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Feasibility study of the deployment of photovoltaic energy at the Hospital Senhora Aparecida, in the city of Luz - MG

Elaine Gonçalves da Costa
elainesigas@gmail.com
Gabriella Caetano Ferreira
gabriellacaetano.eng0305@gmail.com
Jorge Luís Ferreira
jorrgilluis@hotmail.com
Franciane Cristina Rodrigues Carvalho
Centro Universitário UNA de Bom Despacho - Rodovia BR-262, Km 480, s/n - Zona Rural, Bom Despacho - MG, 35600-000
franciane.carvalho@prof.una,br

Abstract. *The scarcity of energy resources has encouraged research and implementation of new ways of obtaining clean and renewable energy. As a result, significant diversification was observed in the Brazilian energy matrix, decreased dependence on the water system and minimized environmental damage. Brazil has a privileged condition, as it has a large solar incidence and a vast territorial extension, making it an excelled country in harvesting energy from the sunlight. Within this context, the case study for implementation of a photovoltaic power plant was carried out in a philanthropic hospital located in the city of Luz - MG. Thus, this work has as its main objective to report the viability, optimization, and the logistics from the system's implementation. The adopted methodology consisted initially of data survey on the hospital's electric power consumption and the solar incidence in the region. Next, the model already installed was evaluated regarding its sizing and the number of installed plates (solar panels). Finally, a payback analysis was performed to assess the practicability of implementing the photovoltaic system. The relevance of the study consists in identifying financial benefits, mainly after the payback period; besides the evident reduction of the socio-environmental impact. It is expected, at the end of this study, to verify if the implementation of a photovoltaic system is feasible in hospital units, in order that the same procedure can possibly be replicated in other units in the region. Thus, it is concluded that the photovoltaic system acquired by Hospital Senhora Aparecida presented a Payback of 35 months, that is, after 2 years and 11 months the energy generated by the solar incidence covered the investments made. In addition to the financial benefits, there were also benefits related to the cancellation of the environmental impact, as well as diversification of the Brazilian energy matrix.*

Keywords: *Payback; Photovoltaic; Renewable energy; Solar incidence, Hospital economics*

1. INTRODUCTION

According to Tolmasquim (2012), the main national energy source in Brazil relies on hydropower plants. As stated by Bronzatti and Iarozinski Neto (2008), 75 % of Brazil's electric power production comes from hydropower plants, which still have a growth potential. de Minas e Energia and de Pesquisa Energética (2005) states that the hydric potential is concentrated in the southeast area of the country, and for de Minas e Energia *et al.* (2007), the higher growth potential of this sector is located on the north area of the country.

Urbanetz Junior (2010), highlights that regardless of the low cost of energy generation on hydropower plants, there are vast environmental impacts related to their construction and due to the creation of sizable water reservoirs. Legal, environmental and geographic restraints have guided the construction of large hydroelectric powerplants, limiting the production and client service. As a restrain example there are auctions of 'run-of-river type hydropower[1] for Madeira river. Alves (2009) supplements that the electric matrix diversification is essential in order to guarantee the energy supply, on account of the sector weakness on the dry season.

Tiepolo *et al.* (2012) highlights as the main energy power sources hydroelectric , nuclear, thermoelectric, Eolic and photovoltaic. de Minas e Energia and de Pesquisa Energética (2005) stresses other electric sources and their share of Brazil's electric matrix, as seen in Figure 1.

[1] Run-of-river type hydropower – Hydroeletric Generation plant whereby little or no water storage is provided, used for daily or weekly regularization, or which uses directly the river flow utilization.

