Optimization of the Energetic Efficiency of Military Facilities

João P. Vieitas

Abstract—Nowadays, energy consumption is a concern with global proportions, not only for environmental reasons, but also economic factors. This worry affects family households but also large facilities where great quantities of energy are frequently consumed. Among these large facilities, military bases are included, in one of which the present work is focused.

In this thesis, an energy audit will be done in the Campo Militar de Santa Margarida, a large military facility in Portugal, to find opportunities to implement alternative energy sources, namely, biomass, offering a greater efficiency and autonomy to the facility.

After analyzing the consumption of the military facility, the biomass production capacity and the biomass to energy conversion technologies that would be more suitable to the Campo de Santa Margarida, it was concluded that a biomass cogeneration gasification power plant with 410kW of installed electrical capacity would be the most interesting project, in economic terms and also energetic. An economic calculation was made in which were considered two cases; in the first one there was a financing by european funds of 30% for the initial investment, and in the other case the initial investment was completely supported by the military facility.

In the first case, after the financing, the initial investment corresponded to 875 350€, and an NPV of 947 473€ was obtained, with an investment recovery time of 10 years. In the second case, the initial investment corresponded to 1 250 500€ and an NPV of 572 323€ was obtained, with an investment recovery time of 13 and a half years. In both cases, the electricity production cost amounted to 0,083€/kWh.

Index Terms—Energy consumption, energy autonomy, biomass, military facilities, gasification

I. INTRODUCTION

Energy consumption in Portugal has been increasing in recent years and with this increase is also associated an increase in the expenses necessary to sustain it [1]. Thus, the focus on forms of energy production that promote energy autonomy using renewable resources has shown signs of increasing, albeit intermittently.

In the search for a reduction in consumption and consequently, a reduction of energy invoices in family households, businesses and buildings in various sectors of the industry, an analysis must be carried out to identify unnecessary losses and expenses. This analysis leads to conclusions on the possibilities for improving energy efficiency.

This work arises from the desire of the administration of the Campo Militar de Santa Margarida (CMSM), in the municipality of Constância, Portugal, to improve the energy efficiency and autonomy of the facility. Since this is a large military installation, the energy consumption (electric and calorific) is high due to the activities carried out and the resident population, leading to the need for a good resource management so that there is a good energy efficiency with the lowest cost.

Due to CMSM’s characteristics and its location, a renewable energy source with high application potential would be a biomass power plant, as will be discussed in the following chapters of this work.

This work will therefore focus on the analysis of energy consumption and the search for alternative energy production solutions for this military installation, namely biomass, that will increase its energy efficiency and autonomy.

II. THE CAMPO MILITAR DE SANTA MARGARIDA

The Campo Militar de Santa Margarida (CMSM) is a large military installation located in the municipality of Constância, district of Santarém, which was built during 1952. It supports the organic units and others placed in the command structure and prepares to act on the entire spectrum of the military operations, nationally or internationally, according to their nature, having also been involved in forest management operations.

CMSM is divided in about 14 units with distinct functions within the installation. All of them have a varied degree of importance, according to their contribution to the proper functioning of CMSM. Among these units there are those that are critical. These will have to continue in operation so that the security and the services of the military facility are maintained, even if there is a failure in the energy supply from the electric network (Table 1).

<table>
<thead>
<tr>
<th>Unit</th>
<th>Feeding TS</th>
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<tbody>
<tr>
<td>C. Saúde</td>
<td>CTM</td>
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<td>CTM</td>
<td>CTM</td>
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<td>CCS e CMSMc</td>
<td>Correios</td>
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<td>BIMECLAG</td>
<td>BIMECLAG</td>
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<td>QG</td>
<td>Unidade de Apoio</td>
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<tr>
<td>GCC</td>
<td>Cavalaria Monobloco</td>
</tr>
<tr>
<td>Paióis</td>
<td>Paióis</td>
</tr>
<tr>
<td>BAS</td>
<td>Oficinas</td>
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</tbody>
</table>

C. Saúde = Centro de Saúde, CTM = Companhia de Transmissões, CCS = Companhia de Comando e Serviços, CMSMc = Campo Militar de Santa Margarida (Unidade), BIMECLAG = Batalhão de Infantaria Mecanizado, QG = Quartel General, GCC = Grupo de Carros de Combate, BAS = Batalhão de Apoio e Serviços.
The energy used by CMSM is received from the medium voltage lines that originate in the EDP distribution substations of Tramagal and Almourol. The energy can be received in two different TSs, denominated in this document by Main TSs, depending on the substation by which the energy is being delivered. Typically, the energy comes from the Tramagal substation and is received at the Cavalaria Torre TS. In exceptional situations, the energy may be received by the Correios TS from the Almourol substation.

