ARTICLE

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The generation of photovoltaic electric power as a complement to the use of generators in weaponry maintenance in military operations

La generación de energía eléctrica fotovoltaica como complemento al uso de generadores en el mantenimiento de armamento en operaciones militares

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Abstract: This study proposes the self-production of electricity in an Armament Maintenance Workshop to rationalize fuel expenses and the acquisition of generators in military operations via photovoltaic generation. The technical and economic feasibility of acquiring a Campaign Energy Module was verified, which would supply 100% of the unit's electrical consumption. The usage times of the equipment comprising the module were surveyed, to quantify consumption and assess the potential for electrical generation, ensuring the project's technical viability. Fuel consumption and its purchase value were also quantified to measure the daily expenditure on electricity. Moreover, the cost of purchasing generators was quantified, to estimate the savings generated by the project. The module was then designed and specialized companies submitted proposals for its construction. Based on the investment value and projected savings, the economic viability of the project was proven, with an estimated return on investment after 150 days of operation, considering a 13-year life cycle for the module.

Keywords: Logistics, Photovoltaic Distributed Generation, Campaign Energy Module, Technical and Economic Feasibility, Military Operations.

Resumen: Este estudio propone la autoproducción eléctrica en un Taller de Mantenimiento de Armamento, con el fin de racionalizar los gastos con combustible y adquisición de generadores en las operaciones militares mediante la generación fotovoltaica. Se verificó la viabilidad técnica y económica de la adquisición de un Módulo de Energía de Campaña para satisfacer el 100% del consumo eléctrico de la fracción. Se recopilaron los tiempos de uso de los equipos que lo componen, para cuantificar el consumo y evaluar el potencial de generación eléctrica que haga técnicamente viable el proyecto. Además, se cuantificó el combustible y su valor de compra, con el objetivo de medir el gasto diario con electricidad. También se cuantificó el costo para adquirir generadores, con el fin de calcular el ahorro generado en el emprendimiento. Luego, se dimensionó el módulo y empresas especializadas elaboraron propuestas para su construcción. Con el valor de la inversión y el ahorro generado, se comprobó la viabilidad económica del proyecto, contabilizando 150 días de operación para el retorno de la inversión, basándose en un ciclo de vida del módulo de 13 años.

Palabras clave: Logística, Generación Distribuida Fotovoltaica, Módulo de Energía de Campaña, Viabilidad Técnica y Económica, Operaciones Militares.

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1 INTRODUCTION

The art of war has constantly evolved throughout history. In this sense, the Brazilian Army, aware of the challenges posed by use of the most advanced technologies considering broad spectrum of conflicts, continuously work to improve its capabilities, so as to fulfill its constitutional missions to the best of its abilities.

Logistics, a combat support function essential to developing all phases of a conflict, is largely impacted by changes in how war is conducted, especially regarding the improvement of weapons systems and other defense products used. Consequently, the Brazilian Army seeks to adapt, whenever necessary, the Land Military Doctrine and particularly the Land Military Logistics to effectively support its troops when employed in the most diverse situations.

Use of equipment with high on-board technology and the high intensity of today's combat have exponentially increased maintenance work during military operations. Consequently, maintenance workshops demand a significant amount of electricity in developing their activities, requiring the use of numerous field generators and large fuel consumption.

In this scenario, using alternative sources for electricity generation like photovoltaic energy emerges as an interesting possibility to change this situation.

Based on consumption estimates and electricity demand of a Light Weapons Maintenance Workshop, deployed in set support[1] to the Maintenance Battalion[2], this work dimensions a Campaign Energy Module (MEC) with transportable off-grid photovoltaic generation that presents technical, economic, and operational viability, reducing the need for campaign generators, lowering consumption of fossil fuel by maintenance logistics activities in operations and generating smaller carbon footprint during troop deployment.

1.1 Problem, objectives, and relevance

Brazil is among the countries with the greatest presence of renewable sources in its electricity matrix, with them representing 89.2% of the domestic supply of electricity available in 2023, according to the National Energy Balance 2024 report – Base Year 2023 (Brasil, 2024, p. 39).

In military operations, especially when the nature of the activities requires constant changes of location and operations in isolated areas, this reality does not occur. Electricity demand is, in most cases, met by using field generators which consume a large amount of fossil fuel, increasing the carbon footprint of military operations.

1 According to the EB70-MC-10.238 Campaign Manual (Brasil, 2022, p. 48), it is the one provided "by a logistical support element in relation to all or several supported elements with which it has a specific link" (our translation).

2 According to the EB70-MC-10.368 Campaign Manual (Brasil, 2021, p. 15), "it is a logistical support element that executes specific activities and tasks of the logistical maintenance and rescue functions to the benefit of the sustainability actions of the most advanced military organizations in the combat zone (ZC)" (our translation)

In this context, despite a still incipient share of the national electricity scenario at 7.0%, photovoltaic energy is the fastest growing worldwide (Brasil, 2024, p. 38). On the other hand, energy production from petroleum derivatives has shown a significant decline in Brazil, mainly because of its major environmental impacts and high cost.

That said, the research problem consists of the following question: **To what extent would implementing a Campaign Power Module in a Light Weapons Maintenance Workshop reduce fossil fuel consumption resulting from the use of field generators to produce electricity during military operations?**

To solve this problem with theoretical foundation and adequate research depth, we defined the following general objective: **to verify the technical and economic feasibility of implementing a Campaign Energy Module in a Light Weapons Maintenance Workshop, when deployed in Joint Support to the Maintenance Battalion, during military operations.**

Based on the energy diagnosis presented, combined with the scope of MEC, a sustainable model will be created for alternative electricity generation in a campaign logistics structure which can be reproduced in other branches of the Brazilian Army.