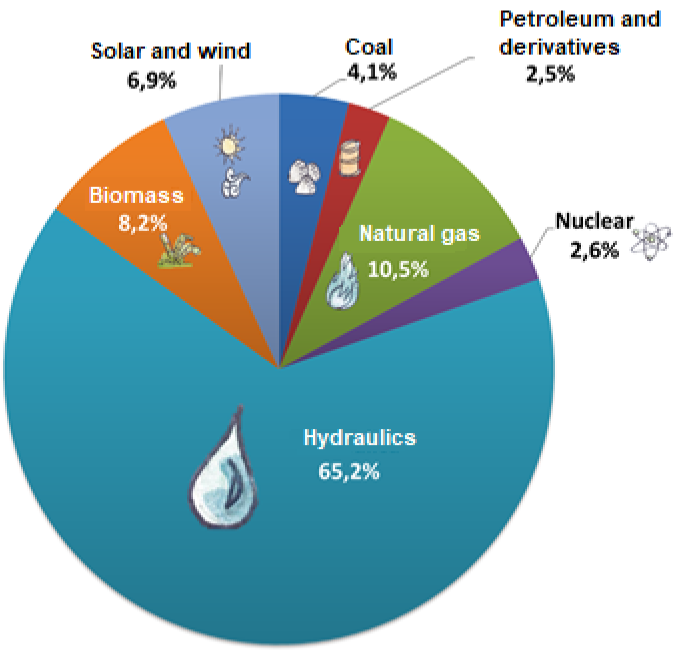

Figure 1. Brazil’s electric matrix distribution

Goldemberg and Moreira (2005) emphasize that to ensure economical growth and improve people life conditions, other types of energy sources should be pursued, ensuring a safe supply. Tiepolo *et al.* (2012) also states that renewable energy sources with low environmental impact have been increasingly sought-after, Eolic and photovoltaic on a strong position, stated for the high investments and growth expectations for the next few years.

Rella (2017) underlines that the country’s electric matrix is approximately 132GW, of which just 0.0008 % is generated through photovoltaic system. According to NASCIMENTO (2018), any type of solar energy capture is designated as solar power, on the other side, Marques *et al.* (2009) states that photovoltaic modules do not use heat on the energy production, but the temperature affects the electric power production efficiency.

According to de Referência para as Energias Solar e Eólica de Sérgio de S. Brito (2008), the solar incidence on Earth is 10 thousand times the global energy consumption. For that matter, Brazil has a privileged position, relatively close to the Equator line, with not much irradiation variation during the day. This way, if all the solar potential is used, there is an estimated production of 283.5 MW and that would be capable to supply twice the current consumption, considering the complete country’s electric matrix (de Pesquisa Energética (2018) apud Rella (2017)).

Marques *et al.* (2009) and Boso *et al.* (2015) highlight two types of installation for the photovoltaic system, On Grid and Off Grid. On the On Grid system, the photovoltaic module generates electric power during the day and the excess is injected on the utility grid for big companies, which are converted into credits that can be used in the future. This system stands out for not using batteries, making its installation more economical; the disadvantage is that it cannot store energy during the night. The Off Grid system is characterized by the necessity of batteries, on which the generated energy is stored and distributed for consumption. This kind of system is indicated to places where utility grid connections are forbidden, hard access places or places that do not have electric nets. The disadvantage is the high cost of installation compared to the On Grid System.

Considering the situation aforesaid, the philanthropic institution ‘Hospital Senhora Aparecida’, at the city LUZ-MG, investigates the implementation of the photovoltaic solar system pursuing environmental and economical awareness. The institution believes that sources of renewable energies are now substantially important to worldwide economic scenario, as for the institution’s economic scenario.

Based on the above considerations, this study seeks feasibility analysis, necessary optimization and logistics considering the On Grid photovoltaic system installed on the institution.

2. DEVELOPMENT

For the study case in question, a data collection was conducted on: the hospital area; energetic consumption; current legislation; and sizing/properties of needed equipment.

2.1 Study Location

The Hospital Senhora Aparecida is located at Avenida Guarim Caetano Fonseca, 146 Luz-MG city. The hospital area is 3645.25 m^2, of which 2959.88 m^2 represents the constructed area. The place contains photovoltaic plates installed on the roof, with a 349.30 m^2 occupied area.

2.1.1 Solar incidence

The solarimetric study is essential for the case study conception, as the energy source of the system is generated transforming solar energy in electric power. Since different regions have distinct solar data, the closet database from the study case location is used.This way, the solar incidence per square meter chosen was the Bom Despacho-MG region. This data was collected from de Referência para as Energias Solar e Eólica de Sérgio de S. Brito (2018) and are disposed in Table 1.