III. TECHNOLOGICAL OPTIONS

In this chapter, three renewable energy production technologies that could potentially be used in CMSM are analyzed. They are wind energy, photovoltaic energy and biomass.

Comparing the alternatives, biomass presents itself with the the highest costs, both in terms of initial investment (2000 to 7000 € / kw) and in terms of fuel (it is the only one that has this need) and also in what operation and maintenance costs (O&M) is concerned (2 to 6% of total investment per year). In terms of efficiency, biomass is the technology with the highest values (18 to 30% in the exclusive production of electricity, and can reach 95% in cogeneration) [2, 3].

Regarding the remuneration for energy delivered to the public grid, the one with the highest remuneration is photovoltaic energy, which can reach € 317 / MWh (more than twice the biomass remuneration, € 119 / MWh) [4]. However, the capacity factor must be taken into consideration due to the fact that it is much lower than that of biomass (manly due environmental factors), meaning that the amount energy produced will be lower for the same installed capacity. In wind power, the pay is the lowest, and the issue of the low capacity factor also applies.

In fact, the capacity factor is of vital importance in the present case, since the aim of this project is to increase the efficiency and autonomy of CMSM. Energy production at a biomass power plant is controllable, is not dependent on atmospheric conditions, and can occur even at night and when there is no wind, something that is not possible for photovoltaic or wind technology, respectively. In case of power network failure, for example, a biomass power plant can guarantee the uninterrupted supply of electrical energy which, in a similar situation, may not happen with photovoltaic or wind energy.

From the study of the energy consumption in CMSM (chapter V), the key factor that causes the increase in the annual consumption is the demand for heat during the months when the lowest temperatures occur. From the options considered, the only one that presents itself as a possible solution for this problem is biomass, since neither wind nor solar energy produce heat capable of being used.

Of course, the electrical energy produced by these two technologies would be used by the military installation, either by selling it to the grid or using it locally, but one of the problems (the heat demand) would always remain unsolved. In a cogeneration biomass power plant, heat can also be utilized, which is beneficial to CMSM, since it can be used to warm the buildings of the installation and the electricity can be sold to the grid or consumed on site. As it will be possible to verify, 1/3 of the energy consumed by the installation is due to heat requirements.

Another factor that leads to the possible viability of biomass is precisely the fuel. Since fuel costs can reach 50% of the electricity production costs, there must be a low-cost source that is reliable in its supply. CMSM owns a large forest area (of approximately 6 412 hectares), which is located around the military facility. The biomass collected in these lands is currently being sold to a company, but it can and should be used as fuel in a biomass plant to be installed in CMSM, since this use will reduce energy production costs, making the bet on this type of production potentially much more economically profitable than other ordinary cases.

IV. BIOMASS

Biomass is defined as the biodegradable fraction of products, wastes and wastes of organic origin from agriculture (including animal and plant substances), forestry and other related industries, such as fisheries and aquaculture, as well as the biodegradable fraction of industrial and municipal residues [5].

A. Biomass Types

According to the literature, biomass can be divided into 4 distinct categories, which are Woody Residues, Dedicated Crops, Agricultural Residues, and Municipal solid waste. Of these, only the first two will be discussed here, as they are the most relevant to the present work.

Woody residues are those generated by the wood products industry, urban waste such as construction and demolition waste, and also the waste left over after thinning for forest cleaning.

Dedicated crops are plantations created exclusively for use as biomass. The production of energy crops requires much less intensive management than most traditional agricultural crops, especially in terms of fertilizers and pesticides [6].

B. Biomass Characteristics

Biomass has some of its own characteristics, and two of the most important ones, which are directly related to each other, are the moisture content and the heating value. The heating value relevant for energy applications is the lower heating value (LHV), which is calculated by subtracting the energy required to evaporate the moisture content of the fuel [7, 8]. The LHV is highly dependent on the moisture content present in the fuel. According to the investigation made in this work, the LHV of woody fuels is relatively uniform, regardless of its origin (Fig. 1) [9].

