DOI: 10.18605/2175-7275/cereus.v12n4p160-177

<< Recebido em: 30/11/2020 Aceito em: 13/12/2020. >>

ARTIGO ORIGINAL

REVISTA CEREUS

ISSN: 2175-7275

A preliminary study on energy consumption scheduling in scenarios with distributed generation

Um estudo preliminar sobre o escalonamento do consumo de energia em cenários com geração distribuída

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RESUMO

A multiplicidade de fontes de geração de energia, aliada à necessidade de uso de alternativas renováveis, aumenta o investimento em geração distribuída. Isso é particularmente verdade no Brasil devido às suas condições climáticas e econômicas. No entanto, para aproveitar ao máximo esse potencial, é necessário desenvolver soluções otimizadas que permitam definir as melhores estratégias de consumo, dadas as condições de geração de energia. Diante disso, este artigo apresenta os resultados iniciais de uma estratégia baseada em Bin-Packing para escalonamento de consumo de energia, levando em consideração diferentes fontes geradoras. Inicialmente é descrita uma proposta de modelagem do consumo de energia e do potencial de geração de energia a partir de fontes fotovoltaicas e de biomassa. Em seguida, através de um estudo de caso os resultados preliminares da proposta são discutidos.

Palavras-chave: Geração Distribuída, Fotovoltaica, Biomassa, Bin-Packing.

ABSTRACT

The multiplicity of sources of energy generation, along with the need to use renewable alternatives, increases investment in distributed generation. This is particularly true in Brazil due to its climatic and economic conditions. However, to take full advantage of this potential, it is necessary to develop optimized solutions that allow the setting of the best consumption strategies, given the conditions of energy generation. Therefore, this paper presents the initial results of a Bin-Packing based strategy for scheduling energy consumption, taking into account different generating sources. Initially, a proposal for modeling energy consumption and the potential for energy generation from photovoltaic and biomass sources is described. Then, through a case study, the preliminary results of the solution are discussed.

Keywords: Geração Distribuída, Fotovoltaica, Biomassa, Bin-Packing.

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1. INTRODUÇÃO

The current global energy matrix has fossil fuels as the main source of energy, which represents limited sources and drives harmful impacts on the environment due to their high emission of CO2 and other Greenhouse Gases (GHG). The scarcity of oil and other fossil sources increases the development of technologies to produce clean energy from sources with less impact on the environment, such as using biomass, solar, nuclear, wind, geothermal, hydroelectric, hydrogen, and others (GRADELLA and GAZOLI, 2012; GAZOLI and VILLALVA, 2012). With this variety of possible energy sources, each with its particularities, it is possible to develop structured hybrid models that will supply or complement seasonal conditions and limitations of the different sources (GABBAR, 2009). Hybrid systems represent an important form for producing renewable energies, combining several primary sources and considering the specific conditions of each one (DOS REIS, 2000).

Regarding the diversity of generation sources, the Brazilian energy matrix structure has a wide plurality, established with important participation of sustainable energies. The energy produced in hydroelectric plants is still its largest renewable source, with an internal supply of around 35% in 2014. In addition to this category, solar photovoltaic energy, obtained through the direct conversion of light into electricity through the photovoltaic effect (DOS REIS, 2000), currently has the greatest economic viability in facilities for small and medium-sized consumer units. Also, bioenergy surpasses hydroelectric energy when adding all the capacities installed from biomass (solid, liquid, and gaseous biofuels) provided by several agricultural and industrial sectors in Brazil. This condition is being directly related to the country's economic base (DE ARAGÃO PEDROSO et al., 2018).

In addition to the diversity of energy sources, Brazil has an above-average potential for exploring and producing electric energy from photovoltaic sources and using biomass. The country has excellent solar radiation availability, which is almost double that available in European countries (GRADELLA and GAZOLI, 2012). Besides, due to its territorial extension, agricultural diversity, ecosystems, and favorable climatic conditions, different types of raw material are available for the generation and co-generation of electric energy using biomass (ARAÚJO, 2016). The joint exploitation of this potential is a great demand response strategy.

Given the potential of power generation taking different sources, it is necessary to develop strategies that can optimize the consumption schedule to exploit the energy generated by the clean sources, thus minimizing the energy consumption from the utility. The first step in developing a strategy with this goal is to model the scenario so that computational tools can be used to obtain the necessary solution. Computer systems for physical structures simulation are critical to study and correctly dimension an electrical structure (LÉVESQUE et al., 2012; TAYLOR et al., 2011). These platforms allow the elaboration of more precise structures and help support decision-making in preparation, planning, and formulation (XU et al., 2016). Intelligent technologies can have significant strategic value due to their inherent flexibility when dealing with different evolutionary trajectories of the system (KONSTANTELOS et al., 2016; NASIRI et al., 2017).

This paper presents a proposal for modeling electricity consumption and energy generation potential in light of what was discussed, considering a distributed generation scenario with photovoltaic and biomass-based potential. This modeling is the initial step in constructing a solution that aims to scale electricity consumption to minimize its cost. The rest of the paper is organized as follows: Section 2. presents the proposed modeling, while Section 3. describes a case study of its application; Section 4. presents a discussion based on the case study; finally, Section 5. describes the final remarks.