Table 1. Daily Average by month - Solar Irradiation ($kWh/m^2.day$)

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
5.87	6.13	5.20	4.96	4.43	4.23	4.51	5.39	5.54	5.62	5.38	5.71	5.25

2.1.2 Solar capture area

In order to evaluate the hospital's photovoltaic system, the coverage area and the position of the existing photovoltaic system were analyzed, additionally to the roof planes position of the installed plates. This way, it was possible to analyze the necessary quantity to meet the hospital's electric power demand need, in a way which would prevent the necessity to build a specific structure for positioning the plates, as shown in Figure 2.

Figure 2. Roof Coverage

2.2 Energy Consumption

The monthly consumption history for electrical power was collected for a 12-month period, as stated in Figure 3. The mean annual calculated consumption was of 9866.9 kWh per month.

Considering the kWh price charged by the city energy provider, and analyzing the institution consumption, there is an average consumption of R$ 6922.80, as shown in Figure 4.

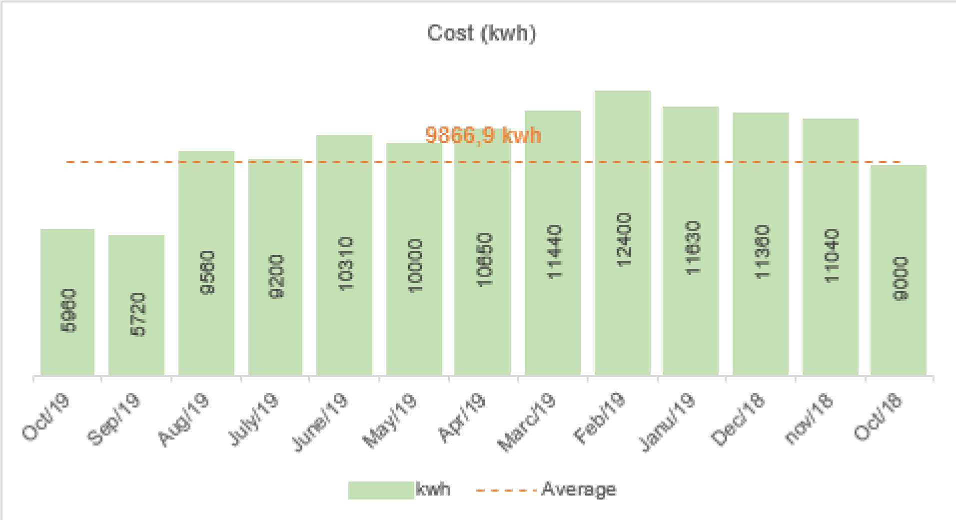

Figure 3. Consumption History

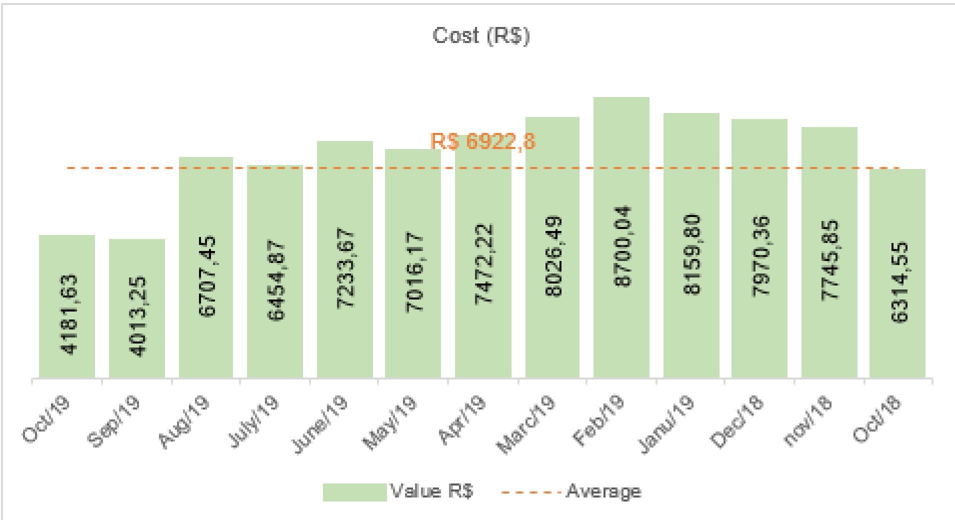

Figure 4. Costs History

2.3 Current Legislation

For the proposed study, technical criteria of the ABNT NBR 10899 /2020 and ABNT NBR 16690/2019 norms, guarantees the system functionality, its safety and durability. ABNT NBR 16274/2014 and ABNT NBR 16149/ 2013 also have minimum requirement for the photovoltaic projects conception when connected to the utility net, and also evaluates the system performance. The sizing criteria should also abide by a ABNT NBR 5410/2008, ensuring good engineering practice.