From the graph it can be seen that, starting from the 25% moisture content, higher values of LHV (of the order of 3600kWh/tn) are already reached, which shows that the moisture content most appropriate for this type of biomass must be equal to or below this value when it comes to combustion technologies that require fuel with low humidity.

C. Production

Residual forest biomass is a by-product of activities carried
out for the purpose of obtaining a main product and as such may have several origins. The main contribution to the production of this biomass comes from the management of forest stands, focused on the production of wood for a set of purposes: agglomerates, sawing, poles or veneers [10].

The primary forest biomass, taking into account the main function of the stands from which it comes from, can be divided into three main categories: timber production forests, non-timber main production forests and forest energy crops [11].

D. Transport

Biomass transport can be divided into primary transport and secondary transport [10]. Primary transport consists of the first transport of the biomass by a forest path, from the place where it is produced to the loader. Secondary transport refers to the transport of biomass that is made from the loader to a terminal or consumer unit and can be done by a tractor or by a truck.

E. Processing

Processing operations carried out specifically for the use of biomass for energy can be divided into grinding, sieving and baling, and facilitate its transport from the place of collection to the place of consumption and also allow the biomass to present itself in the best conditions for energy production.

Grinding is a process whereby biomass is transformed into smaller particles which are usually referred to as chips. Sieving is a post-grinding operation and serves to remove contaminants such as stones and sand. The baling allows the collection of forest remains and has as a principle of compacting the materials in bales, increasing its density [11].

F. Exploitation Systems

In this section, some exploitation systems, which are based on the way the biomass is ground, are presented.

Grinding in the loader is the most common of the forest biomass exploitation systems and consists of transporting it to a site designated as a loader, where it is possible to feed a crusher that directly loads a lorry or makes a pile of chips which will then be loaded, being then transported in this form.

On-site grinding consists of grinding the biomass in the place it is collected, and requires a light mobile crusher, towed by a tractor or forwarder.

The grinding in the consumer unit consists of transportation of the biomass items in one piece to the place where it will be converted into energy. The grinding in the consumer unit, by the available space and by its conditions, is more efficient than in the other systems.

The grinding in the terminal allows it to act as a logistics platform where the processes are more productive. Grinding can be done at the terminal more efficiently or, if the product is chipped, it can be stored in a pile, while losing moisture, and then transported when necessary [10].

G. Generation and Extraction Costs

The generation cost is defined as the biomass cost of production in a given forestry system. It includes costs associated with production, supported by the forest owner, up to the time of biomass extraction [11]. The costs of extracting biomass are defined as the costs of the collection, treatment and transfer of the biomass to the power plant [10].

Studies carried out allow the obtention of estimates for these costs, and in [11], for the center and north of Portugal, the estimated values for the generation of biomass were of 12 to 22€/tn, at 35% humidity.

In [10], through an analysis to a study carried out by the Centro da Biomassa para a Energia presented in [12], Netto divided the extraction costs in extraction in primary transport, grinding, and secondary transport. In the analysis, it was concluded that, to the two first points, it corresponded a cost of about 14,35€/tn.

The cost of secondary transport was determined through surveys carried out with five national carriers, allowing the construction of a linear regression, which relates the distance traveled with transport costs (€/tn), and is presented below (1).

\[
\text{C.Second.Transp (€/km)} = 3,368 + 0,07632 \cdot \text{Distance (km)} \tag{1}
\]

For CMSM, it was considered and average traveled distance of 10km, having the cost for the secondary transported gotten the value of 4,13€/tn, making the total cost of extraction stayed at 18,48€/tn.

H. Equipment Costs

The operations of biomass gathering require specific equipment, in which an investment is necessary. Some of these equipments are presented in Table II, considering an exploitation system with grinding in the terminal [13, 14].

<table>
<thead>
<tr>
<th>Type</th>
<th>Model</th>
<th>Price (€)</th>
</tr>
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<tbody>
<tr>
<td>Forwarder</td>
<td>Timberjack 1410B</td>
<td>65 000 1)</td>
</tr>
<tr>
<td>Grinder</td>
<td>JENZ AZ 30-80</td>
<td>110 000</td>
</tr>
<tr>
<td>Feeder</td>
<td>GUERRA 83N1</td>
<td>29 500</td>
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</tbody>
</table>

1) Second hand equipment.