To achieve the general study objective, the article is organized as follows: section 2, entitled "Methodology," details the procedures used in the research. Section 3 presents the theoretical framework that underpins the understanding of the topic addressed. Section 4 presents the results obtained throughout the study. Finally, section 5 discusses the main conclusions and implications of the work.

2 METHODOLOGY

This work sized and analyzed the economic feasibility study for implementation of a Campaign Energy Module in a Light Weapons Maintenance Workshop of the maintenance battalion when acting in military operations.

We sought to understand the impacts that energy self-production via solar energy would have on the use of generators and on the consumption of fossil fuels, during the operation of a maintenance logistics unit in the campaign.

The methodology included a bibliographic review of legislation, theses, dissertations, articles, and other (national and international) references already made public on the topic "electricity generation," focusing on renewable energy sources, especially solar photovoltaic, which offered subsidies for identifying procedures, advantages and limitations related to the theme.

Documentary research and the researcher's professional experience identified the electrical equipment necessary for the effective operation of a Light Weapons Maintenance Workshop, part of a maintenance battalion, when used in military operations.

Hence, we estimated the average daily operating hours of each piece of equipment during operations to quantify the consumption and demand for electricity of this logistics structure and assess the need for energy generation potential to support it.

Fuel consumption of the campaign generators, used according to the Brazilian Army's doctrine, in this same situation was also estimated to determine the costs involved in the process and verify the economic viability of implementing the MEC.

Based on data collected in previous phases, the study sought to correctly size the MEC, calculating the daily generation provided by each photovoltaic module. As such, we determined the quantity of photovoltaic panels and batteries needed to meet the energy demand of the Light Weapons Maintenance Workshop, as well as the compatibility of the inverter and the additional equipment required. The energy generation survey was ratified using a specific software, called PVSyst®, widely used in photovoltaic sizing, both for on-grid and off-grid systems.

Finally, specialized companies were asked for sales quote for MEC construction to quantify the investment required to implement the project, thus enabling verification of its technical and economic feasibility.

One study limitation was the difficulty in estimating the equipment contained in a Light Weapons Maintenance Workshop, since there is no legislation or regulation within the Brazilian Army that establishes the basic configuration of such a structure.

The Material Distribution Chart (QDM) of the Maintenance Battalion, a doctrine document with restricted access that details the organic materials of each unit fraction, is still undergoing development, with only an experimental version existing, which is quite limited in terms of the equipment contained in the Weapons Maintenance Platoon[3].

Another relevant limitation was finding companies specialized in the installation of photovoltaic panels that would voluntarily provide the necessary sales quote for the scope of work.

3 THEORETICAL FRAMEWORK

To measure the interrelationship between "photovoltaic generation" and "rationalization of the use of generators in campaigns," one must understand how the implementation of photovoltaic systems has, from their emergence to the present day, impacted small-scale electricity production in Brazil.

Understanding how the need for electricity is managed in military operations and the costs involved in this process is relevant to elucidating the problem presented. From this "broad" understanding, the possibility of an analytical approach and, consequently, a detailed study on the subject will be discussed.

To discuss the proposed issues, this section will be divided into the following topics: distributed generation, photovoltaic energy, photovoltaic systems, Campaign Energy Module, and conventional return methods.

3 Section of the Maintenance Battalion responsible for furnishing and operating the Weapons Maintenance Workshops.

3.1 Distributed generation

Historically, the electric power in Brazil has been concentrated in large plants, responsible for producing electricity and distributing it to end consumers through an extensive transmission and distribution network.

However, this centralized model presents concrete challenges that impact the efficiency, resilience, and sustainability of the energy system. Estimates show that energy losses during transmission can reach up to 8% in high-voltage lines, representing a significant amount of energy wasted along the route, especially due to Brazil's continental size, where the distance between hydroelectric plants in the Amazon and urban centers can exceed 2,000 km.

Vulnerability to failures in large power plants or transmission lines was highlighted in recent events, such as the blackout of 2009 which left around 60 million people without power for several hours due to a failure in the transmission of a high-voltage line.

To address these issues, the world is moving quickly to adopt more small, local power generation structures. Governments around the world want to accelerate the transition from a completely centralized energy generation model to a distributed one (Berrío; Zuluaga, 2014).

Another relevant aspect is the environmental impact caused by the burning of fossil fuels: according to data from the International Energy Agency (IEA), coal, natural gas, and oil-fired power plants are responsible for approximately 40% of global CO_2 emissions. An emblematic Brazilian example is the Belo Monte plant which, despite being a major source of renewable energy, also raises debates about the environmental and social impacts related to its construction and operation in the heart of the Legal Amazon.

In this context, distributed generation (DG) proposes a decentralized approach in which energy generation occurs on a smaller and more localized scale, often close to consumption points. Barker, Raitt and Weisenmiller (2013) define DG as a generation system of up to 20 MW in size, composed of renewable fuels and technologies and that is connected to the low-voltage grid or that supplies energy directly to the end consumer.

Finally, project effectiveness in terms of generating electricity from solar sources requires a deeper understanding of the concepts of photovoltaic energy.

3.2 Photovoltaic energy

Photovoltaics is a form of renewable energy that converts sunlight directly into electricity via the photovoltaic effect, which manifests itself in certain materials, called semiconductors, capable of generating an electric current when exposed to sunlight.

The direct use of sunlight represents a technically viable and sustainable alternative, offering solutions to energy demands with immense potential for electricity production through photovoltaic technology (Tavares, 2020), which can be used on grid projects or in isolated systems (off grid).

3.3 Photovoltaic systems

Among the several applications for photovoltaic systems, the most common are water pumping, telecommunications, remote monitoring, and electricity supply for installations. **Due to the purpose of this work, we will only analyze the implications regarding the electricity supply to installations**.

