Group 10

Final Project

Rail Transportation Management

Solar photovoltaic assistance for a Brazilian Light Rail Vehicle

Diogo da Fonseca Soares

Mariko de Almeida Carneiro

March, 2019

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List of Abbreviations

LRV	Light Railway Vehicle
BLRV	Brazilian Light Railway Vehicle
CBTU	Brazilian Company of Urban Trains
SWOT	Strengths, Weaknesses Opportunities, Threats
TOWS	Threats, Opportunities, Weaknesses and Strengths

1. Brief description of the chosen topic

In recent times, much research is being carried out to develop sustainable forms of transportation. This is necessary because transportation sector is a source of CO_2 emissions and is a cause of global warming.. Since fossil fuels are fast depleting, besides being detrimental to the environment, there is a need to shift to renewable sources of energy. Solar energy is the ultimate source of all forms of fossil fuels available on earth, from petroleum oils, natural gas to coal. Solar energy can be used for both electricity generation for the national grid through grid-tied photovoltaic topologies as well as in transport sector. The use of solar power assistance in transportation sector is one strong path to reduce CO_2 emissions

According to the Brazilian Greenhouse Gas Emissions Estimate System (SEEG, 2017), the transportation system in the state of Paraiba is a large offender that has no respect for GHG emissions. Among the means of transport of Paraiba are the road, river and rail, the latter being connected to the cities of Cabedelo, Joao Pessoa, Bayeux and Santa Rita. The Brazilian Company of Urban Trains (CBTU), a public company, controls the urban rail system of Paraiba since 1984.

Given this scenario, a strategy for the Joao Pessoa rail system arises and is preparing to mitigate environmental impacts as much as provide economic benefits with an insertion of renewable technology in its rail system. This, this work aims to analyze the feasibility of solar photovoltaic assistance for a Brazilian light rail vehicle Joao Pessoa railway.

2. Research Results

To address this challenge it was developed a study on the potential of environmental and economical results of the installations of solar panels in the LRV operated in Joao Pessoa railway to provide assistance on electric load. The results show that the installation of photovoltaic system in the roofs of the five BLRVs of Joao Pessoa railway can save about R$ 800,000.00 in 10 years and reduce the emission of 54.5 tons of CO2.

3. Hypotheses

Is it feasible to install solar photovoltaic modules on the BLRV rooftop to supplement the diesel generator sets with power?

Is the area available on the roof of the BLRV sufficient to meet the electrical lightening load though photovoltaic modules?

4. Strategy and operative objectives

- Reducing cost of fuel consumed in LRV electric load;
- Reducing greenhouse emission generated by the diesel combustion;
- Increasing environmental responsibility and improve company's image between stakeholders.

5. Preliminary Remarks

5.1 Theoretical Foundation

5.1.1 Solar Energy

Since the beginning of the Industrial Revolution, problems involving the environment have been aggravated due to the explosion of excessive economic activity. The growth of need for energy generation to sustain socioeconomic development is also related to this imbalance of nature. Thus, it can be said that the production of electricity through renewable sources, emerges as a possible solution to achieve sustainable social development (PROENÇA, 2007).

The consolidation of the use of photovoltaic energy as a viable source for energy generation has intensified over almost two centuries of history, marked by the search for more efficient materials for photo conversion, as well as reduction of costs, and increase of productivity. This tendency is due to the fact that photovoltaic energy is considered a source of clean energy, because there is no emission of pollutants during the process of generating energy, besides photovoltaic modules having a long useful life (BRITO et al. 2018).

According to Feitosa (2010) one of the factors that put the photovoltaic energy to advantage, when compared to other renewable sources of energy, is its range of application possibilities. Currently, the installation of photovoltaic panels on the roofs of homes has become increasingly frequent in order to contribute to the energy demand necessary for their supply, as well as the installation of solar poles intended for public street lighting. Another area that favors the application of photovoltaic energy is the agricultural sector, through so-called luminous traps, where energy from photovoltaic panels is used to power LED lamps, capable of attracting and capturing pests present in crops.

5.1.2 Rail Solar Energy System in the world

Few countries have successfully commissioned and operated trains fitted with solar photovoltaic (SPV) system on its rooftop. In Italy, amorphous silicon modules were installed on five passenger coaches, two locomotives and three freight coaches (Trentini M, 2015). In 2010, TER-SCNF (Transport Express Regional Societe Nationale des Chemins defer Français), the state-owned railway of France tested a Diesel Multiple Unit (DMU) fitted with thin-film CIGS (Copper Indium Gallium Selenide) SPV modules. This SPV system with capacity of 990 Wp mounted on the rooftop partially supplied power for electrical lighting system inside the DMU (disasolar, 2012).