2. PROPOSED MODELING

In the proposed modeling of energy consumption and generation, rural properties with photovoltaic and biomass production plants are considered the scenario. The modeling also considers that the equipment usage schedule is performed weekly; the hour is used as the allocation unit. The adoption of these assumptions is because, in this period, the scenario’s primary electrical needs are expected to be represented, leaving only sporadic cases that will be ignored.

The proposed modeling is based on results already consolidated on Distributed Generation (DG) and energy consumption (RUZBAHANI et al., 2019; TANG et al., 2013; CARON and KESIDIS, 2010; GAZOLI and VILLALVA, 2012; MITO et al., 2018). The representation of the energy generation potential is treated independently for the photovoltaic and from biomass categories. Consumption modeling, in turn, takes into account the specifics of potential equipment. Particularities of the scenario, such as seasonality, energy availability, the start time of production, and equipment management, are considered in the model. Based on these results, it is proposed the modeling of target scenario as a Bin-Packing problem for solving the scheduling of electricity consumption. The components of the modeling are presented below.

2.1 Electricity consumption modeling

The problem here treated consists of scheduling a set of equipment usage taking into account the estimated electricity consumption for each of them and the consumption time duration. Based on previously proposed models (RUZBAHANI et al., 2019; TANG et al., 2013; CARON and KESIDIS, 2010), the set of equipment is denoted by $E = \{e_1, \ldots, e_n\}$, where n is the number of equipment. Each equipment is categorized in one of two types, according to its load:

- **Priority loads:** whose usage time duration must respect a predetermined time interval. It is assumed that it is not possible to schedule these loads out of the established range.
- **Schedulable loads:** whose electricity consumption can be shifted to a different time interval to benefit from periods of higher energy generation by own sources.

Although the proposed modeling uses periods represented by hours as the allocation unit, it is unlikely that the equipment will operate for periods equivalent to exact hours. Thus, let $T = \{t_0, \ldots, t_{23}\}$ be the time periods in which the equipment can be allocated for operation. Each $t_i \in T, 0 \leq i \leq 23$ is equal to one hour and has 60 time units available for scheduling, equal to minutes, ranging from i:00 to i:59.

As an assumption the energy demand is previously known. Thus, each equipment $e_j, 1 \leq j \leq n$ has an electricity demand profile d_j represented by a tuple $d_j = (\omega_j, \tau_j, hm_{\text{initial}_j}, hm_{\text{end}_j})$, where ω_j represents the nominal power of the equipment in W (extracted from the plate or manufacturer's manual); τ_j is the duration of equipment usage, measured in minutes (the allocation is made considering as maximum the consumption of one full day, being $1 \leq \tau \leq 1,440\ (24 \times 60)$; $hm_{\text{start}_j} = \{x \mid 0{:}00 \leq x \leq 23{:}59\}$ is a set of minimum time at which the equipment usage must get started, while $hm_{\text{end}_j} = \{x \mid 0{:}00 \leq x \leq 23{:}59\}$ is a set maximum times when the usage must be ended. By definition $|hm_{\text{start}}| = |hm_{\text{end}}|$, that is, the sets are equipotent with an injector function f with domain hm_{start} and contra-domain hm_{end}. For instance, with $hm_{\text{start}_j} = \{05{:}00, 09{:}30\}$ and $hm_{\text{end}_j} = \{14{:}00, 17{:}30\}$, $f(05{:}00) = 14{:}00$ and

$f(09\colon\ 30) = 17{:}30$ meaning that the usage of the e_j equipment should start from 5 am and end by 2 pm and again start from 9:30 am and end by 5:30 pm. As constraints,

$\forall x \in hm_{\text{start}_j} \rightarrow x \leq f(x) - \tau_j$ and, if e_j has schedulable load then $hm_{\text{start}_j} = \{0{:}00\}$, $hm_{\text{end}_j} = \{23{:}59\}$.

From the nominal power of equipment (ω_j) and the time duration of its usage (τ_j), it is possible to calculate its electrical energy consumption (c_j, in kWh), according to Equation 1.

$$c_j = \frac{\omega_j \times \max(\frac{\tau_j}{60}, 1)}{1000} \tag{1}$$

Conceptually, the objective of scheduling electricity consumption is to minimize an objective function that measures the total cost of using the equipment, subject to the operational restrictions of the types of equipment and energy generation capacity. Assuming that renewable energy sources can provide λ_h KWh in a given hour $h, 0 \leq h \leq 23$, the utility energy request is given by $min(0, \Lambda_h - \lambda_h)$, with Λ_h being the total consumption at this time (in KWh). Similar to most related works, it is assumed that the concessionaire provides price information. Based on this, if p_h is the price of electricity contracted at the time of consumption, then the total electricity cost for each day is given by Equation 2.

$$\sum_{h=0}^{23} min(0, \Lambda_h - \lambda_h) \times p_h \tag{2}$$

2.2 Potential energy modeling

Potential energy modeling considers sources of photovoltaic and biomass-based energy. In both cases, the modeling is performed based on results already consolidated in the literature, with the necessary adaptations. In photovoltaic energy generation, the granularity of data on solar radiation (necessary to obtain the potential estimate) is given per hour. On the other hand, the generation of biomass is treated, taking into account larger intervals, usually per day. Thus, although energy consumption modeling considers the allocation of intervals based on minutes, it is assumed, without loss of generality, that the modeling of potential energy considers hourly intervals, with the estimated value being kept constant for a given hour.