With the prices presented, the total investment that is expected to be necessary in operating equipment adds up to a total of € 204,500, which may vary depending on the vendor.
V. OPTIMIZATION – CMSM VISITS

During the work, some visits were made to CMSM, and the main data obtained from these visits is presented below:

- Data on the electricity invoices of 2016;
- Record of electricity consumption peaks;
- Record of the weekly electricity consumption;
- Measurements made in TSs of the critical units.

In this chapter an estimate will be made for the average summer and winter consumption in the units where measurements were made with the wattmeters. With this estimate it is intended the obtention of results that allow the isolation of the consumptions in the different units, relating them with the total installation. This estimate will be based on the percentage difference in summer and winter consumptions obtained by the peak and weekly records. It is also assumed that, to the variation of the total installation consumptions, corresponds a variation of the same percentage in each one of the installation units.

In this document, the summer months correspond to the months of June, July and August, and the winter months correspond to December, January and February. Given the importance of the heat consumed in the winter, and since it is neglected in the summer, for the purposes of analysis the reference month to be used in the winter consumption estimates is the one with the highest daily consumption averages that, by the data discussed in the following sections, corresponds to the month of January. On the same basis, the reference month to be used in the summer consumption estimates is the month with the lowest daily consumption averages, which corresponds to the month of June.

As the measurements were made in September, it is first determined the percentage difference of the average power consumption of the total installation in September and January, and also the difference of the peak power in the same months. The same is then made for the month of June. Subsequently, these percentage differences are applied to the individual measurements made in the units, and the averages and peaks are obtained for each one in both winter and summer.

A. Electricity Invoices

a) Base Electric Consumption

With the data of electricity invoices (whose information was compiled in an Excel sheet) it was possible to obtain an annual load diagram of the total installation (Fig. 2). It was also possible to determine the consumption of electricity for non-calorific effects (annual base consumption) and for calorific effects.

Since the electricity used for heating in the summer is considered negligible, the average power in this period corresponds to the annual base power, on which is added the electric power used for heating.

The average power in the summer months was of 300kW. Thus, the base electric consumption can be obtained by multiplying this base power by the number of hours of the year (8766 h), which results in 2630 MWh. Also, in the data of the invoices the total value of energy consumed during the year could be obtained. This figure was of 3727 MWh. Subtracting from this value the base electric consumption, one obtains the consumption of electricity used for heating, that is, 1097 MWh.

b) Unitary Electricity Price

Some individual electricity invoices were also made available, which made it possible to estimate, based on the various items invoiced, the unitary price of electricity paid by CMSM to the electricity grid. This value was estimated as 0,10€/kWh.

B. Peak Records

Peak data recorded in the main counter indicates 12 values of peak consumption of the installation registered between 10/12/2016 and 9/14/2017 (Fig. 3). In this piece of data it is important to retain the information on the difference between the months of less use of the heating equipment and the months of more intense use.

For winter, January has the highest peak, 1322 kW, which corresponds to 280% of the peak registered in September (472 kW). For the summer, it is the month of June that has the highest peak, 568 kW.

As stated earlier, it is important to retain from this analysis the difference between the peak of winter (higher point-of-use of electricity for heat production) and the peak of summer (less point-of-use of electricity for heat production), which can be used as an estimate of the peak power used for the production of heat. The value of this power corresponds to the difference between the January peak (1322 kW) and the July peak (516 kW), which is of 806 kW.
C. Weekly Records

The weekly records are so named because their purpose would be to record the energy consumption as indicated on the main counter (located in the Cavalaria Torre TS) each week. However, from the data obtained, it is verified that there are records made with 2, and even with 3 weeks of interval, which means that there are weeks without any record. The records available shall cover the period from 11 January 2017 to 11 September of the same year. From these records, it was possible to calculate the averages for the respective periods between measures (always taking into account the number of days to which the record relates) (Fig. 4).

Fig. 4. Average powers calculated through the weekly consumption registries (year of 2017).

The month which presents the highest average consumptions is the month of January, with an average power of around 745 kW, due to the greater use of the heating equipment. June has a daily average of around 273 kW.

