equation 3 (Pinho & Galdino, 2014).

$$N_m = (E_{real}/P_m) \tag{3}$$

Where, N$_m$: the number of modules (dimensionless); E$_{real}$: the real average annual daily consumption (kWh day^{-1}); P$_m$: the module's power (W).

2.5.4 Maximum Number of Photovoltaic Modules by Inverter

Calculated using Equation 4, the maximum load of photovoltaic modules per inverter took into account a load range of 10% of the inverter's power (Pinho & Galdino, 2014).

$$M_{nm} = (P_{inv}/P_m) \tag{4}$$

Where, M_{nm}: the maximum number of modules (dimensionless); P_{inv}: the inverter's power (W); P_m: the module's power (W).

2.5.5 Maximum Number of Modules by MPPT and Mumber of Strings in Parallel

The maximum number of modules by Maximum Power Point Tracking (MPPT) was calculated using Equation 5. And the number of strings in parallel by MPPT input was calculated through Equation 6 (Pinho & Galdino, 2014).

$$(M_{vi}/M_v) \leq M_{nmmppt} \leq (M_{vmi}/M_v) \tag{5}$$

Where, Mvi: the inverter's minimum voltage (V); Mv: the module's voltage (V); Mvmi: the inverter's maximum voltage (V); M_{nmmppt}: the maximum number by MPPT (dimensionless).

$$N_{ps} = (I_{mi}/I_{mp}) \tag{6}$$

Where, N_{ps}: the number of pararell strings by MPPT (dimensionless); I_{mi}: the inverter's maximum current (A); I_{mp}: the operating current (A).

The components of the photovoltaic system available in the domestic market were used. A survey in the market was made, and it was opted for the photovoltaic module and the Canadian Solar® inverters, module model CS6U-330P, which costs R$689.00; inverter CSI-50k-KLT of 50 000 W of power, R$32 590.00; and CSI-30k-KLT of 30 000 W of power, R$22 590.00.

The Stringbox NeoSolar® was chosen for the protection part, Stringbox Pro 4 × 2 model, which has the following characteristics: support to four input strings, two outputs, IP65 frame, two 3P switch disconnector 25A 1000Vcc, two surge protectors PV SCI 1000 Vdc, and two surge protection systems (DPS) CC FV 1000V, costing R$1 700.00.

For fixation of the photovoltaic modules with 2 m, 0.99 m and 0.035 m height, width and length, respectively, soil structures were used. Due to the area the systems required for the installation, the cost of the structure was R$749.00, being possible to install up to four modules per structure.

Other costs of civil structure and grounding in the design of the photovoltaic system were disregarded, since the specialized companies did not respond to the budget requests in time.

3. Results and Discussion

The electric power consumption of the enterprises and Equations 1, 2 and 3 were used for the sizing of the installed power of the grid-tie photovoltaic systems, as shown in Table 1.

Table 1. Sizing of the photovoltaic systems' installed power

Enterprises	Electric Power Consumption	Equation 1	Equation 2	Equation 3
Aviaries	167 603 kWh	77.11 kWp day^{-1}	96.38 kWp day^{-1}	292 modules
Small Silo	40 045 kWh	23.66 kWp day^{-1}	29.58 kWp day^{-1}	92 modules
Medium Silo	145 802 kWh	84.20 kWp day^{-1}	105.25 kWp day^{-1}	318 modules
Large Silo	593 190 kWh	320.88 kWp day^{-1}	401.11 kWp day^{-1}	1 216 modules

The required photovoltaic systems' installed power was used. The costs of the equipment required for each system were verified. The equipment was surveyed in the domestic market, and the final cost of the enterprises was obtained and shown in Table 2.