For the generation of biomass, the material originated from swine and dairy cattle manure is considered. To measure the biogas production coefficient and the consequent energy transformation to electric energy, it is necessary to have the number of animals present on the property and the management method. In swine farming, it is also necessary for the animals to be classified according to their period or classification in the herd.

The estimate for effluent production is based on the results of GAZOLI and VILLALVA (2012). Table 1 presents the results, taking into account the estimated effluent production per day (L, given in liters for each animal per day), the amount of matter in Volatile Solid (VS, given in grams per L), and methane production (B_0, given in cubic meter of CH_4 per kilogram of VS).

Table 1. Estimate for effluent production.

Farming	**Category**	$L_{\text{animal}}/\text{day}$	$VS(\text{g}/L)$	$B_0(\text{m}^3_{\text{CH}_4}/\text{kg}_{VS})$
Swine	Maternity (matrix female and piglets)	27.00	35.38	0.45
	Piglet nursery	1.40		
	Matrix (female)	16.00		
	Matrix (male)	9.00		
	Growth and termination	7.00		
Cattle	Dairy	2.60	50.54	0.4

Source: (GAZOLI and VILLALVA, 2012).

From the presented parameters, the biogas production is determined considering the amount of effluent available for each category of animal, based on the results of MITO et al. (2018).

The Equation 3 provides the daily production of biogas (DPB), given in m^3/day, considering a certain category of animal in Table 1. In this equation a is the number of animals in the category; AW is the average weight (kg); SW is the standard weight (kg); DCF is a daily confinement fraction (between 0 and 1); VS is volatile solids (kg per animal per year); MCF is the methane conversion factor for the system's baseline (*Biodigestor de Lagoa Coberta*); B_0 is the methane production capacity by manure ($\text{m}^3_{\text{CH}_4}$ per kg_{VS}); F_b is the uncertainty correction factor and CH_4 is the percentage of methane in biogas.

$$DPB = a\frac{AW}{SW} \times DCF \times VS \times \left(\frac{MCF \times B_0 \times F_b}{CH_4}\right) \tag{3}$$

According to PECORA (2006), it is possible to convert the chemical energy of biogas molecules into mechanical energy and, in turn, into electrical energy through transformation into controlled combustion. The most used methods for this type of conversion are those used in turbines and internal combustion engines, both by gas. In this work, it is used internal combustion engines, more specifically, the Otto Cycle engines that are characterized by performing internal burning of the mixture of steam and fuel inside a cylinder (CORRÊA, 2003). The Equation 4 shows the total yield (η) of an Otto Cycle Engine (OCE) using biogas as fuel, where ζ is the specific consumption (given in g/kWh) and LCV is the lower calorific value of the fuel (given in MJ/kg). The total performance of an internal combustion engine varies from 20 to 30% (DALBEM, 2018).

$$\eta = \frac{3600}{\zeta \times LCV} \tag{4}$$

Regarding the photovoltaic generation potential, a Photovoltaic System (PS) is composed of a set of equipment necessary for the absorption of solar irradiation and its transformation into electrical energy. An important part of this process is conversion, transmission, distribution, protection systems, and connections. According to LIU et al. (2014), a PS can be in an on-grid model, connected to the distribution network of the local electricity utility or off-grid, isolated. Table 2 describes the main equipment used in the installation of a residential low voltage PS.

Table 2. Main equipment used in a Photovoltaic System.

Equipment	Description
Photovoltaic panels	Formed by a set of photovoltaic cells, which varies according to the model, electrically interconnected and encapsulated. It aims to capture and transform solar radiation into electrical energy.
Inverters	It has the function of inverting the energy generated in the photovoltaic panels from Direct Current (DC) to Alternating Current (AC). It also performs PS measurement and safety functions.
Cabling	There are two types of cabling used in a PS: the DC cables that connect the modules to the inverter and the AC cables that connect the inverter to the receiving network. Any dimensioning of cable size and gauge will depend directly on the dimensioning of the project.
Main switch	This switch is important in case of network failures or for repair and maintenance of PS equipment. One of its functions is to isolate the inverters of the photovoltaic modules.

Circuit breakers	They are devices used to protect the entire PS against network surges, overload, and others.

Source: (LIU et al., 2014).

There are two types of solar radiation that affect the Earth's atmosphere:

i) the irradiance that hits a horizontal surface is called global irradiance in the horizontal plane (G) composed of direct (G_b) and diffuse irradiance (G_d);

ii) irradiance on an inclined surface in any direction is the reflection caused by vegetation, terrain, construction and other surfaces that may cause some alteration (PEREIRA et al., 2017).