In 2011, the Indian Railways installed 1 kWp capacity SPV modules on the rooftop of trains at Pathankot, Punjab, India. The SPV modules power an electrical load of 420 W. Similar attempts were made by KalkaSimla Mountain Railway, Himachal Pradesh, India to supply power for six LED bulbs of 6 W each (RailNews, 2012). These experiments were done for narrow gauge rail coaches, which run at a maximum speed of 40 km/h.

Although the experiments of installing SPV system on trains were successful, few scientific data is available in the public domain for further research and development of Solar Rail Coaches. In 2013, a similar study carried out in Iran, showed that 74% of the power requirement of a coach can be supplied by SPV system during hot months and 25% during cold months. The maximum yield of the SPV system was 63.7 kWh, with an annual reduction of 37 tons of CO_2 emission (Rohollahi E et. al, 2014).

The Indian Railways being one of the largest railway networks in the world operates around 12,000 trains per day. It is also one of the largest consumers of diesel in the country, with an annual consumption of 2.7 billion liter, which includes locomotion and power supply for coaching stock (Gangwar M.,2014).

Hence, efforts are being made by the Indian Railways to reduce fossil fuel consumption and to adopt eco-friendly technologies. Solar energy can find wide application in the railways sector, especially in tropical countries. The Indian Railways operates 63,511 coaches which include both conventional coaches and Linke Hofmann Busch (LHB) coaches (Darshana KM et al, 2015).

Most of these coaches remain exposed to sunlight throughout the year. This provides an opportunity for the Indian Railways to explore the possibility of operating Solar Rail Coaches across the country. This would reduce the diesel consumption of End-on Generation (EOG) system which is the power supply for the electrical load in LHB coaches (Vasisht MS et.al, 2014). In this connection, the project 'Solar Rail Coach' was conducted by Divecha Centre for Climate Change, Indian Institute of Science (IISc), Bangalore, in association with Integral Coach Factory (ICF), Chennai. A LWSCN Coach, which is a LHB Second Class Sleeper Coach, manufactured by ICF was retrofitted with two flexible SPV modules. This coach, named as 'Trial SPV Coach' was run at speeds up to 120 km/h by coupling it to three popular trains of the country. The trials were conducted during the onset of south-west monsoon, so that it would indicate the performance of PV system under low sunshine conditions.

In a study made by Vasisht et al. (2014) with Indian Railways an investment on solar photovoltaic modules atop train coaches can save 90,000 liters of diesel per year per train-set and also reduce 239 tons of CO2 emission per year per train with a return on investment of around 4 years. Another example from Adelaide City Council concluded that electric all-eletric buses charged with solar photovoltaic system had far less cost of operation than diesel powered buses (Adelaide City Council, 2007).

Besides India and Australia, more examples of trains supplied by photovoltaic energy are found in France and Italy (Vasisht at al., 2014).

5.1.3 CO_2 emission and global warming

Climate change of anthropogenic origin is a widespread issue worldwide, which has generated, in addition to an international pact such as the Kyoto Protocol, the National Policy on Climate Change established by law No. 12,187 / 2009, which has made an international commitment to reduce emissions (GMA) in Brazil (MMA, 2017) and the current global pact at the 21st Conference of Parties (COP21) of the United Nations Framework Convention on Climate Change (UNFCCC) in strengthen the world's response to the threat of climate change, and strengthen countries' capacity to deal with the impacts of climate change (ONUBR, 2017).

According to the World Health Organization (WHO), air pollution is the greatest environmental risk to human health and its reduction contributes to reduce the occurrence of diseases such as heart, respiratory, spillage, lung cancer, among others. It is estimated that in 2012 environmental air pollution was the cause of the premature death of 3.7 million people in the world (WHO, 2016).

The transportation sector is a major contributor to the global CO2 emission and global warming (Vasisht et al., 2014) and according the Brazilian Greenhouse Gas Emissions Estimate System (SEEG, 2017) the state of Paraiba transportation system is the largest offender in terms of GHG emissions. The energy that is composed of cargo transportation and passenger, electric power, residential and industrial sector is the largest emitter of CO_2 equivalent (CO2-e) and with around 53% of the state's GHG emission.

Many studies has shown the benefits of the photovoltaic system to supply energy for train and buses. In a study made by Vasisht et al. (2014) with Indian Railways an investment on solar photovoltaic modules atop train coaches can save 90,000 liters of diesel per year per train-set and also reduce 239 tons of CO2 emission per year per train with a return on investment of around 4 years.