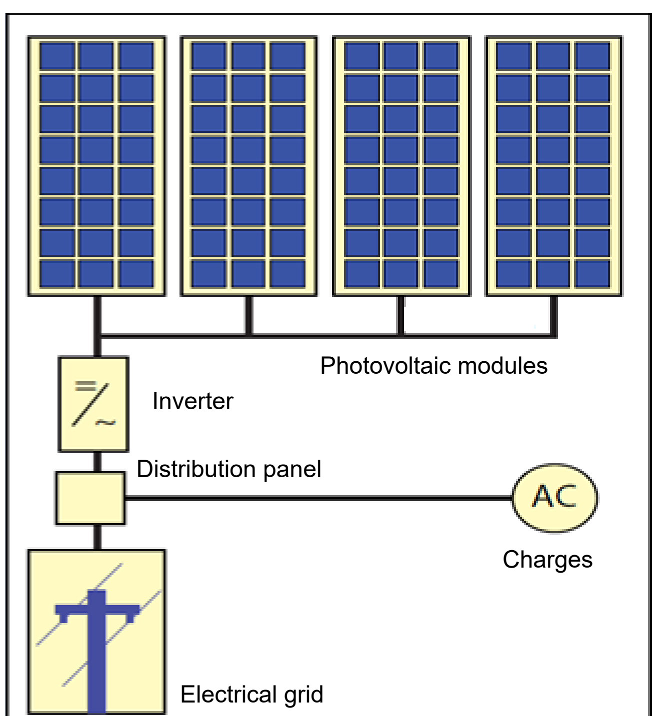
3.3.1 Grid-connected photovoltaic systems (GCPS)

GCPS differs from the isolated photovoltaic system (IPS) because it does not require battery installation, as it is connected directly to the electrical grid, thus functioning as a complementary source to the electrical system.

EPE Technical Note (Brasil, 2012) explains that, in a system connected in parallel to the electrical grid, the direct current produced by the modules must be converted into alternating current.

Thus, inverters must be part of the system not only due to the electronic equipment that can be coupled to it, but mainly to perform specific functions of recognizing internal defects in the installation, overvoltage, and overcurrent protection, continuous adjustment of the maximum power point according to temperature and adaptation of the dynamic behavior of generation in response to the specific needs of the electrical grid. Figure 1 shows a simplified GCSP.

Figure 1 – Simplified diagram of a grid-connected photovoltaic system



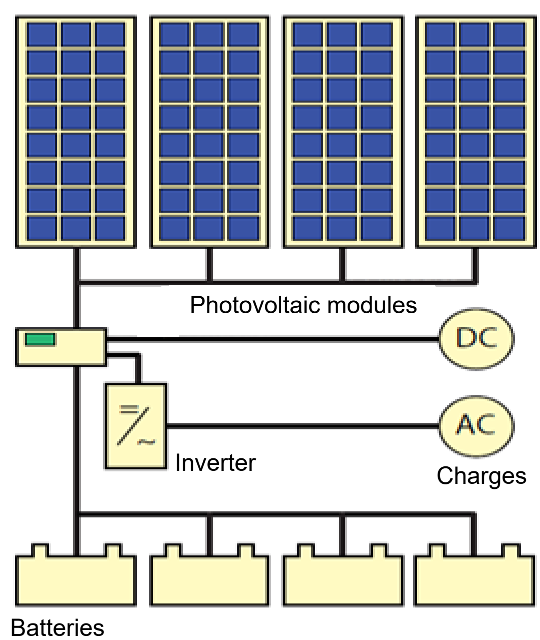
Source: Jäger *et al*. (2014, p. 221).

3.3.2 Isolated Photovoltaic Systems (IPS)

Jäger *et al*. (2014) presents isolated photovoltaic systems as dependent exclusively on solar energy. These systems can consist only of photovoltaic module and inverter[4]. In this case, however, energy consumption is proportional to solar radiation during sunny hours, leaving the unit without power at night and on days with less solar radiation. To get around this problem, batteries must be installed to store energy.

In battery systems, it is necessary to install a charge controller that disconnects the PV module from the system when the battery is charged and reconnects it when the battery reaches a certain discharge limit, increasing set performance and extending the useful life of the system. The battery must also be sized correctly so that it accumulates enough charge from the energy produced during the day to be used at night and during periods of unfavorable weather conditions. Figure 2 shows a simplified isolated photovoltaic system, and Figure 3 is an example of a domestic photovoltaic system.

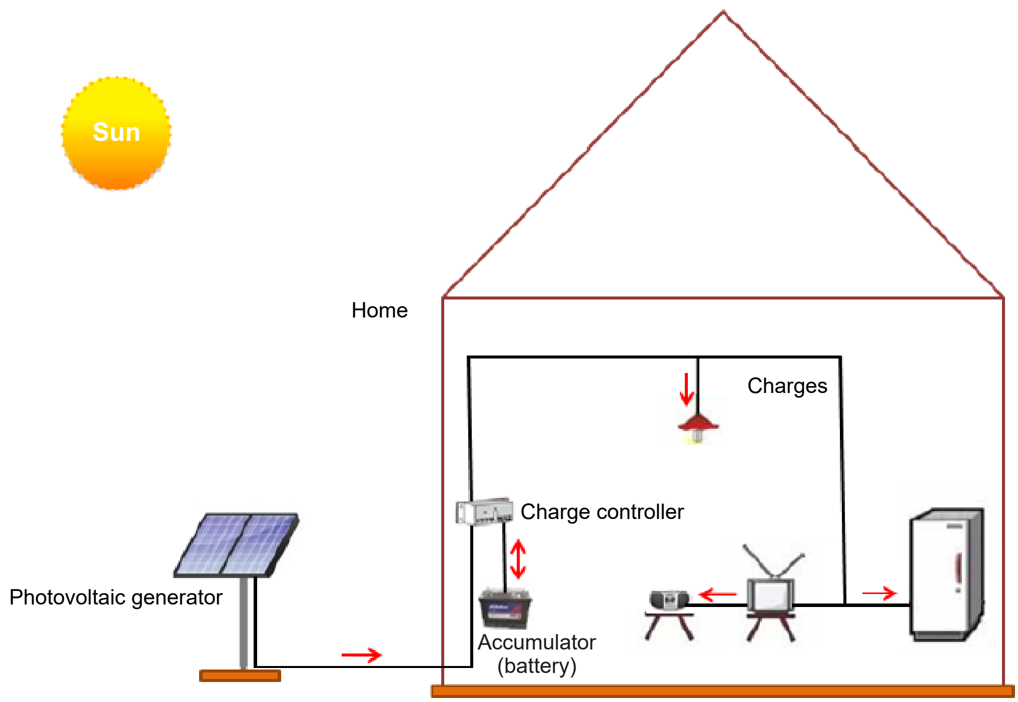
Figure 2 – Simplified diagram of an isolated photovoltaic system