Another factor of great importance to determine the amount of energy produced by a PS is to estimate the number of Hours of Full Sun (HFS) that the modules will be exposed to solar radiation. The HFS estimate is the time interval, in hours throughout the day, that hypothetical solar irradiation remains constant at 1,000 W/m^2 considering that the total energy over the day is equivalent to that provided by the Sun in that given local (PINHO and GALDINO, 2014).

The amount of electrical energy available at the PS output is determined by dimensioning the number of photovoltaic modules and inverters, together with the available irradiance. It is necessary to consider the variations that the photovoltaic modules may undergo in their performance depending on variations such as temperature and shading, nominal power factor (AC), and the generator's peak power. The Equation 5 describes the calculation of the nominal peak potential of the photovoltaic module (P_{FV}), expressed in Watt Peak (Wp), where E is the daily consumption annual building average (Wh/day); TD is the performance fee, and HFS is the daily average of the HFS incurred in the photovoltaic module plan.

$$P_{\mathrm{FV}} = \frac{\left(\frac{E}{TD}\right)}{HFS} \quad (5)$$

In the modeling, it is also necessary to consider the relationships between the powers that result in the Inverse Dimensioning Factor (IDF). IDF values should be between 0.75 and 0.85, depending on what is described in the inverter manufacturer's manual. The Equation 6 gives the value of this variable, where P_N is nominal power in alternating current of the inverter (in W), and P_P is the peak power of the photovoltaic panel (in Wp).

$$\text{IDF} = \frac{P_N}{P_P} \tag{6}$$

Other factors, such as cable resistance, switching, and the system's technical losses, will not be considered in the proposed modeling.

2.3 Electricity consumption scheduling as a Bin-Packing problem

The problem of electricity consumption scheduling given the potential energy generation for each hour can be seen as a Bin-Packing variation. Bin-Packing is a $\mathcal{NP}$-Hard optimization problem defined as follows (GAREY and JOHNSON, 1979): Given a finite set I of numbers (the item sizes) and one constant B (the bin size), what is the best packing, i.e. how many bins are necessary to pack all the objects (what is the minimum number of subsets in a partition of I into N or less subsets), such that the sum of elements in any of the subsets doesn't exceed B?

In this paper, the aim is to assign equipments to a time period, i.e., decide at what time the energy consumption will take place. The planning horizon is made by hours (= bins). The goal is to assign equipments to hours. Ideally, the equipment's electricity consumption (= item size) should be less than or equal to the energy generation potential of the hour (= bin capacity) for which it was scheduled. This must be done in order to avoid using the utility's. An example is given by Fig. Figura **1**, where the assignment of equipments to hours is considered. Table 3 summarizes analogies between Bin-Packing and the current problem.

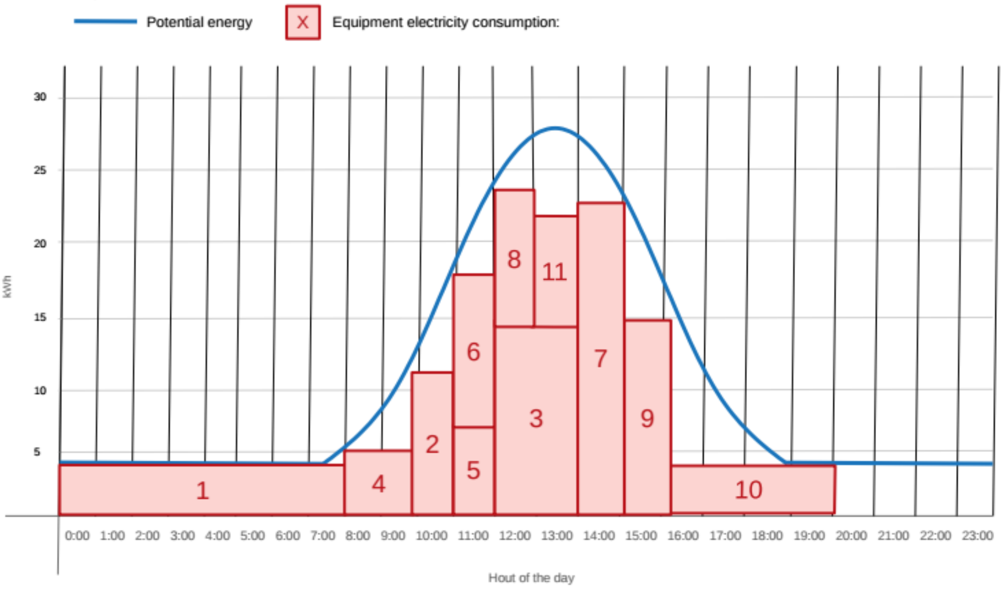

Figura 1. Representation of equipment scheduling problem as Bin-Packing.

Table 3. Analogies between Bin-Packing and equipment scheduling problem.

	Bin Packing Problem	**Equipment Scheduling Problem**
Data	Item	Equipment
	Bin	Hour
	Size of an item	Electricity consumption of equipment
	Capacity of a bin	Potential energy generation of hour
Problem	Assign items to a bin	Assign equipments to one or more hours
Constraints	Capacity of bins	Duration of equipment usage cannot be splitted
		Electricity consumption can be higher than potential energy generation
Criteria	Minimize the number of used bins	Minimize usage higher than potential generation

Source: (GAZOLI and VILLALVA, 2012).