Table 2. Cost of photovoltaic systems per enterprise

Equipment	Cost (R$)	Aviary (96.38 kW)	Small Silo (29.58 kW)	Medium Silo (105.25 kW)	Large Silo (401.11 kW)
CS6U-330P	689.00	292	92	318	1,216
CSI-50k-KLT	32 590.00	2	-	2	8
CSI-30k-KLT	22 590.00	-	1	-	-
StringBox	1 700.00	4	2	4	16
CC 10 mm² (m)	14.00	800	400	800	1 500
Ground fixing structure (unit)	749.00	73	23	80	304
	Total (R$)	*339 045.00*	*112 205.00*	*362 202.00*	*1 374 440.00*

The aviary complex consists of three aviaries, each with the capacity of 25 000 heads of chicken per batch, and it receives 5.5 batches per year, totaling 412 500 heads of chicken per year. During the study period, there were 515 550 heads of chicken, and the electric energy consumed was 167 603 kWh, with the cost of R$45 562.87.

The first index related the amount of energy per chicken head. The result was 0.325 kWh of energy consumed per head. The second index related the cost of the energy consumed per head of chicken and resulted in the cost of R$0.0885 per head. The third index related the cost of the annual photovoltaic system, which was R$13 651.80, being that in the same study period the cost of the system was R$17 042.25 for the amount of chicken heads per year, and the cost of R$0.033 per head was obtained.

In the small silo, in the study period, from June 2017 to July 2018, there were 1 696.026 tons of stored soybean, and 6 tons of corn. The quantity of grains of one variety was much higher than the other, thus the totality was considered to be only of soybean.

The cost of electricity consumed off-peak was R$17 388.86, the total energy was 40 045 kWh, and 1 702 026 tons of soybean were stored. It was obtained an index that related: the energy consumed by the quantity of stored grains, which was 23.53 kWh ton^{-1}; and the cost of energy consumed off-peak per tons of grain, totaling R$10 216.ton^{-1}. In addition, the annualized cost of the photovoltaic system was divided by the amount of stored grains, generating the index of R$2 637 ton^{-1}.

The average silo stored 949 157 tons of soybean and 1 430 780 tons of maize during the study period, from July 2017 to June 2018, totaling 2 379.94 tons of grains.

The cost to the electric energy consumed off-peak was R$61 275.65, and the total energy was 145 802 kWh. It was obtained an index that related: the energy consumed by the quantity of stored grains, which was 61.26 kWh ton^{-1}; and the cost of energy consumed off-peak per tons of grain, totaling R$25 746 ton^{-1}. In addition, the annualized cost of the photovoltaic system was divided by the amount of grains stored, generating the index of R$ 6 087 ton^{-1}.

The large silo for large sized-grains stored 31 081 tons of soybean, 23 991 262 tons of corn, and 4 130 382 tons of wheat, during the study period, from July 2017 to July 2018, totaling 59 202.64 tons of grains.

The cost to the electric energy consumed out of tip was of R$257 804.88, and the total energy was of 593 190 kWh. It was obtained an index that related: the energy consumed per ton of grain stored, which was 10.01 kWh ton^{-1}; and the cost of energy consumed off-peak per tons of grain, totaling R$4.35 ton^{-1}. In addition, the annualized cost of the photovoltaic system was divided by the number of grains stored, generating the index of R$1 006.ton^{-1}.

Through the indexes, it was verified that the photovoltaic systems helped to reduce the costs of production. It was observed that for the complex of three aviaries the costs of production in relation to electric energy went from R$0.0885 to R$0.033 per head of chicken. In the grain storage enterprises, it went from R$10.216 to R$2.637 per ton of grain stored for the small silo, from R$25.476 to R$6.087 in the medium silo, and from R$4.35 to R$1.006 in the large silo.

4. Conclusion

It was concluded that the reduction in cost of production is related to the rate charged by the electric energy consumed, since for the complex of three aviaries that has a rate of R$0.272, the reduction was of 62.71%, and for the grains storage enterprises that have rates of R$0,434, R$0,420 and R$0,434, reductions were of 75.79%, 76.35%, and 76.87%, for the small, medium and large silo storage enterprises, respectively.

It was also concluded that the reduction in cost of production has a linear relationship: the greater the sizing of the photovoltaic system, the greater the reduction in the cost of production, when the enterprises have the same electric energy rate.

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