Source: Jäger *et al*. 2014, p. 220.

4 Inverter circuit is a device that converts direct electric current into alternating current. In the IPS, it is necessary to connect electronic equipment to the system, as they require alternating current to function correctly.

Figure 3 – Simplified diagram of the isolated home photovoltaic system



Source: Pinho and Galdino (2014, p. 259).

3.4 Campaign Energy Module

Military operations require electricity. The United States Department of the Army (2024, p. VII) emphasizes that modern warfare is sustained by systems powered by electricity, making electrical energy an essential element in all combat functions. Its doctrine provides for a series of structures with the capacity to generate, transmit, and distribute energy at the most diverse levels.

The United States Department of the Army (2024, p. 1-5) explains that tactical power systems have limited power generation and distribution capabilities, but they enable greater mobility for troops. Its manual adds that these systems are sized according to the unit's requirements and that electrical energy sources include individual power devices, generators, fuel cells, hybrid power, stored energy, and alternative and renewable energy sources.

The Brazilian Army, unlike the US Army, does not yet have specific elements within the mission and capacity to provide electricity in combat. Normally, the units themselves are responsible for providing the power necessary for the operation of their structures and equipment, and in special cases, they may be supplied by logistical support troops.

At the same time, Land Military Doctrine works on the Army's Operational Concept within an operational environment across a broad spectrum of conflicts. The Brazilian Army (Brasil, 2017, p. 2-16) defines that the actions of the Land Force are subject to the simultaneous or successive combination of offensive, defensive operations and cooperation and coordination with agencies, which may occur in war and non-war situations.

This concept encompasses the demands of the units that make up the Land Force, which require flexibility and modularity in the application of their resources. In this sense, especially at the tactical level, similar to the US Army, the Brazilian Army also needs energy systems with high mobility that can generate and distribute electrical energy.

The Campaign Energy Module is a small-scale photovoltaic energy system that does not require connection to the utility's power grid and operates as an isolated electrical system (Debastiani, 2023, p. 2). This device can be configured according to the need for generating electricity, in addition to the size and weight compatible with the structure and operation in which it is used.

The United States Department of the Army (2024, p. 2-6) argues that, depending on mission variables and environmental conditions, alternative energy sources can supplement or replace conventional power generation sets, reducing the need for external fossil fuel acquisition.

Said document points out that photovoltaic modules connected to a battery pack and a control panel are a common example of an alternative energy source used at the tactical level. Figure 4 illustrates this configuration for electricity generation in the field.

Figure 4 – Photovoltaic source devices in the field

Source: United States Department of the Army (2024, p. 2-8).

The Brazilian Army, through the Department of Construction Engineering (DEC), has been looking for alternatives to enter this reality of energy generation by alternative and self-sustainable sources.

Chart 1 describes the technical specifications of a prototype Campaign Energy Module, developed by the Military Works Directorate, with a photovoltaic power generation capacity of approximately 9 kWh per day and 5 kWh of storage.

Chart 1 – Configuration of the Campaign Energy Module prototype

No.	Equipment	Qty.	Function
1	550 Wp photovoltaic module	4	Electricity generation from photovoltaic solar sources.
2	3 kW off-grid inverter with integrated charge controller	1	The inverter allows the inversion of the energy generated by the photovoltaic modules, from direct current (DC) to alternating current (AC). The integrated charge controller allows the management of stored energy and protects the battery, preventing under and overvoltage surges.
3	Lithium battery with 5 kWh storage capacity	1	Storage of energy produced during the day for use at night.
4	127V/220V Transformer	1	It allows to supply energy at 127V and 220V, enabling the use of the Campaign Energy Module in all regions of Brazil.
5	Solar ballast-type structure	1	Allows the attachment of photovoltaic modules.
6	String box	1	Manages the energy produced.
7	Surge Protection Devices (SPD) and Circuit Breakers	8	Manages the DC and AC surge protections, as well as the general shutdown of the panel, outlets (127V and 220V), and the exhaust system.
8	Forced ventilation system (exhaust fan and fan)	1	Allows internal control of the working temperature of the electrical panel, preventing overheating. It consists of a fan at the bottom and an extractor at the top, installed on opposite sides of the electrical panel, maximizing heat exchange.
9	Self-supporting electrical panel	1	Provides shelter for the inverter, string box, transformer, exhaust/fan system, DPS and circuit breakers. It also supports the external installation of the lithium battery. It is equipped with a parking system, with four supports and two wheels to facilitate moving the frame.

Source: Debastiani (2023, p. 2).