The modeling proposed differs from the classic Bin-Packing problem because, since the number of hours is fixed, the reduction in the number of bins is not considered as an objective. Another difference is related to the scheduling constraint of an item whose size is greater than the capacity of the bin. In the modeled scenario this restriction does not exist, although it should be avoided as it represents consumption by the utility. Thus, solutions already consolidated in the literature can be used to solve the problem considered.

Because it is a highly complex problem, there is no strategy that always finds an exact solution in polynomial time. Thus, the most adopted proposal is the use of heuristic strategies, among which can be mentioned (CHOWDHURY et al., 2015):

- **First Fit (FF):** FF starts with the most active bin and tries to pack every item in it before going into the next bin. If no suitable bin is found for the item, then the next bin is selected to put in the new bin.
- **First Fit Decreasing (FFD):** In FFD the items are sorted in non-increasing order and then items are processed as the First Fit algorithm. It is actually the First Fit algorithm with the items are decreasingly sorted.
- **Best Fit Decreasing (BFD):** Like FFD, BFD also sorts items in non-increasing order. It then chooses a bin such that minimum empty space will be left after the item is packed.

- **Worst Fit Decreasing (WFD):** It works exactly same as BFD except that instead of choosing bin with minimum empty space it chooses bin with maximum empty space to be left after the allocation of the item in that bin.
- **Second Worst Fit Decreasing (SWFD):** Same as worst fit, it just choose bin with second minimum empty space. It is also known as Almost Worst Fit Decreasing (AWFD).

3. MODELING USAGE CASE STUDY

To demonstrate the proposed modeling usage, a case study was carried out on a rural property located near the city of Uruaçu – Goiás, Brazil. The selection of this property was carried out using sampling for convenience. It has generation potential through the considered sources since it labors with swine and dairy cattle breeding. The results of this case study are described following.

3.1 Energy consumption

The selected property modeling was carried out, taking into account a time period of 10 days, between September 14th, 2020, and September 23th, 2020. In the analysis of energy consumption, only the electric park's functional structure necessary for the operation of production activities was considered.

Due to space limitations, only the results related to a single day will be discussed, selected randomly from the analyzed working days. Table 4 presents the energy consumption model for September 16th, 2020, in which n = 16 equipment was modeled, of which 10 was used on this day.

Table 4. Estimate for effluent production.

ID	Description	Load	ω	τ	hm_{start}	hm_{end}	c
e_1	Milk tank 01	Priority	1,864.25	1,440	$\{0{:}00\}$	$\{23{:}59\}$	1.86
e_2	Milk tank 02	Priority	1,491.4	0	$\varnothing$	$\varnothing$	0.00
e_3	Water pump G-02	Schedulable	1,103.25	210	$\{0{:}00\}$	$\{23{:}59\}$	1.10
e_4	Water pump G-03	Schedulable	2,206.5	0	$\varnothing$	$\varnothing$	0.00
e_5	Water pump G-04	Schedulable	1,471	0	$\varnothing$	$\varnothing$	0.00
e_6	Water pump G-05	Schedulable	1,471	195	$\{0{:}00\}$	$\{23{:}59\}$	3.52

e_7	Water pump ORD-01	Priority	735.5	10	$\{08{:}15, 08{:}20\}$	$\{16{:}10, 16{:}15\}$	0.31
e_8	Water pump ORD-02	Priority	735.5	33	$\{08{:}15, 08{:}30\}$	$\{16{:}00, 16{:}30\}$	0.18
e_9	Water pump COR	Schedulable	1,471	505	$\{0{:}00\}$	$\{23{:}59\}$	3.52
e_{10}	Compressor 01	Schedulable	1,471	0	$\varnothing$	$\varnothing$	0.00
e_{11}	Compressor 02	Schedulable	1,471	0	$\varnothing$	$\varnothing$	0.00
e_{12}	Boiler	Priority	3,000	335	$\{05{:}00, 08{:}30\}$	$\{14{:}00, 16{:}00\}$	3.00
e_{13}	Milking 01	Priority	2,206.5	335	$\{05{:}00, 08{:}30\}$	$\{14{:}00, 16{:}00\}$	2.21
e_{14}	Crusher	Schedulable	7,354.99	395	$\{0{:}00\}$	$\{23{:}59\}$	12.27
e_{15}	Silo 01	Schedulable	2,206.5	395	$\{0{:}00\}$	$\{23{:}59\}$	3.93
e_{16}	Silo 02	Schedulable	2,206.5	0	$\varnothing$	$\varnothing$	0.00

The values of ω were obtained by consulting the equipment manuals, while to establish τ, hm_{start}, and hm_{end} data was collect by interview with employees of the property. The value of c is calculated using the Equation 1.

3.2 Available energy potential

The application of the energy potential model based on biomass took into account the number of animals on the property on the date discussed (September 16th, 2020). The total amount of effluents, calculated according to the indicators presented in Table 1, is shown in Table 5. The data on energy potential itself will be discussed in the next section.