2.4 Equipment Sizing/Specification

It is necessary to define characteristics for the photovoltaic generator, number of plates and load inverter.

2.4.1 Photovoltaic system already installed on the hospital premises

The current hospital's photovoltaic system can be connected either On Grid or Off Grid. The installed system at the hospital is On Grid. This type of connection enables to produce energy for the energy provider as well as consuming energy of it. In the end of the month, a balance of generated and consumed energy is calculated.

The On Grid connection can be checked in Figure 5. This wat, there is a connection of the Photovoltaic Generator on the utility grid of the energy provider, using a load inverter, that transforms direct current to alternate current, this last available for the utility grid.

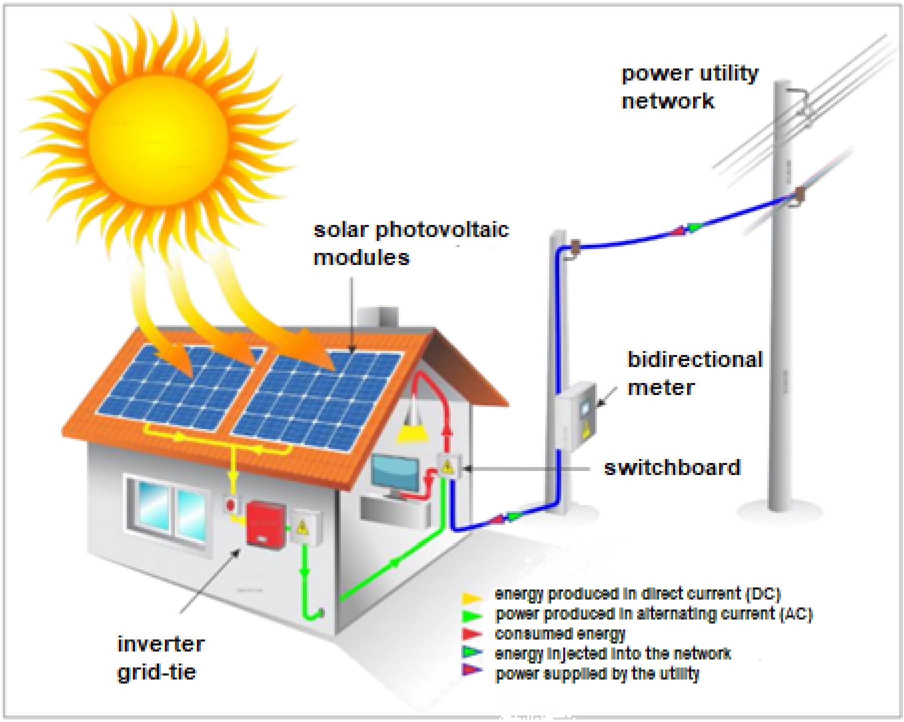

Figure 5. On Grid Conection

It is possible to connect using different phase systems, but for each type of available phase a minimum consumption is stated, in order to keep connected on the utility grid. Using the energy provider bills, the following connection rates are stated:

- For single-phase connection: minimum consumption of 30 kWh/month;
- For two-phase connection: minimum consumption of 50 kWh/month;
- For three-phase connection: minimum consumption of 100 kWh/month; used for calculation bases.

2.4.2 Photovoltaic Generator Sizing

The photovoltaic generator sizing is one step to guarantee the energy generation. It is necessary to have a solar irradiation analysis, an efficiency analysis (impacted by the cable plates technology, which causes energy losses), and the specification of the required load inverter. The set of all system equipment are important in order to guarantee a quality system efficiency. The Power for the Photovoltaic module can be determined by Equation 1.

$$PP_{MFV} = \frac{\frac{E}{TD}}{HSP_{MA}} = 75,62W_P \tag{1}$$

Defined as:
PP_{MFV} (kWp) = Peak Power – Photovoltaic Generator
E (kW/h) = Electric Power Average Daily Consumption;
TD (%) = Efficiency;
HSP_{MA} (h) = Average hours of peak sun light incident on the photovoltaic module
For the photovoltaic generator sizing, an average daily consumption of energy was considered and a type of installation for the power grid. It is essential to point that the efficiency is based on the lost of part of the light energy which is converter in heat, dirt accumulation, electric incompatibility and converter type. The obtained losses were about 18 %, as shown in Table 2. Accordingly, the efficiency was 82 %.