3.5 Conventional return methods

Wantroba (2007) presents several methods for evaluating investments and making decisions about whether or not to accept them. In this sense, we highlight the following methods:

- payback;
- discounted payback;
- net present value;
- internal return rate;
- modified internal return rate;

Since the mathematical analysis of investment costs serves, within the scope of this study, as an auxiliary means for analyzing the collected data, and not an objective in itself, we will highlight the first two methods, as they are simpler and more appropriate to our needs.

3.5.1 Payback

According to Wantroba (2007), it can be defined as the number of years or months to recover the investment value, being the first formal method used to discover the return time that an investment takes to pay.

It is calculated by the ratio of investment to revenue, adding future cash flows for each year until the initial cost of the capital project is at least covered. That is, the longer the payback time, the less interesting the investment becomes (Wantroba, 2007).

3.5.2 Discounted payback

According to Wantroba (2007), the biggest criticism involving the payback calculation has always been that it disregards the time value of money. Discounted payback considers this factor, using cash flows expressed in present values. To do this, it uses the formula of present value at compound interest.

$$VP = \frac{VF}{(1+k)^n}$$

In which “PV” is the present value, “FV” is the future value, “k” is the interest rate, and “n” is the number of periods between the current date and the settlement date of the project (Wantroba, 2007).

Since only cash flows during the payback period are analyzed, disregarding flows beyond this period, the project may be considered invalid because it takes too long to be settled (Wantroba, 2007).

Thus, the investment required to acquire the MEC must have a cost appropriate to the savings it will provide in fuel consumption and the reduction in the need to purchase generators, under the risk of this investment not being economically viable.

4 RESULTS

Research results obtained from the literature review, fuel cost estimation, sizing of the Campaign Energy Module and sales quote of specialized companies are presented and discussed below to extract arguments, information, and conclusive data about the problem raised.

4.1 Diesel oil consumption by the Light Weapons Workshop

This topic focused on quantifying the average daily diesel oil consumption for a Light Weapons Maintenance Workshop operating in the context of a military operation. We also surveyed the expenses with fuel acquisition in the same context, as well as the quantitative number of campaign generators employed, and the costs involved in their acquisition.

As the MEC is intended to supply the total electricity demand of the logistics structure, eliminating the need to use field generators for this purpose, the average daily consumption was calculated in a situation of maximum logistical effort, when the need for weapon maintenance is greatest.

Fuel consumption was calculated based on the lowest power generator available on the market and provided for in the Brazilian Army's doctrine, with sufficient generation capacity to meet the energy demand of the structure under study. We also considered the scenario in which no other energy source is available, requiring use of the generator 24 hours a day.

Energy costs for operating a Light Weapons Maintenance Workshop during campaign were estimated using the existing pricing in the Bidding Process No. 00017/2022 (SRP) from the Army Procurement Center, a Military Organization that makes up the Logistics Command (COLOG), Sectoral Management Body (ODS) that carries out major logistical acquisitions within the Brazilian Army.

Similarly, the amount required to acquire campaign generators was extracted from Purchase Result 007/2023 of the 1st Mechanized Cavalry Brigade Command, the most recent bidding process conducted by the Brazilian Army found in the Federal Government's Purchasing Panel, which considered the campaign generators provided for in the experimental QDM contained in the Maintenance Battalion's doctrine.

4.1.1 Estimated fuel consumption

Table 1 presents the electrical equipment that makes up a standard Light Weapons Maintenance Workshop of the Maintenance Battalion, and an estimate of the operating time and electrical energy consumption of these equipment during a day of operations, in a situation of maximum logistical effort.

Table 1 – Energy consumption of a Light Weapons Maintenance Workshop

No.	Equipment description	Qty.	Power	Operating time	Energy consumption
1	380V three-phase industrial bench drill and tapping machine	1	750 W	4 hours	3 kWh
2	60 Feet 200 Liters Air Compressor with 220/380V Three-Phase Open Motor	1	5 HP / 3.75 kW	4 hours	15 kWh
3	1HP Three-Phase Grinder 220/380V 60Hz	1	1 HP / 750 W	2 hours	1.5 kWh
4	14" Notebook	2	60 W	12 hours	1.44 kWh
5	LED lamp	4	20 W	12 hours	0.96 kWh
6	Mobile phone charger	4	50 W	6 hours	1.2 kWh
7	220V industrial air cooler	2	210 W	12 hours	5.04 kWh
TOTAL CONSUMPTION					28.14 kWh

Source: Elaborated by the authors.

Analyzing Table 1 allows us to estimate the average daily energy consumption using the following formula: Consumption (kWh) = Power (W) x Operating time (h)/1000, in which the consumption of each equipment must be calculated individually, considering the manufacturer's information regarding the power and the quantity and operating time employed.

Total average consumption was thus calculated as the sum of the powers of the listed equipment, constant in the Light Weapons Maintenance Workshop, obtaining an energy consumption of around 28 kWh. The maximum power demanded, with all equipment connected simultaneously, is approximately 5.8 kW.

Table 2 shows the mathematical relationships for converting the maximum power demanded in kW to kilovolt-ampere (kVA), a constant measurement unit of the International System of Units (SI) and in which field generators are sold. As this is not the focus of this work, we will not delve into the physical aspects involved in the process.

Table 2 – Conversion from useful power to generator power

Useful power (kW)	5.8 kW*
Power factor	0.8
Generator power (kVA) = usable power/power factor	7.25 kVA

Source: Elaborated by the authors.

* Value extracted from Table 1.