Table 5. Total production of effluents in the case study.

Farming	**Category**	a	L/day	$VS(\text{g})$	$B_0(\text{m}^3_{\text{CH}_4})$
Swine	Maternity (matrix female and piglets)	8	216.0	7,642.08	3.44
	Piglet nursery	90	126.0	4,457.88	2.01
	Matrix (female)	40	640.0	22,643.20	10.19
	Matrix (male)	2	18.0	636.84	0.29
	Growth and termination	268	1,876.0	66,372.88	29.87
Cattle	Dairy	82	213.28	10,779.27	4.31
Total			3,089.28	112,532.15	50.10

Regarding photovoltaic generation, the irradiance and temperature data used for the PS's energy quantification are from a meteorological station provided by National Institute of Meteorology (INMET) (2019), located in the city of Porangatu – Goiás, Brazil, close to the property. As at the time of writing this work, no data were available for September 16th, 2020; this way, the data for September 16th, 2019, were used. This analysis strategy is acceptable since the data in this category are subject to seasonality and have a similar pattern given by the year period (GRADELLA and GAZOLI, 2012). The results of the potential energy will be discussed in the next section.

4. DISCUSSION OF RESULTS

When applying the proposed modeling in the case study, it was possible to generate data on energy consumption and potential for the considered period. Figure **2** shows the values for the analyzed day. It is worth mentioning that consumption took into account the period in which the equipment was used, which occurred without any auxiliary scheduling mechanism. Also, the calculation of energy from biomass is performed per day, with the gotten value divided equally between the hours.

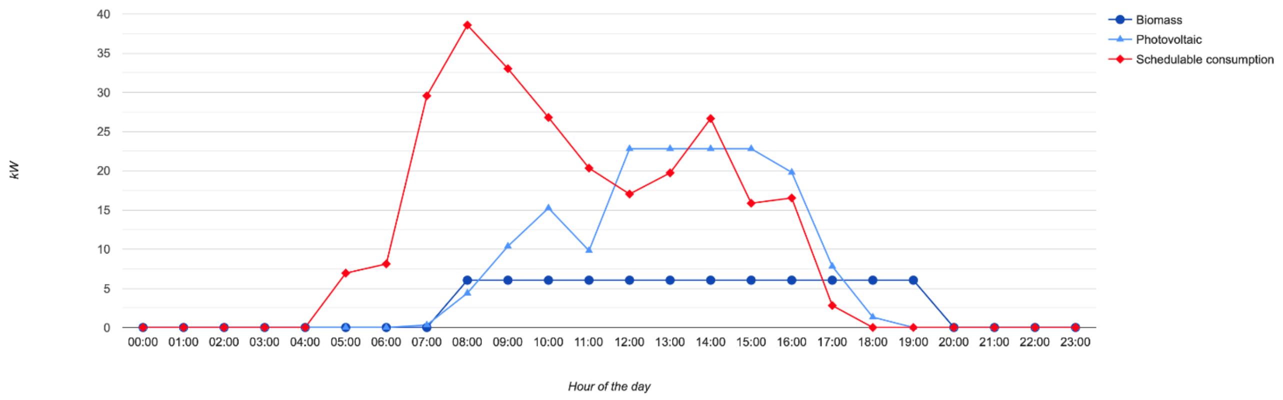

Figure 2. Comparison of consumption and potential energy on September 16th, 2020**.**

As shown in Fig. **2**, the absence of an optimization strategy means that the potential energy is not used properly, since a large part of the consumption load is carried out off of periods of the higher generation. This behavior suggests that a scheduling solution can minimize or at least considerably reduce the utility amount of energy consumed. To solve this problem, different heuristics related to Bin-Packing (COFFMAN JR et al., 1996) are currently being studied.

As a first attempt in the construction of an optimized solution for the consumption schedule, a simplification of the problem was carried out. More precisely, it was considered only the scheduling of schedulable equipment and without necessarily considering continuous periods of use, that is, the scaling was carried out independently for each hour, considering the equipment usage profile.

Since the energy from biogas can be arranged, as long as the number of hours and production per hour is not exceeded, this parameter was used to set the capacity of the bins, together with photovoltaic production. In this way, the definition of the hours when biomass generation will be used is established as a result of the heuristic itself.

Regarding the solution found, due to the use of energy from the concessionaire in the treated scenario, scaling is possible even if the capacity of the bins is not sufficient given the consumption. Thus, the following adaptations in the heuristics were considered:

- First Fit (FF): the first hour in which the production (photovoltaic plus by biomass) is sufficient for the operation of the equipment is used. If there is none, the first hour of unused production is supplemented with energy from the utility.
- First Fit Decreasing (FFD): the items are sorted in non-increasing order and then items are processed as the First Fit algorithm.
- Best Fit Decreasing (BFD): the hour when production (photovoltaic plus by biomass) is sufficient for the equipment to function and is closer to demand is used. If there is none, the hour when the remaining production is closest to demand is supplemented with energy from the utility.
- Worst Fit Decreasing (WFD): the time when production (photovoltaic plus by biomass) is sufficient for the operation of the equipment and the further away from demand is used. If there is none, the time when the remaining production is most distant from demand is supplemented with energy from the utility.
- Second Worst Fit Decreasing (SWFD): same as WFD but choose the second hour that meets the criteria.