2.4.3 Number of plates definition

At this stage, it is necessary to define the number of photovoltaic modules to supply the hospital's electric power demand, by equation 2.

$$N_P = \frac{PP_{MFV}}{P_{MOD}} = 230 \tag{2}$$

Table 2. Energy losses

Temperature loss	7 a 18 %	Electrict Incompatibility	1 a 2 %
Dirt Accumulation	1 a 8 %	Direct Current (DC) cable	0.5 a 1 %
Alternated Current (AC) Cable	0.5 a 1 %	Load inverter	2.5 a 5 %
Global Avarage: = 0.18			

Defined as:
N_P = Number of photovoltaic modules
PP_{MFV} (Wp) = Peak Power – Photovoltaic Generator
P_{MOD} (Wp) = Maximum Peak Power of Photovoltaic Module
The power for each module is defined as 330 W.

2.4.4 Load Inverter Sizing

One of the primary equipment on the Photovoltaic System is the Load inverter, as it transforms DC energy, generated by photovoltaic modules, into AC, whico will be utilized afterward.

The next step is to make a generator power peak analysis, verifying that the load inverter responds to the photovoltaic system in a safe and efficient way. Due to the solar irradiation variation, whether for angle shifting or temperature variation, the load inverter was defined based on the PP_{MFV} of 75.62 kW_P. Therefore, it was estimated two 40 kW inverter to supply the energy generation, as stated in Table 3.

Table 3. Inverter Power

Brand	CANADIAN	LITTO	FRONIUS	ECOSOLYS
Power (kW)	40	35	30	50

2.5 Data Analysis

For a comparative analysis of the installed versus dimensioned model, the first step is to understand the average monthly consumption and the costs for the electric energy consumed by the institution. The next step was to verify the solar incidence on the area, as the photovoltaic generator sizing and the number of modules and the load inverter definition.

Finally, an analysis of the quotations is done for the photovoltaic system acquisition. Afterward, a comparative table is made for the main characteristics for the installed system and dimensioned system, including a financial analysis using Payback calculation.

3. RESULTS AND DISCUSSION

The obtained results were divided in evaluating the current installed model and payback analysis.

3.1 Payback Analysis

In order to consider the photovoltaic energy implementation at hospital Senhora Aparecida viable, it was investigated the consumption of electric power, the type of the installed system, the project investment and the Payback (time to return the investment).

For an energy generation estimated of 9902 kWh/month with a monthly saving of R$ 6569.40 or R$ 78828.13 annually, the payback estimated was of 41 months.

The data collection on system price were based on the present-day market price and electric installation companies, this way making it possible to project the system implantation price. With data collection it was possible to estimate the final costs of the photovoltaic system installation, as exhibited in Figure 6.

For Payback Determination the Selic rate was picked, it is one of the economic meters for the country and it determines the basic interest rate on the economy. Thus, a rate of 2.0 % per year, which is the defined rate by Copom since August the 5th, 2020. The achieved results are in Figure 7.

Faces with this information, the quotations for project installation were interpreted in order to notice the best cost-effectiveness for the photovoltaic system acquisition. The total cost analysis for the system implementation is shown in Table 4.