Table 2 shows the need for a 7.25 kVA generator to supply the useful power of the equipment used in the Light Weapons Maintenance Workshop. According to the experimental QDM of the Maintenance Battalion, generators of 4 to 15 kVA are planned for the Weapons Maintenance Platoon. However, Ordinance No. 275-EME (Brasil, 2019) standardizes the acquisition of generators for the Brazilian Army with powers of 5 kVA, 10 kVA, 15 kVA, 35 kVA, 50 kVA, 75 kVA, 100 kVA, 200 kVA, 300 kVA, 400 kVA, 500 kVA, and 750 kVA and from the manufacturers Agrale, Yamaha, Honda, Toyama, Sthil, Caterpillar, Cummins, Motomil, Scania, MWM, Stemac, GeraPower, Branco, Heimer, and YANMAR.

Thus, a generator on the market with lower power that meets all these requirements is the Toayama 10 kVA power generator. According to data collected on the Click Geradores website[5], which specializes in the sale of energy generating systems, this equipment has an average consumption of approximately 4.5 liters of diesel per hour of work. As the generator will be used 24 hours a day, we arrive at a consumption of 108 liters of fuel in operating the Light Weapons Maintenance Workshop.

4.1.2 Estimated expenses for energy costs

Result by Supplier (Annex A), a document extracted from Auction No. 17/2022 of the Army Procurement Center, the sector responsible for purchases within the COLOG, shows that

5 Available at: https://www.clickgeradores.com.br/gerador-de-energia-toyama-tdwg12000sge-n-10kva-diesel-partida-eletrica-monofasico--110v-220v. Access on: Aug. 6, 2025.

the Brazilian Army pays around BRL 7.20 per liter of diesel oil purchased. We therefore estimate that the energy cost for a Light Weapons Maintenance Workshop in the campaign will be around BRL 777.60 per day of operation.

4.1.3 Estimated investment in generator acquisition

The Purchase Survey Result (Annex B), obtained from the Federal Government's Price Panel, a publicity tool implemented by the Access to Information Law (Brasil, 2011), indicated that the Brazilian Army's most recent acquisition process for equipment of this type was priced at BRL 15,926.08.

Finally, according to the Brazilian Army's equipment use and maintenance system, it is unfeasible to continuously use a field generator, which is powered by an internal combustion engine, during the 24 hours of a Military Operations day. Correct sizing of the electrical supply system of a Light Weapons Maintenance Workshop, therefore, requires at least two generators, reaching an acquisition cost of around BRL 31,852.16.

4.2 Campaign Energy Module Configuration

Some solutions are already available in the Brazilian market that enable generating renewable energy in off-grid systems capable of meeting the electricity supply needed during troop deployment.

We selected two modular options that present the same capacity and technology for photovoltaic generation and energy storage with the same inverter technology. They differ mainly in how the system is installed and assembled: while module 1 is self-transportable (Figure 5), installed on a trailer and towed by a non-specialized vehicle, module 2 (Figure 6) requires installation on solar ballast, being transported disassembled inside a non-specialized vehicle.

Figure 5 – Module 1: Self-transportable Campaign Energy Module

Source: The authors.

Figure 6 – Module 2: Campaign Energy Module on solar ballast (example with four modules)

Source: Debastiani, 2023.

The solutions, as per Table 3, are composed as follows:

Table 3 – Campaign Energy Module Configuration

Equipment	Quantity		Useful life
	Module 1	Module 2	
600Wp monocrystalline photovoltaic module	6	6	25 years
Hybrid frequency inverter with integrated charge controller, Growatt brand, with a power of 5 kW	1	1	13 years
Lithium iron phosphate battery (LiFePO4), Growatt brand – 5kWh capacity	2	2	5,000 cycles
String box	1	1	-
127V/220V Transformer	-	1	-
Eyelet type hitch for coupling to vehicle	1	-	-
Military wheel and tire	1	-	-
Self-transportable frame	-	1	-
Solar ballast-type structure	-	1	-
Average daily generation per module	14.4 kWh	14.4 kWh	-
Energy storage per module	10 kWh	10 kWh	-

Source: Elaborated by the authors.

Both options will have an energy generation capacity greater than the total storage capacity, meaning that part of the energy demanded by the workshop during the day will be consumed immediately, without the need to be stored for later consumption.

4.3 Budgets for acquiring the Campaign Energy Module

The Campaign Energy Module configuration required to provide the electricity necessary for operating the Light Weapons Maintenance Workshop was sent to two companies, which will be called Company A and Company B, both specialized in the photovoltaic sector.

Company A presented the budget (Annex C) for module 1, installed on a trailer platform. This project eliminates the need to train a team for assembly and disassembly, and facilitates moving the equipment since it simply needs to be hitched to any vehicle with a towing winch. On the other hand, its cost of BRL 135,000 for each module with nominal power identical to that proposed by Company B requires an investment of BRL 270,000 to supply the Light Weapons Maintenance Workshop.

Company B submitted its commercial proposal (Annex D) for module 2, transportable and installable on a solar ballast-type mounting base. This option requires a trained team to assemble and disassemble the equipment, which can be transported in an operational vehicle as long as it is correctly packaged. However, it has an attractive cost of BRL 71,011.53 for each module with a nominal power of 3.6 kW. According to the data collected for this work, two modules are necessary, totaling an investment of around BRL 142,023.06.

Since the logistical installation motivating this study is normally located in the rear area of the Combat Zone, the speed of assembly and movement of the Campaign Energy Module is not a priority. We therefore selected Company B's budget to verify the economic viability of this project, as it is cheaper and better aligned with the principle of cost-effectiveness in public administration.

4.4 Calculating return on investment

We calculated the return on investment required to acquire two campaign energy modules to supply 100% of the energy consumption of a Light Weapons Maintenance Workshop in operations using the discounted payback method.

According to the budget (Annex D), the required investment amount is BRL 142,023.06. The savings generated by not needing to purchase two generators, calculated in item 4.1.3, is BRL 31,852.16. Likewise, there are savings with the reduction in fossil fuel purchase, raised in item 4.1.2, in the order of BRL 777.60 per day of operation.