The results of heuristics in the case study are presented in Figures **3** to **7** in comparison to manual scheduling.

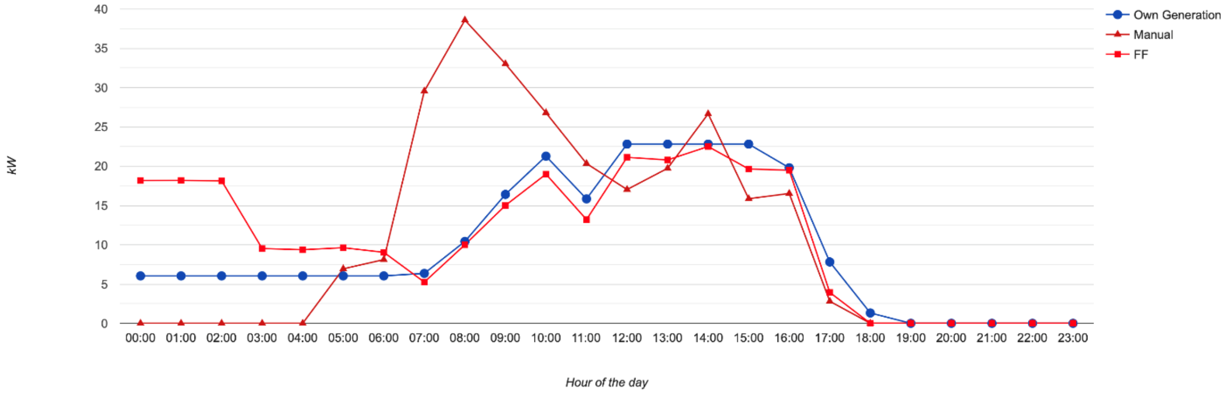

Figure 3: Consumption scheduling using the FF heuristic.

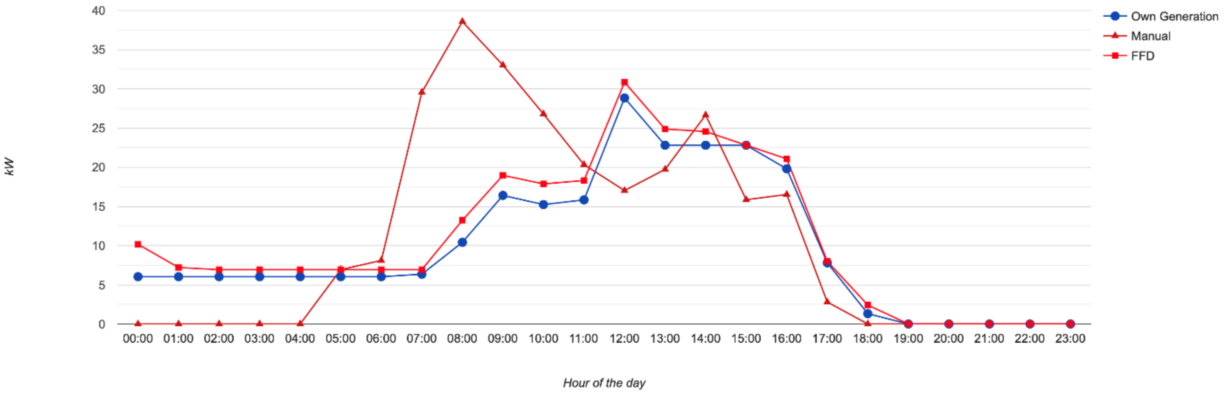

Figure 4: Consumption scheduling using the FFD heuristic.

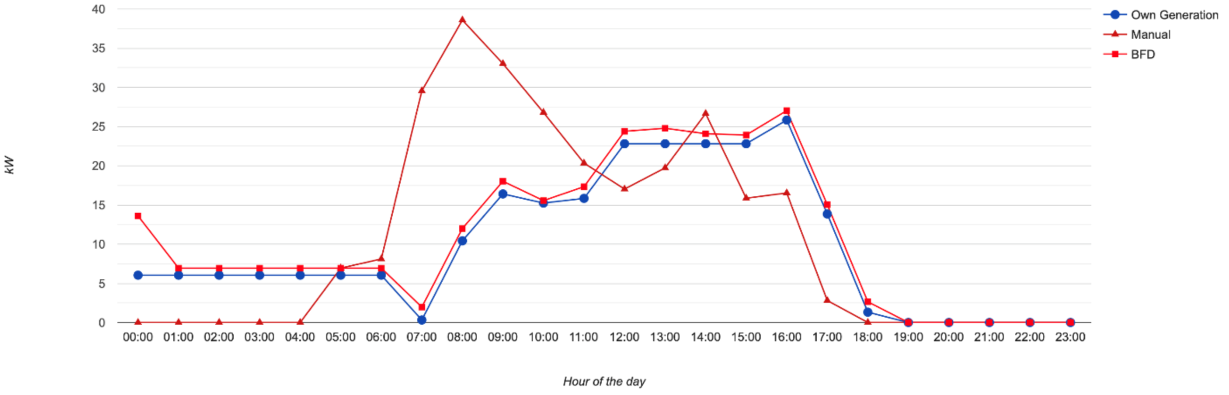

Figure 5: Consumption scheduling using the BFD heuristic.