6. Methodology

6.1 Case of study

To check the feasibility of providing solar power assistance for LRV (light rail vehicle), it is required to know, analyze and evaluate the performance of a train consisting of a LRV. For this, the LRV manufactured by BOMSINAL and operated in Joao Pessoa Rail System was selected and details about various types of electrical loads, diesel consumptions of the generator cars, and area of roof-top available for installation of solar photovoltaic modules were collected. The transition from source to destination has been termed as one trip. The route taken by the train consists in a 30km trip from Cabedelo to Santa Rita that takes 60 minutes, as shown in figure 1. The focus of this work was to assist the power supply for the electrical load in the five LRV of Brazilian Urban Trains Company (CBTU) in Joao Pessoa with photovoltaic system to reduce cost with fuel and greenhouse gases emission.

Figure 1 - Route map of the train considered for case study - Joao Pessoa, Brazil.

6.2 Scope and Limitations

The LRV provides two motor-generator sets that generate 100kW each. Thus, the total generated power is 200kW. The exception is the LRV 05 that features only 85kW motor-generator sets, generating a total power of 170kW. The energy consumption includes:

- 06 air conditioners of 15kW each;
- 44 fluorescent lamps of 40W;
- 02 fan motors of 2860W.

In total, we have a nominal power consumption of 97.48kW. Hence, in 01 hour of operation the nominal consumption of the LRV is 97.48kWh. Though, the electric components are not always activated and the average energy consumption found in a field research made in sunny days (more usage of air-conditioning) was about 27% of the nominal power, 26 kWh. To find out the fuel consumption for a power generation of 26 kWh, it was generated a curve with field data from the LRV collected in several times of the days during different days of the week.

Considering Figure 2, the curve generated estimates the fuel consumption to a given electric power. When extrapolating the curve to find the fuel consumption of 26 kWh, it is possible to calculate a fuel consumption of 8,7 liters per hour. As previously mentioned, a complete LRV trip from the two final stations (Cabedelo to Santa Rita) takes 60 minutes. In this context, given the price of the fuel (diesel) of R$ 3.99, a LRV trip costs R$ 34.83.

To calculate the annual cost of diesel to provide electric load in one LRV, we took into consideration that each LRV works fan average of five hours per day, five days per week, being one day available for maintenance, as the system closes on Sundays. Therefore, the estimated total annual cost of diesel consumption for electric load in each LRV is R$ 45,278.88.

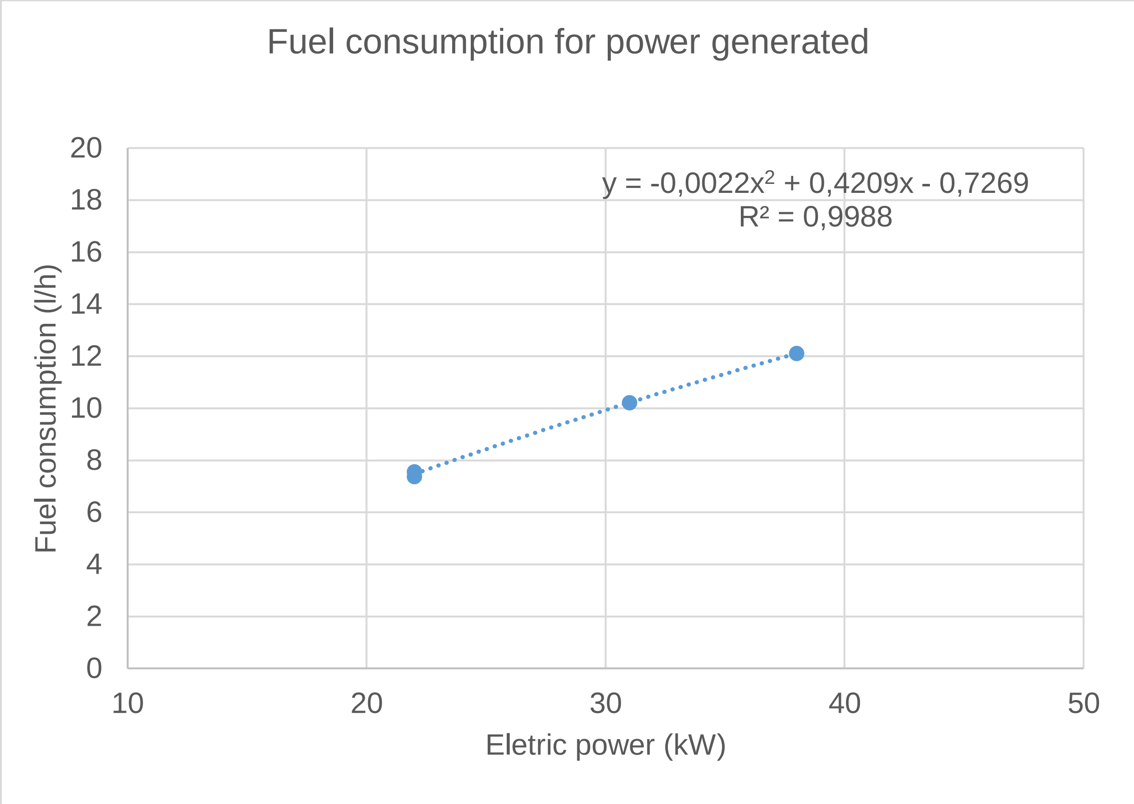


Figure 2 - Curve relationship between fuel consumption and electric power in the BLRV