Facing the quotations, the one that presents the lowest cost presented savings of R$ 6564.42. An estimated loan was calculated, having a 35-month term. This way, the costs currently used for electric power consumption will be redirected

MATERIAL AND LABOR	UNITY	TOTAL	QUOTATION 1	QUOTATION 2	QUOTATION 3	QUOTATION 4	CHEAPEST QUOTATION
Photovoltaic board 330 W	un	230	R$ 160770.00	R$ 173650.00	R$ 183770.00	R$ 169050.00	R$ 160770.00
Photovoltaic inverter	un	2	R$ 51998.00	R$ 53560.00	R$ 52989.00	R$ 59765.00	R$ 51998.00
Photovoltaic cables 2x6mm d.c e a.c.	m	320	R$ 1939.20	R$ 2419.20	R$ 2208.00	R$ 2496.00	R$ 1939.20
Labor	un	1	R$ 40000.00	R$ 44000.00	R$ 42800.00	R$ 49000.00	R$ 40000.00
TOTAL							R$ 245707.20

Figure 6. Quotation of materials and installation

NPV	45448.93	discount rate	2.0 %

SIMPLE PAYBACK			DISCOUNTED PAYBACK			
Simple payback takes place in 3.2 years or 3 years and 3 months			Discounted payback occurs in 3.4 years or 3 years and 5 months			
Year	Free Cash Flow (FCF)	FCF accumulated	Year	Free Cash Flow (FCF)	PV of FCF	PV of FCF accumulated
0	- R$ 254707.20	R$ -254707.20	0	- R$ 254707.20	- R$ 254707.20	- R$ 254707.20
1	R$ 78828.13	- R$ 175879.07	1	R$ 78828.13	R$ 77282.48	- R$ 177424.72
2	R$ 78828.13	- R$ 97050.94	2	R$ 78828.13	R$ 75767.14	- R$ 101657.58
3	R$ 78828.13	- R$ 18222.81	3	R$ 78828.13	R$ 74281.51	- R$ 27376.07
4	R$ 78828.13	R$ 60605.32	4	R$ 78828.13	R$ 72825.01	R$ 45448.93

Figure 7. Calculated payback

Table 4. Quotation for On-Grid photovoltaic system implementation

	Total Cost	Monthly Savings	Generation estimation (kWh/month)	Payback (months)
Quotation 1	R$ 240000.00	R$ 6564.42	9896	35
Quotation 2	R$ 389320.00	R$ 4860.00	13392	72
Quotation 3	R$ 293205.00	R$ 6400.00	10490	48
Quotation 4	R$ 264000.00	R$ 5871.50	10856.84	45
Quotation 5	R$ 311635.10	R$ 6343.00	10399	36

for the loan installments, predicting, in 25 years, savings on the order of R$ 1969326.00 (one million, nine hundred and sixty-nine thousand, three hundred and twenty-six reais).

In addition to the financial impact after liquidating the loan installments, a social-environmental impact also can be outlined, bringing other institutions and people to be attracted to acquiring the system, contributing more and more to the environment.

3.2 Evaluation on installed model

A proposed target was the evaluation of the installed model facing the calculation on the technical standards which meets the engineering good practices. For sizing the project's equipment, the same parameters were used to all participant bids quotations, so that there was not much divergence on the results and, therefore, a better cost-benefit assessment on the disposed quotations. Table 5 demonstrates the comparison of the generation model offered by the company that installed the current system on the Hospital Senhora Aparecida to the model of the previous sections.

The analysis detects that the current model might overload the inverter due to its dimensioned power. After of this evaluation, it is reasonable that an additional load inverter is acquired, in order that it operates within its nominal power, being more efficient and safer for the photovoltaic system.

4. CONCLUSION

The present study suggests the feasibility of a photovoltaic system for the Hospital Senhora Aparecida, in the city of Luz-MG. Considering the present energetic sight, on which the renewable and sustainable energy sources are alternatives for environmental balance and world's energetic needs, the photovoltaic system is a great potential. Besides, the abundance of solar radiation emitted into Earth enables the photovoltaic systems to be the main source of electric energy in the

Table 5. Comparison on the photovoltaic systems

	Installed System	Projected System
Consumption (kWh)	9867	9867
Generation proposal (kWp)	75,24	75,62
Generation estimated (kWh)	9896	9902
Photovoltaic Pannels (W)	228 – 330	230 – 330
Inverters	1 unity of 60 kW	2 unities of 40 kW
Payback (months)	35	41

world.

The photovoltaic system purchased by the Hospital Senhora Aparecida was considered cost-effective, presenting a 35-month Payback. After this return time, the system brings considerable financial benefits for the institution, and sustainability and social-environmental positive impact. Additionally, the current installed load inverter was considered possibly overloaded, as a result of its power dimension. On this view, it is suggested the addition of a load inverter.

5. ACKNOWLODGMENTS

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