The attractive rate adopted will be the Selic Rate, which until June 2024 was at 10.40% per year, according to data from the Central Bank of Brazil (Taxas..., 202-). Table 4 presents the discounted payback for acquiring the Campaign Energy Module, using all the parameters presented.

Table 4 – Discounted Payback for Campaign Energy Module

Operation days	Cash value	Cash flow/Savings	Future value
0	-142.023,06	31.852,16	-110.170,90
30	-110.170,90	23.126,80	-87.044,10
60	-87.044,10	22.927,33	-64.116,77
90	-64.116,77	22.729,58	-41.387,19
120	-41.387,19	22.533,54	-18.853,65
150	-18.853,65	22.339,19	3.485,54

Source: Elaborated by the authors.

Analyzing Table 4, we conclude that the payback will occur after approximately 150 days of operation, which proves the economic viability of the project, since the photovoltaic modules have a useful life of 25 years with a minimum efficiency of 80% according to the manufacture's module datasheet. For the batteries and inverter, the estimated useful life is 5,000 daily cycles and 13 years, respectively, making this a long-term solution.

Finally, using the Campaign Energy Module also reduces CO_2 emissions into the atmosphere, contributing to environmental preservation and improving the image of the Brazilian Army in Brazilian civil society, as well as mitigating the carbon footprint of military activity.

5 CONCLUSION

This study sought to solve the following problem: **To what extent would implementing a Campaign Power Module in a Light Weapons Maintenance Workshop reduce fossil fuel consumption resulting from the use of field generators to produce electricity during military operations?**

For this purpose, the following general study objective guided the work as to respond, positively or negatively, to the previous question: **to verify the technical and economic feasibility of implementing a Campaign Energy Module in a Light Weapons Maintenance Workshop, when deployed in Joint Support to the Maintenance Battalion, during military operations.**

Guided by this objective, we conducted a literature review to, among other aspects, understand how electricity is generated and consumed in Brazil, how a Campaign Energy Module works and should be dimensioned, and how the return on investment is calculated.

Additionally, we survey which electrical equipment should be a part of a Light Weapons Maintenance Workshop and their corresponding energy consumption when used in a military operation. The study also relied on quantifying fuel costs and the acquisition of generators needed to support this logistics facility.

Sizing the Campaign Energy Module based on the data collected and the budgets sent by two companies specialized in photovoltaic solutions also served as a basis for solving the problem.

As expected, the results obtained confirmed the achievement of an energy self-production model from photovoltaic energy, which was technically and economically viable and would serve as a model to be implemented by other operational structures of the Brazilian Army.

However, despite the reduced payback period compared to the equipment's life cycle, implementing a project of this size requires high investment, hindering its execution by the public administration due to the large number of military installations that require electrical energy in a military operation. We also found, during the course of this project, that no system for supplying electrical energy during military operations is in place within the Brazilian Army.

Thus, future studies should study the creation of an infrastructure—both in terms of materials and specialized personnel, technical documentation, and legislation—that is responsible for meeting the electricity demands during military operations, which are growing in the current scenario, as already exists in other armies, such as the United States.

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ANNEX A

MINISTÉRIO DA DEFESA
Comando do Exército
CENTRO DE OBTENÇÕES DO EXÉRCITO

Pregão Nº 00017/2022(SRP) - (Decreto Nº 10.024/2019)

RESULTADO POR FORNECEDOR

34.274.233/0001-02 - VIBRA ENERGIA S.A

Item	Descrição	Unidade de Fornecimento	Quantidade	Critério de Valor (*)	Valor Unitário	Valor Global
1	Gasolina **Marca:** Vibra Energia **Fabricante:** Petrobras **Modelo / Versão:** GASOLINA COMUM **Descrição Detalhada do Objeto Ofertado:** Gasolina Comum: Combustível refinado de petróleo para uso em motores ciclo Otto (explosão por centelha), com adição de etanol anidro combustível em percentual definido por legislação vigente, conforme Resolução ANP 807 de 23 de janeiro de 2020, alterada pela Resolução ANP Nº 828, de 1 setembro de 2020.	Litro	6000000	R$ 5,7400	- **Valor c/ Desconto:** R$ 5,7343	0,1000% **Valor c/ Desconto:** R$ 34.405.800,0000
2	Óleo diesel **Marca:** Vibra Energia **Fabricante:** Petrobras **Modelo / Versão:** OLEO DIESEL B S10 **Descrição Detalhada do Objeto Ofertado:** Diesel B S10: Combustível refinado de petróleo para uso em motores ciclo Diesel, com adição de biodiesel (óleo diesel de origem vegetal ou animal) em percentual definido por legislação vigente, conforme Resolução ANP Nº 45, de 25/08/2014, alterada pela Resolução ANP Nº 798, de 01/08/2019 e Resolução 50/2013.	Litro	30000000	R$ 7,5100	- **Valor c/ Desconto:** R$ 7,1698	4,5300% **Valor c/ Desconto:** R$ 215.094.000,0000
3	Óleo diesel **Marca:** Vibra Energia **Fabricante:** Petrobras **Modelo / Versão:** OLEO DIESEL B S500 **Descrição Detalhada do Objeto Ofertado:** Diesel B S500: Combustível refinado de petróleo para uso em motores ciclo Diesel, com adição de biodiesel (óleo diesel de origem vegetal ou animal) em percentual definido por legislação vigente, conforme Resolução ANP Nº 45, de 25/08/2014, alterada pela Resolução ANP Nº 798, de 01/08/2019 e Resolução 50/2013.	Litro	4000000	R$ 7,4200	- **Valor c/ Desconto:** R$ 7,1811	3,2200% **Valor c/ Desconto:** R$ 28.724.400,0000
					Total do Fornecedor:	**R$ 278.224.200,0000**

Valor Global da Ata: **R$ 278.224.200,0000**

(*) É necessário detalhar o item para saber qual o critério de valor que é utilizado: Estimado ou Referência ou Máximo Aceitável.