D. TS Measurements

The measurements were made on the low voltage side of the TS using two FLUKE 1735 wattmeters, provided by Instituto Superior Técnico, the records corresponding to an approximate period of 24 hours in each TS. The measured TS correspond to those identified in Table I, with the exception of the ST of Oficinas and Paióis due to their difficult to access. These measurements allowed the obtention of the individual consumption averages in the respective units and, from the data of the weekly registers and the peaks, to estimate these same values in the summer and winter periods, but in the individual units.

Having the measurements being made in September, the values of this month were used to make the estimates. Thus, the percentage differences between the months of September and January, and September and June (Table III), were determined from weekly and peak record data.

From this data, and together with those obtained in the measurements, it was possible to estimate the consumption of critical units during the winter and summer months (Table IV).

E. Optimization Solution

A summary of the values obtained for the total installation and for the individual units is presented in table V.

In order to make the energy production profitable, an energy source to be installed in the CMSM would have to produce enough heat to meet this need while having sufficient capacity to make the critical units of the plant autonomous by providing electrical power in the event of grid failure.

As will be seen below, in the cogeneration technologies considered, the heat energy produced is always higher than the electric energy, which implies the existence of heat waste. To minimize this waste, the heat output of the power source must be equal to the difference between peak consumption in winter and summer, which corresponds to 806 kW.

For electric power, a power plant with a capacity close to the summer peak of the critical units would allow them to become autonomous in case of grid failure, both in winter and summer, because the increase in consumption in winter is due to the heat demand, which would be supplied by the heat generated by the biomass power plant.

Thus, a biomass power plant suitable for CMSM could be considered to have an electricity generation capacity close to

<table>
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<tr>
<th>Table III</th>
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<tbody>
<tr>
<td>PEAK POWERS (P&lt;sub&gt;e&lt;/sub&gt;) AND DAILY AVERAGES (P&lt;sub&gt;me&lt;/sub&gt;) OF CONSUMPTION FOR JANUARY, JUNE AND SEPTEMBER, AND THEIR PERCENTUAL DIFFERENCES.</td>
</tr>
<tr>
<td>Monthly</td>
</tr>
<tr>
<td>September</td>
</tr>
<tr>
<td>January</td>
</tr>
<tr>
<td>Percentage</td>
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<tr>
<td>June</td>
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<td>Percentage</td>
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<th>Table IV</th>
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<tr>
<td>PEAK AND AVERAGE CONSUMPTION MEASURED IN SEPTEMBER, AND ESTIMATES FOR THOSE (P&lt;sub&gt;e&lt;/sub&gt; E P&lt;sub&gt;me&lt;/sub&gt;) IN JANUARY AND JUNE.</td>
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<tr>
<td>PT</td>
</tr>
<tr>
<td>Setembro (kW)</td>
</tr>
<tr>
<td>Janeiro (kW)</td>
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<tr>
<td>Junho (kW)</td>
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<tr>
<td>Total (kW)</td>
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<th>Table V</th>
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<tbody>
<tr>
<td>RESULTS OF THE ANALYSIS MADE TO THE CONSUMPTIONS IN CMSM.</td>
</tr>
<tr>
<td>Period/Power</td>
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<td></td>
</tr>
<tr>
<td>P&lt;sub&gt;e&lt;/sub&gt;-P&lt;sub&gt;me&lt;/sub&gt; (kW)</td>
</tr>
<tr>
<td>P&lt;sub&gt;e&lt;/sub&gt;/P&lt;sub&gt;me&lt;/sub&gt; (kW)</td>
</tr>
</tbody>
</table>

In order to make the energy production profitable, an energy source to be installed in the CMSM would have to produce enough heat to meet this need while having sufficient capacity to make the critical units of the plant autonomous by providing electrical power in the event of grid failure.

As will be seen below, in the cogeneration technologies considered, the heat energy produced is always higher than the electric energy, which implies the existence of heat waste. To minimize this waste, the heat output of the power source must be equal to the difference between peak consumption in winter and summer, which corresponds to 806 kW.
the summer peak of critical units (about 450 kW) and capacity for the production of heat close to that used in winter, plus the eventual losses of the hot water distribution network (about 900 kW).