Each LRV possess a roof area of 61 m^2 available for solar panel installation. For a standard solar module of 1.984 m^2 producing 370W each it will be possible to install 30 modules in each LRV. The average period in Joao Pessoa with direct normal irradiance per day is 5 hours. Thus, applying equation 1, the daily energy produced in a LRV is estimated on 55,5 kWh. That represents 43% of the energy consumed by the train operated during the 5 hours of direct normal irradiance, of 130kWh. To find the potential diesel saved due to the photovoltaic system assistance it was used the curve showed in Figure 2, and a saving of approximately 15.85 liters of diesel per day was found. The annual saving for five days per week of operation, for each LRV is about R$ 16,449.53. The following table presents the train characteristics with solar panel.

Equation 1 $$Solar\ power\ electric\ generation:\ DNI\ x\ N \times P$$

DNI: direct normal irradiance (hours)

N: number of solar panel modules

P: maximum nominal power of each module

Table 1 - Summary of BLRV and solar panel characteristics in Joao Pessoa railway

Name of the train	Santa Rita-Cabedelo BLRV
Distance from source to destination	30 km
Duration of 1 Trip (source to destination)	1 hours
Total sunshine period during the day	5 hours
Electrical load (per BLRV) i. Average electric load measured in the trains for comfort energy	26 kWh
Details of the fuel used by generator i. Type of fuel used ii. Price per litre of fuel	Diesel B S-10 R$ 3,99
Average fuel consumption by generator cars for 1 trip	8.7 liters
Expenditure on fuel for supplying for electrical load during the trip	R$ 34.83
Roof-top area of the LRV	61 m^2
Solar power module characteristics: -Nominal power -Area:	370 W 1.984 m^2
Solar power electrical generation on each LRV per day	55,5 kWh
Average fuel reduction using the solar panels per day	15.85 liters
Total number of trips per train considering 5 trips per day, 5 days per week, during the year	1,300
Cost of fuel consumption for each LRV per year -with solar panels supply -without solar panel supply	R$ 28,829.35 R$ 45,278.88

The proposed design for the 30 modules of photovoltaic system to be installed in the LRV is found in Figure 3. The roof area in the LRV can provide up to 43% of the electric load, being not sufficient yet with the current solar photovoltaic technology available to provide all energy required to lightening and air-conditioning. But yet, it can save about 36% of diesel consumption.