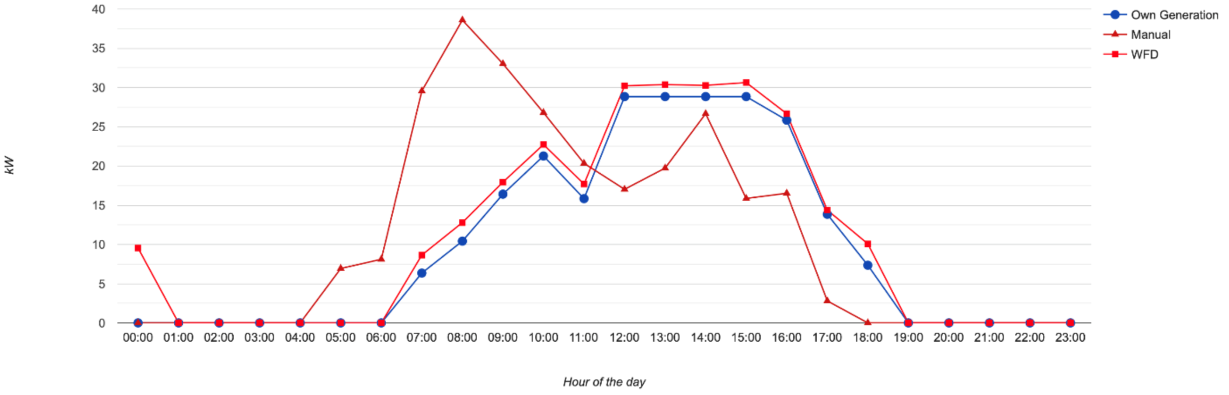

Figure 7: Consumption scheduling using the WFD heuristic.

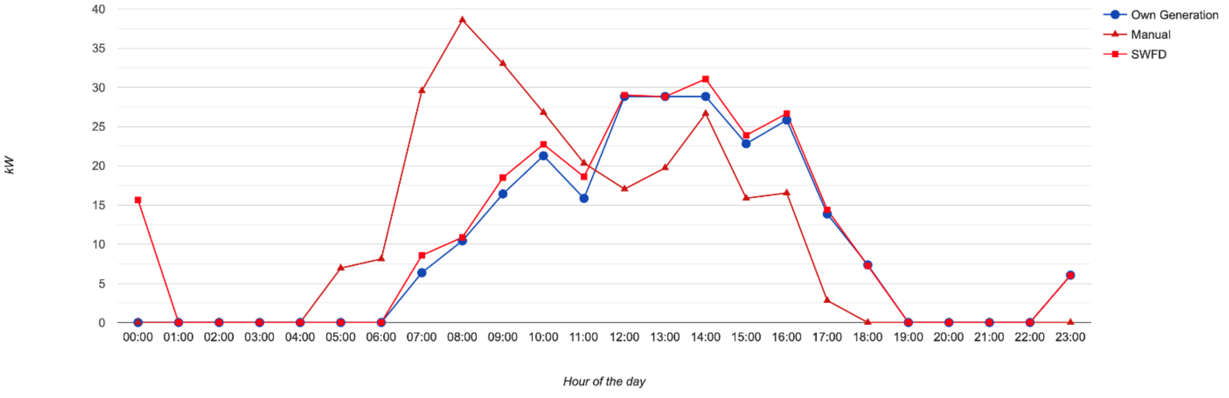

Figure 6: Consumption scheduling using the SWFD heuristic.

The variable amount of energy production is due to the scheduling of hours of use of biomass production. With the exception of the FF heuristic, the others managed to exploit the generation potential well, and the WFD and SWFD heuristics had the additional advantage of concentrating the scheduling in a period. To assist in the interpretation of the results, Table 6 presents the total consumption measured in each heuristic.

Table 6. Total of energy consumption per heuristic.

Heuristic	Total energy consumed by the utility (KWh)	Energy produced and not used (KWh)
FF	49.7795	20.5181
FFD	29.2614	0.0
BFD	29.2614	0.0
WFD	29.2614	0.0
SWFD	29.4241	0.1627

5. FINAL REMARKS

This paper proposed an approach to model potential energy and energy consumption considering photovoltaic and biomass-based generation. In addition to the proposed modeling, a case study of its application on a property was presented, as well as a discussion of the results obtained.

The proposal presented here constitutes a first step in developing a solution that will use energy consumption schedule to explore the potential of own generation and reduce the amount of energy consumed from the utility. As a next step, adjustments to the proposed model (e.g., the representation of dependence between equipment that must be used together) need to be carried out to implement the scheduling process. As future work, it is proposed the application of modeling in an optimization strategy and the improvement of preliminary results.

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