VI. PROJECT

After determining the order of magnitude of the capacity to be installed in the biomass power plant, it’s necessary to choose the most appropriate technology, taking into account the reality of the CMSM and its resources. A power plant with a power rating of 400 kW is considered a small-scale power plant [15-17], and the usual biomass conversion technologies cannot be used profitably in this context.

Two technologies widely discussed in the literature that are applicable in the context of the CMSM are the Organic Rankine Organic Rankine Cycle (ORC) and the Gasification [18-20]. It will be among these conversion technologies that will be the best choice for the application in CMSM, always having as its base the resources and needs of the same, as well as the analysis done to the consumptions, detailed in chapter V.

A. Technologies

a) Organic Rankine Cycle

In the Rankine Organic Cycle (ORC) there are the same components as in a power plant with water vapor (a boiler, an expansion device capable of producing mechanical energy, a condenser and a pump), its working principle being similar to the Rankine Cycle with steam. However, the working fluid is an organic compound characterized by a lower boiling temperature than water, which allows the production of energy from low temperature heat sources. It is possible to apply some variations to the cycle architecture, such as the installation of a heat recuperator between the outlet of the expansion device and the condenser, through which the pumped liquid passes [21].

In small-scale cogeneration systems, organic fluids are preferable to water because of their mechanics leading to good turbine efficiencies at both full and partial load, which is one of the main reasons why ORC is adopted for biomass. Another advantage is that water has good efficiencies at high pressures, which implies greater safety measures, which are not economically viable in small systems. Although the specific investment for an ORC system is higher than a steam cycle system, operating costs are considerably reduced due to their good controllability, high degree of automation, and low maintenance costs [22].

Based on some existing cases, it is possible to verify that plants with this technology have a total efficiency of up to 90%, with the electric efficiency being around 15% and the thermal one 75% [21].

b) Gasification

The biomass gasification process consists of the conversion of a solid / liquid organic compound to another in a gaseous phase and in a solid phase. The gas phase is typically called "synthesis gas", has a high calorific value and can be used for the production of energy and biofuels. The solid phase, referred to as "coal", includes the unconverted organic fraction and the inert material present in the biomass. This conversion represents a partial oxidation of the carbon present in the material and generally occurs in the presence of a gasification agent, such as air, oxygen, steam, or carbon dioxide [23]. This synthesis gas is then used in gas engines for the production of electricity, and the heat generated by its combustion can also be used.

A disadvantage of gasification is the presence of impurities in the synthesized gas. The existing limit to the amount of impurities that are accepted in the internal combustion engine, calls the necessity of cleaning the gas produced by removing contaminants and reducing them to a certain minimum acceptable level [24].

Gasifiers can be divided into three different types: fixed bed, fluidized bed, and entrained flow. A key feature of gasifiers that must be taken into account is the installed power limit for which they are suitable. A particular gasifier may not be suitable for all capacities in which gasification can be applied, and there is a limit of applications for each of the gasifier types [3] (Fig. 5).

Fig. 5. Intervals of application of the different gasifier types.

Considering the previous paragraph, it is verified that the type of gasifier that best suits the order of magnitude of the determined ideal power for installation in the CMSM (about 450 kW) is the Downdraft Fixed Bed gasifier (DFB). This type of gasifier presents good efficiencies when combined with an internal combustion engine where gas from the gasification process is used [25, 26].

Concerning the gasification (with DFB gasifiers coupled to a gas generator), the electric efficiency typically corresponds to one-third of the total efficiency, with the remaining two-thirds corresponding to the thermal efficiency. Typical values are 25% electrical efficiency and 55% thermal [26].

c) Specific Investment

In relation to the specific investment costs of the two technologies under analysis, it was decided to make estimates based on existing power plants. From this data, linear regressions were constructed for both technologies, which relate the installed capacity with the specific investment for each of them.

For the ORC, nine case studies were used [27-29] and the regression is shown in Fig. 6. For DFB gasification, ten case studies [30-32] were used and the regression is presented in Fig. 7.
Thus, it is necessary to find a balance between the production of electrical energy and the production of heat, during the decision of the capacity to be installed.

In chapter V, it was observed that the difference between the peak of winter and the peak of summer (peak of heat power used during the year) corresponded to about 806 kW. To minimize heat wastage, a power plant would have to provide a heat output close to this value to cover the winter peak, and at the same time cover the electrical energy needs of some of the critical units of CMSM during the year.