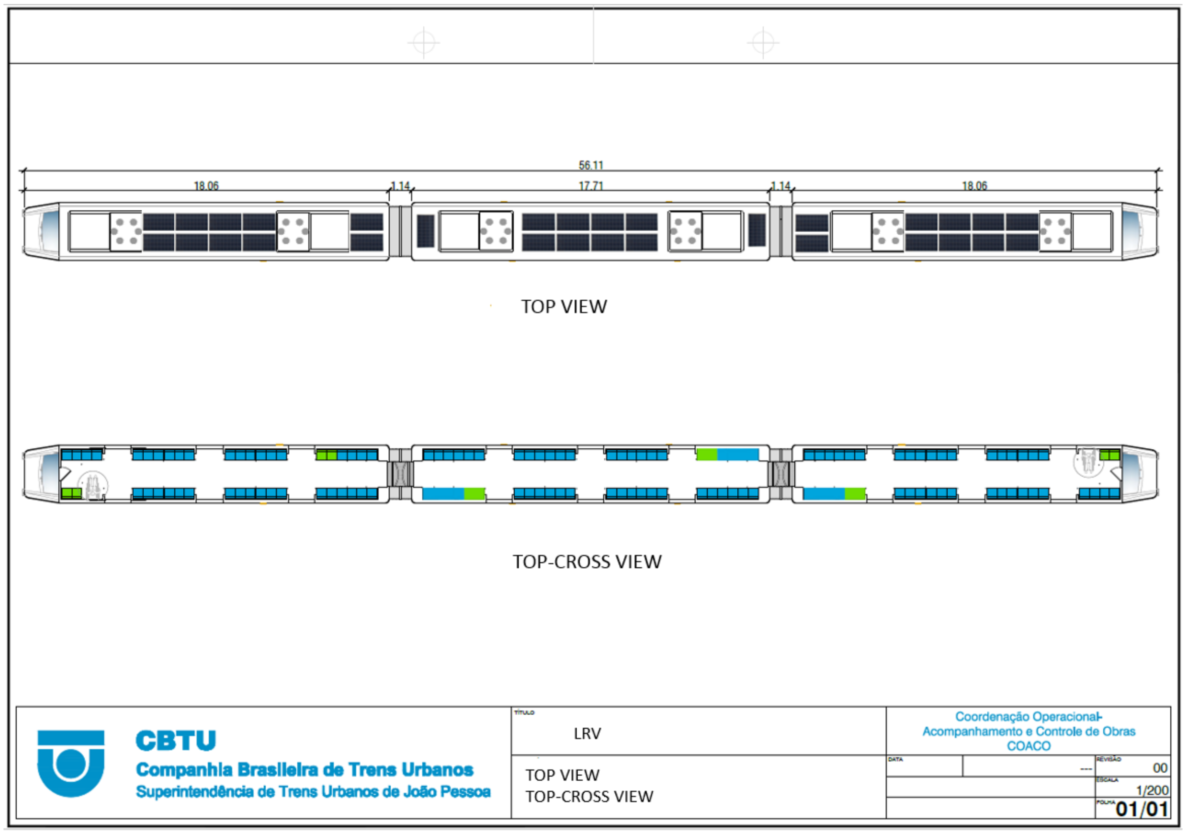


Figure 3 – Proposed design of photovoltaic system in the LRV

6.2.2 CO_2 emission reduction

The CO2 emission by diesel fuel of LRV in Joao Pessoa railway system can be calculated by the sum of the results found in Equation 2 and Equation 3, based on GHG Protocol system.

The Equation 2 measures the equivalent CO_2 emitted from pure diesel combustion. As the Diesel commercialized in Brazil is mixed with alcohol produced from organic matter, it is necessary to calculate also the emission of CO_2 from alcohol combustion part.

Equation 2:

$$E(t) = ECOF x\ GWP\_CO_2 + ECHF\ (t) \times GWP\_CH4 + ENOF(t) \times GWP\_N2O$$

On what;

E (t) = Total emissions (t CO2-e)

ECOF = CO2 emissions (t) fossil (The sum of all fossil fuels (liters or m3) x Fossil fuel emission factor (kg CO2 / liter) / 1000

ECHF (t) = Emissions of CH4 (t) (The sum of any commercial fuel quantity (liters or m3) x Commercial Emission Factors (kg CH4 / liter) / 1000

Emissions of N2O (t) (The sum of all commercial fuel quantities (liters or m3) x Commercial Fuel Emission Factors (kg N2O4 / liter) 1000

Equation 3:

$$\mathbf{EB(t) = FEB \times SQB}$$

On what;

EB (t) = Emissions of biogenic CO2 (t CO2)

FEB = Biofuel Emission Factor

SQB = It is the sum of all biofuel amounts that exist in commercial gasoline required by Brazilian law in liters

The results of the CO2 fuel combustion emission in Joao Pessoa railway system by the LRVs are shown in Table 2. The total CO_2 emission from fuel combustion is estimated of 1,048.82 per year.

Table 2 – CO_2 emission from fuel combustion in Joao Pessoa railway

Source	FUEL	Qt. (liters)	tCO_2-e	tCO_2 - BIOMASS	Total tCO_2
Combustion of fuel in LRV	Diesel	398.252	**981,05**	**67,77**	**1,048.82**

However, only a part of the total CO_2 emission from fuel combustion is released due to the electrical load supply for the LRVs (e.g. air-conditioning and lightening) being the majority amount released to traction. Thus, the photovoltaic installation in all 5 LRVs could result in a total reduction of 5,2% of CO2 emission, approximately, 54 tons of CO_2 per year.

6.3 Strategic analysis

To analyze the project, the SWOT method was chosen to give a better picture about the photovoltaic system installation in the LRV.