ANNEX B

Painel de Preços | MINISTÉRIO DA GESTÃO E DA INOVAÇÃO EM SERVIÇOS PÚBLICOS | GOVERNO FEDERAL BRASIL

MÉDIA	MEDIANA	MENOR
R$ 29.952,36	R$ 6.510,00	R$ 0,50

Quantidade total de registros: 0

Registros apresentados: 53 a 53

FILTROS APLICADOS

Nome do Material (PDM)	Órgão
GERADOR ENERGIA, MOTOR GERADOR ENERGIA, GRUPO DIESEL GERADOR	**COMANDO DO EXERCITO**

RESULTADO 53

DADOS DA COMPRA

Identificação da Compra: 00007/2023
Número do Item: 00072
Objeto da Compra: Pregão Eletrônico - Aquisição de material permanente tipo mobiliário em geral, aparelhos e utensílios domésticos, máquinas e equipamentos, utensílios de cozinha, ferramentas, equipamentos de telefonia, eletrodomésticos, eletrônicos e outros em favor do Cmdo da 1ª Bda C Mec e demais Unidades da Gu de Santiago - RS.
Quantidade Ofertada: 15
Valor Proposto Unitário: R$ 16.533,33
Valor Unitário do Item: R$ 15926,08
Código do CATMAT: 460082
Descrição do Item: GERADOR ENERGIA, POTÊNCIA MÁXIMA:11 KVA, TENSÃO SAÍDA:110/220 V, FREQUÊNCIA NOMINAL:60 HZ, ROTAÇÃO:3.600 RPM, TIPO MOTOR:DIESEL, NÚMERO DE FASES:1, CARACTERÍSTICAS ADICIONAIS:MOTOR 4 TEMPOS, TIPO DE PARTIDA:ELÉTRICO
Descrição Complementar:
Unidade de Fornecimento: UNIDADE
Modalidade da Compra: Pregão
Forma de Compra: SISRP
Marca: TOYAMA
Data do Resultado: 26/10/2023

DADOS DO FORNECEDOR

Nome do Fornecedor: GESSICA ZARZEKA OLIVO - GRM MAQUINAS E LOCACOES
CNPJ/CPF: 97541831000102
Porte do Fornecedor: Micro Empresa

DADOS DO ÓRGÃO

Número da UASG: 160422 - COMANDO 1 BRIGADA DE CAVALARIA MECANIZADA/RS
Órgão: COMANDO DO EXERCITO
Órgão Superior: -

Relatório gerado dia: 09/07/2024 às 17:18
Fonte: paineldeprecos.planejamento.gov.br

ANNEX C

Company A's proposal

COMMERCIAL ASPECTS:

- Unit price for purchasing a Mobile Solar Generator (GSM): BRL 135,000.00
- Quantity: 2 units

TAX ASPECTS:

- Taxes included: exempt from IPI and ICMS

LOGISTICAL ASPECTS:

- Freight: EXW Belo Horizonte

TECHNICAL SPECIFICATIONS:

- Mobile Solar Generator (GSM)
- Eyelet coupling
- 6 solar modules of 600Wp
- 2 x Lithium LiFePO4 batteries – 100Ah 48V
- 1 x 5kW inverter charger
- Input for diesel generator/AC grid
- Military wheel and tire
- Dimension in transport position: (W x L x H) 2.45 X 3.00 X 2.75m
- Dimension in operating position: (W x L x H) 7.00 X 3.00 X 18m
- Visual programming: military green color

Belo Horizonte, July 22, 2024.

ANNEX D

Company B's proposal

mtec ENERGIA

Proposta Comercial – USF Off-Grid Transportável

Objeto da Proposta: Fornecimento e Instalação de Usina Solar Fotovoltaica (USF) não conectada à rede (Off-Grid) transportável com potência nominal de 3,5 kW (3,6 kWp).

A/C: Exército Brasileiro

Número da Proposta: 2023-07-431

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1. **Item da Proposta**

Fornecimento e Instalação de Usina Solar Fotovoltaica (USF) não conectada à rede (Off-Grid) transportável com potência nominal de 3,5 kW (3,6 kWp).

ITEM	ESPECIFICAÇÃO	Qtde	VALOR (R$)	
			Unitário	Total
1	A usina fotovoltaica deverá ter capacidade de fornecer energia elétrica ininterruptamente a uma oficina de manutenção de armamento em operação militar, contendo os seguintes equipamentos: 06 PAINEL SOLAR HONOR SOLAR HY-M18/144H 600W 01 INVERSOR GROWATT SPF3500ES - 230V - 1MPPT 01 STRING BOX 1000 18KA 1-2E/2S 01 GROWATT SHINE WIFI-F - OFF GRID 3KW 01 CABO P/ BATERIA AXE 01 BASE P/ BATERIA AXE 02 BATERIA GROWATT AXE 5.0L 5KWH 01 BASE DE MONTAGEM TIPO LASTRO SOLAR	2	71.011,53	142.023,06

Valor Total: **R$ 142.023,06 (cento e quarenta e dois mil, vinte e três reais e seis centavos)**

2. **Informações Adicionais**

A validade da proposta é de 30 (trinta) dias.

A confirmação da proposta poderá ser feita via e-mail, WhatsApp ou pessoalmente.

O dimensionamento do kit fotovoltaico foi realizado conforme instrução da equipe de engenharia do exército, considerando, basicamente, uma carga essencialmente experimental.

Brasília, 12 de julho de 2024.

Daniel Luiz Sebber / Diretor Comercial / CREA-SC: 109858-7