Using ORC with electric and thermal efficiency of 15% and 70%, respectively, an electric power of 400 kW would lead to a heat output of 1870 kW, causing a very considerable heat waste. Another way of looking at the problem would be to first determine the heat output. With this one being 900 kW, the electric power would be 195 kW, which would be very low and would not benefit the CMSM much.

In the case of gasification, with an electric and thermal efficiency of 25% and 55%, respectively, an electric power of 400 kW would lead to a heat output of 880 kW, which is already considered as a more appropriate value. Establishing first the heat output as 900 kW, the electric power would be 410 kW. The latter option offers the possibility of making a large part of the critical units of the CMSM autonomous, while at the same time covering all the heat needs during the year. There will always be a waste of heat that could eventually be used for the drying of biomass, which until now is considered to be carried out outdoors.

Thus, the technology chosen to make the economic analysis is gasification with 25% and 55% electric efficiency, respectively, and with an electric power of 410 kW.

**B. Fuel – Biomass in CMSM**

The data obtained for the forest area surrounding CMSM showed the approximate total area of the land to be about 6 412 hectares and included the species of trees that fill this area. Table VI shows the average values of residual biomass production for the region of the country where the CMSM is located (coastal center) [40], for some forest species that are part of its land.

<table>
<thead>
<tr>
<th>Species</th>
<th>Productivity (tn/ha/year)</th>
<th>Total annual Per species in CMSM (tn)</th>
<th>Total annual (tn)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Eucalyptus</td>
<td>3</td>
<td>1 189</td>
<td>4 449</td>
</tr>
<tr>
<td>Pinus Pinaster</td>
<td>1.08</td>
<td>2 058</td>
<td></td>
</tr>
<tr>
<td>Pinus Pinea</td>
<td>3</td>
<td>551</td>
<td></td>
</tr>
<tr>
<td>Quercus suber</td>
<td>0.41</td>
<td>651</td>
<td></td>
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</tbody>
</table>

Currently, the biomass collected in the land (around 300 tons per year) is considerably lower than its potential and is destined for the company CAIMA - Indústria de Celulose, S.A., and is sold at a price of 11€/tn.
C. Financing

To reduce the financial effort required during the investment in a biomass plant, an application can be made on some European funding platforms, which have funds set aside for these types of investment. These funds have among their objectives the promotion of energy development with a view to reducing pollutant emissions, energy saving and also energy efficiency increase.

From the various European funds, three are presented here, which are the EEEF (European Energy Efficiency Fund) [41], the Marguerite fund [42], and the EAFRD (European Agricultural Fund for Rural Development) [43]. These funds finance projects which include the construction of biomass cogeneration power plants. In addition, the Marguerite fund has already financed two projects in Portugal, in two biomass power plants of 15MW each, located in rural areas of the municipalities of Fundão and Viseu [44, 45].

D. Feed-in Tariffs

In a renewable energy power plant, the investment made in its construction is recovered by the consumption of the energy produced, or by its sale to the public grid. In the case of biomass power plants classified as such, a specific feed-in tariff may be applied. Power plants that produce electricity and also heat generated by the process, can also be called cogeneration plants, and the feed-in tariff is specific to these power plants. For the present case, these are the two types of classifications that can be made when registering the power plant; as a biomass power plant, or as a cogeneration power plant.

As a biomass power plant, the remuneration regime is applied after the attribution of power to be injected into the network by the responsible government entity. The value of the tariff is determined through an ordinance by the government. However, up to the writing date of this document, no ordinance had been published regarding the subject, indicating the amount of the tariff to apply to the remuneration regime of these plants. Despite this, it is possible to withdraw from the website of the Entidade Reguladora dos Serviços Energéticos information regarding the current average monthly remuneration for the production of electricity from biomass plants, which has a value of 119,07€/MWh.

As a renewable cogeneration plant, the tariff is updated quarterly by dispatch, with the last available dispatch (Dispatch No. 17/2018, dated April 19) indicating a reference tariff with a value of 84,30€/MWh.

According to the research carried out for this document, the attribution of injected power to the network by biomass power plants is currently closed. Thus, in chapter VII, where the economic analysis is done, CMSM’s biomass power plant will be considered as being a renewable cogeneration power plant being the tariff considered the one specific for this case.