Table 3 - SWOT Analyzes for solar system implementation in LRV

SWOT analysis	**POSITIVES**	**NEGATIVES**
INTERNAL FACTORES	**S (Strengths)** - Reduction of cost with fuel - Reduction of CO_2 emission	**W (Weakness)** - Few cases of trains using solar systems to compare - Lack of budget in the company designated to solar panels acquisition - Cost with maintenance is difficult to estimate

EXTERNAL FACTORS	O (Opportunities)	T (Threats)
	- Increasing of market and suppliers for solar energy technology - Visibility	- Depredation

Table 4 - TOWS Strategic Analyzes for solar system implementation in LRV

SWOT		Analysis of external factors	
		Opportunities	**Threats**
Analysis of internal factors	**Strength**	**SO strategy** - Develop a marketing campaign for "green-train"	**ST strategy** - Increase social relationship with railway nearby communities
	Weakness	**WO strategy** - Look for external financial support	**WT strategy** - Try to validate first in one LRV and observe aspects such as depredation and other unknown factors

SO Strategy

- ***Develop a marketing campaign to "green-train":*** make marketing campaign to increase the visibility of Joao Pessoa railway system with the use of renewable energy and the reduction of CO_2 emission

ST Strategy

- **Increase social relationship with railway nearby communities:** make usage of the money saved with fuel cost reduction to support activities with the local community and enhance the relationship between the population living close to the railway and avoid depredation of the trains

WO Strategy

- **Look for external financial support*:*** If the company do not provides investment to the solar panel acquisition, it shall look for other financial resources, for example, renewable energy funds.

WT Strategy

- **Try to validate first in one LRV and observe aspects such as depredation and other unknown factors*:*** In Joao Pessoa railway there are many people living nearby and sometimes we face problem with depredation of the train. Than it is important to first install the solar panels in one train and observe the feasibility of the use the new technology in the other four trains.

7. Cost Benefit Analysis

The cost benefits analyzes associated to the solar system implementation in BLRV to Joao Pessoa railway system considers the positive and benefit aspects. The SWOT Analyzes presented in topic 6.2.2 describes some of these aspects. Among the benefits, it is highlighted the reduction cost with fuel detailed in topic 9. Financial Plan. Moreover, the photovoltaic assistance can conserve up to 20,670 liters of diesel, a non-renewable source of energy and avoid the emission of 54 tons of CO_2 emission in one year.

The negative aspects are also discussed in the topic 6.2.2 though the SWOT Analyzes. Overall, the project may lead to an improvement in the Joao Pessoa railway system not only in economical aspect, but also in environmental and social branches.

7. Risk Analysis

To analyze the risk of the implementation of a photovoltaic system in the LRV it was chosen the FMEA (Failure Mode and Effect Analysis) model. The following figures presents the FMEA and its Plan of Recommended actions.

Table 5 – FMEA

FAILURE MODE	EFFECTS (S)	CAUSE(S)	DESIGN CONTROLS (DETECTION)	ATRIBUTES			
				Severity	Occurrence	Detection	RPN
Depredation	Destruction of solar panels	The population living around the train line has a habit of throwing stones and other components at the trains.	Visual inspection	10	10	7	700
Waste of energy produced	Loss of energy that could be used in the system	The energy produced are used only during the trip, however with the train parked or stopped the energy is wasted	Count the hours when the train was under solar irradiation without operation	10	7	8	560
Climatic effects	Decrease in solar radiation and an automatically decrease of energy	When rain occurs or the weather is cloudy it decreases solar radiation and automatically the energy production	Electric energy produced information on system equipment	9	5	5	225
Shadow on solar panels	Decrease in solar radiation and automatically decrease energy	Factors such as high building near the system, slope of the solar plate and movement of the sun can affect the energy production	Electric energy produced information on system equipment	9	6	5	270
Inadequated maintenance	System failure	Few qualified staff for maintenance in the state of Paraiba	Inspection and Tests with people experience in solar	7	9	10	630

SEVERITY AND OCCURRENCE RATINGS	
Remote	1
Very Low	2
Low	3
Moderate	4,5,6
High	7,8
Very high	9,10

DETECTION RATINGS	
Very high	1
High	2,3
Moderate	4,5,6
Low	7,8
Very low	9
Remote	10

RISK PRIORITY NUMBER	
Low	1 a 99 - No corrective action needed
Moderate	100 a 500 - Evaluate necessity of action
High	501 a 1000 - Corrective action required

Table 6 – FMEA recommended actions

Recommended Actions - Model 5W1H							
Failures	**Actions**	**What**	**Who**	**When**	**Where**	**Why**	**How**
Depredation	**3**	Decrese destruction of solar panels	HR and Marketing	Continuos	With community	The population living around the train line has a habit of throwing stones and other components at the trains.	1 .Implementation of environmental education for the population close to the train line stop throwing waste within the system; 2. Implementation of social projects with the community to improve communication between the company and population; 3. Implementation of marketing on the difficulties that train depredation
Waste of energy produced	**1**	Use totaly of energy produced of system	Maintenance	Continuos	In train	The produced energies are used only in the trip, however with the stopped train the energy is wasted	Implementation of batteries in the train to reserve energy produced with the train stopped
Climatic effects	**1**	Reserved energy for bad climatic	Maintenance	Continuos	In train	When rain occurs or the weather is cloudy it decrease solar radiation and automatically the energy production	Implementation of batteries in the train to reserve energy produced with the train stopped
Shadow on solar panels	**2**	Choosing the best inclination of the solar painel for better performance	Maintenance	Continuos	In train	Factors such as high building near the system, slope of the solar plate and movement of the sun can affect the energy production	Implementation of the best inclination of the solar painel for better performance with the study of the movement of the sun and the path traveled by the train
Inadequate maintenance	**1**	Improve the system failure	HR	Continuos	In train	Little of persons qualified for maintenance in the state of Paraiba	Search in other states better qualification for solar panel maintenance

8. Project Plan, Implementation Plan

The 5W2H Method was chosen to elaborate the Implementation Plan. The Plan was divided in five steps, for each LRV: acquisition, installation, operation, monitoring and finally to restart the process to the other BLRVs. The expected period necessary to go from acquisition to operation is 10 months, as showed in the following Table.

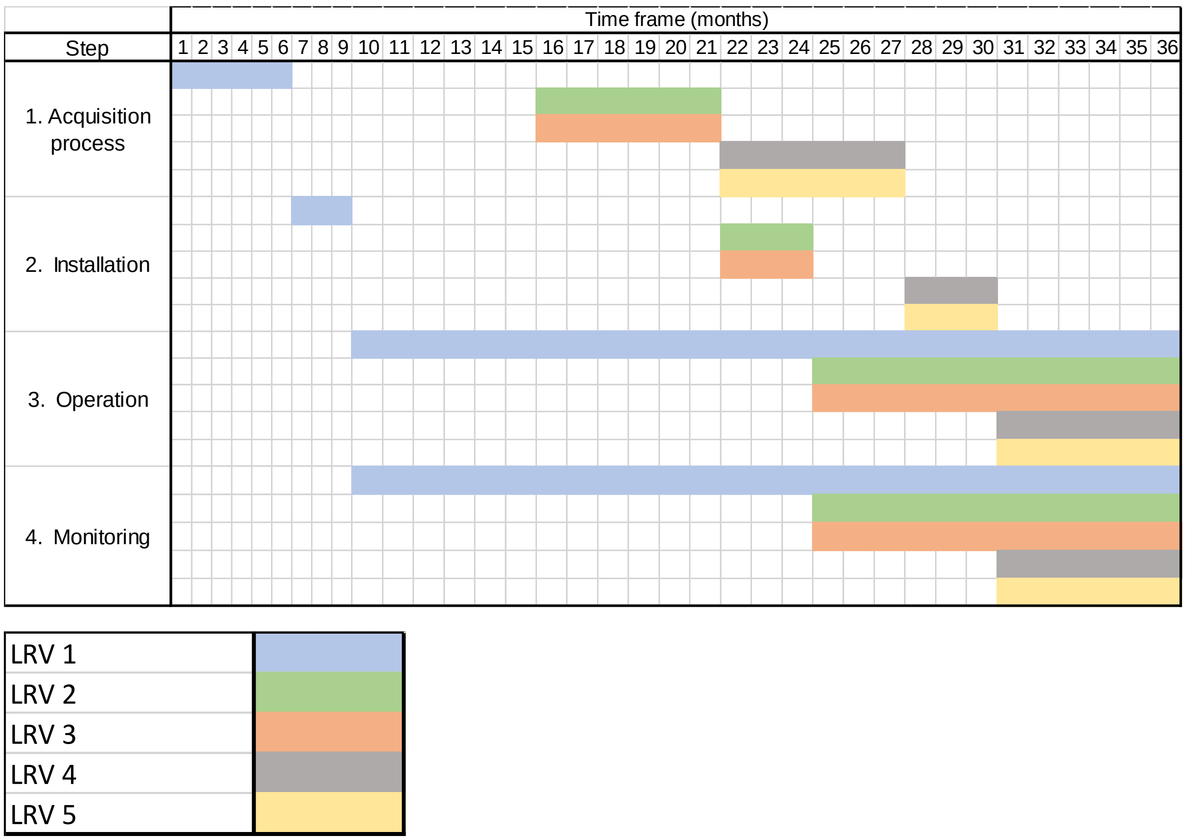
Table 7 – Implementation Plan – 5W2H Method

What	When	Where	Why	Who	How	How much
1.Acquisition process	Until month 6	Office	Assure the best components will be acquired	Engineering department and Bidding department	-Determine technical specifications to start acquisition process of photovoltaic system for LRV 1; -Contact suppliers for offers; -Bidding process	R$ 40,000.00 for each LRV
2.Installation	Until month 09	Workshop	Assure the product will be properly installed	Supplier and maintenance department	-Product receive and installation; -Initial operational tests	Included in the acquisition cost
3.Operation	From month 10	Railway	Validate the solar photovoltaic assistance	OCC	-Operate the LRV during the day to catch the best sunlight irradiance	No extra costs
4.Monitoring	Every 12 months for maintenance and every month to data review when necessary	Workshop	Assure the photovoltaic system is being best used and working properly	Maintenance and Engineering Department	-Equipment maintenance; -System efficiency data review	R$ 1,000.00 per year
5.Proceed with the same plan for the next other BLRV	From month 16	Previously mentioned	Implement the photovoltaic system in the other LRVs	Previously mentioned	Previously mentioned	Previously mentioned

The strategy adopted for implementation considers a transition period of 36 months, for purchase and installation of solar panels on the train:

- LRV 01: 12 months
- LRV 02 and 03: 24 months
- LRV 04 and 05: 36 months

The following chart shows the schedule plan for the photovoltaic system implementation.



9. Financial Plan

a) Planning the P&L

The business model assumes a partial replacement of the electric load of the Brazilian LRV in Joao Pessoa using solar panels.

Thus, CAPEX is composed of:

- Solar Panels (R$ 39.000,00/LRV)
- Infrastructure adjustments (R$ 1.000,00/LRV)

Operating costs (OPEX) were estimated based on internal parameters:

- Maintenance assignments (R$ 1.000/ year/LRV)

b) Planning the cash flow

In order to estimate the cost of contracting this equipment, it was used the discounted cash flow method from the perspective of the service provider. For this, the adopted SELIC tax was 6.75 % yearly. For the solar panel cost we did not consider annual increase by SELIC tax due to the fact that the solar energy market is increasing in Brazil and the cost to technology is reducing.

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	1 year	2 year	3 year	4 year	5 year	10 year
Investments	R$ 40.000,00	R$ 80.000,00	R$ 80.000,00	R$ -	R$ -	R$ 5,00
Cost reduction	R$ 16.449,53	R$ 52.679,63	R$ 93.725,84	R$ 100.052,34	R$ 106.805,87	R$ 148.058,91
Financial Income	-	-	-	-	-	-
Expenses	R$ 1.000,00	R$ 3.202,50	R$ 5.697,78	R$ 6.082,38	R$ 6.492,94	R$ 9.000,80
Result	-R$ 24.550,47	-R$ 56.730,49	-R$ 52.531,74	R$ 37.892,32	R$ 140.762,98	R$ 890.405,84

Figure 4 - Cash flow of BLRV solar system implementation

The simplified cash flow, presented in Figure 3, is intended to demonstrate the main components considered in the financial evaluation. The beginning of positive results starts from 3 to 4 year.

c) Calculate the net present value

The figures below show the total cost with electrical load for assistance in the five LRV units for the next 10 years, from two perspectives:

- **Considering the proposed new system**

	1 year	2 year	3 year	4 year	5 year	10 year
costs of current syste	R$ 226.394,40	R$ 241.676,02	R$ 257.989,15	R$ 275.403,42	R$ 293.993,15	R$ 407.545,99
costs of new system	R$ 40.000,00	R$ 80.000,00	R$ 80.000,00	R$ -	R$ -	R$ 5,00
Cost reduction	R$ 16.449,53	R$ 52.679,63	R$ 93.725,84	R$ 100.052,34	R$ 106.805,87	R$ 148.058,91
total costs (yearly)	R$ 249.944,86	R$ 268.996,39	R$ 244.263,31	R$ 175.351,08	R$ 187.187,28	R$ 259.492,09
Total accummulated	R$ 249.944,86	R$ 518.941,25	R$ 763.204,56	R$ 938.555,64	R$ 1.125.742,92	R$ 2.269.165,98

Figure 5 – Total cost of BLRV with electrical load without photovoltaic assistance

- **Keeping the current system**

	1 year	2 year	3 year	4 year	5 year	10 year
costs of current syste	R$ 226.394,40	R$ 241.676,02	R$ 257.989,15	R$ 275.403,42	R$ 293.993,15	R$ 407.545,99
Total accummulated	R$ 226.394,40	R$ 468.070,41	R$ 726.059,56	R$ 1.001.462,98	R$ 1.295.456,12	R$ 3.091.273,32

Figure 6 - Total cost of BLRV with electrical load without photovoltaic assistance

In addition to all the environmental benefits, technological upgrading and image gains of the company the numbers show that in the **next 10 years** the solar energy system **will represent a saving of R$ 822,107.35 for the company.** That saving must raise through the years due to the solar panels durability of approximately 25 years.

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