E. Hot Water Distribution Network

Although this is not the focus of this work, some information about the hot water distribution network for CMSM will be given here.

The distribution network can be divided in two parts, which are the primary network, and the secondary network. The primary network consists of the external network, which distributes water from the power plant to the point of consumption. The secondary network corresponds to the network at the points of consumption, receiving water from the primary network and distributing it through the rooms of the house, accommodation, etc.

In relation to the costs of the primary network, there is considerable variation in the various case studies found, since most of the soil conditions could not be ascertained (the installation is more expensive when there’s need to move asphalt and cheaper when the soil consists of only earth or gravel, as it happens in rural areas), nor if the installation was made through burial of the pipes or if technical zones were used. However, an installation cost of 1 072 000 € was estimated in a 2,8 km network for the CMSM.

The secondary network is also composed of several components, the most prominent ones being the radiators and the piping. In conversation with CMSM’s administration and also by the analysis of some blueprints made available, there are about 30 lodgings spread by the military installation, with varying degrees of occupation. The number of rooms in these lodgings ranges from about 10 to 25 people. According to the budget requested from the company GALP, the amount of the investment necessary to install the secondary network in the lodgings was of 20 000€ per lodging, making a total of 600 000€ for 30 lodgings.

VII. Investment and Profit

For the economic evaluation, the simplified model of the LCOE (Levelized Cost of Energy) will be used, together with the NPV (Net Present Value) and the IRP (Investment Recovery Period), widely used in the literature for evaluation within the topic dealt with in this document [4]. Table VII shows the values used in the economic analysis, and in Table VIII are the results of the application of the model. Their analysis will be done in the final chapter, along with the conclusions of the work done.

From the values in Table VII stands out the investment and also the cost of the biomass. In the economic calculation it was considered that 30% of the installation costs of the power plant would be covered by European funds. This value is within what is typical regarding these funds, and it may even be higher, reaching over 50% in some cases. As for the biomass cost, production costs are not accounted for, since there is already some work in this area in CMSM and, if investment in new plantations is necessary, it is assumed that these costs will also be covered by European funds. However, it was considered that the investment needed in forestry equipment is supported by CMSM.

Although the cost of installing the primary hot water distribution network is not accounted for in this project, the investment in the installation of the secondary network is taken into account and considered to be supported by the CMSM.

VIII. Conclusions

In both cases considered, the NPV obtained is positive, which points to a viable project under the conditions considered. The IRP is relatively long considering that the
The IRP would be reduced in 3 years, and substantially increases the costs of the project and may even make it unviable if the only source of profit is the sale of electricity at the feed-in tariff determined for cogeneration power plants. However, if the heat is also sold, it might pose an interesting situation for further analysis, but possibly in military installations closer to urban centers or larger rural populations, where the trade of this type of energy is justified.

The study carried out in this work was focused on the CSMs, but the method can be extrapolated and applied in other military installations present in the country, so that they become more energy efficient and autonomous. A military installation is always a facility of great importance and must be prepared to deal with sudden energy failures. If measures are taken to overcome these shortcomings and at the same time contribute to a more environmentally friendly and efficient installation, it will add value to the military installation itself, to the country and to the environment.

Gasification, although less widespread in the market than the ORC, is a promising technology in terms of energy efficiency and for application in cogeneration power plants, presenting higher electrical efficiencies. Although the thermal efficiency is lower, it is better suited to the needs of CSMs, allowing less heat to be wasted. On the other hand, O&M expenses are clearly higher than the case where the ORC is applied. Despite these higher costs, the economic calculation under the defined conditions, deemed the project as economically viable, offering obvious advantages to CSMs.

The issue of the hot water distribution network is particularly important because its implementation costs considerably increase the costs of the project and may even make it unviable if the only source of profit is the sale of electricity at the feed-in tariff determined for cogeneration power plants. However, if the heat is also sold, it might pose an interesting situation for further analysis, but possibly in military installations closer to urban centers or larger rural populations, where the trade of this type of energy is justified.

The study carried out in this work was focused on the CSMs, but the method can be extrapolated and applied in other military installations present in the country, so that they become more energy efficient and autonomous. A military installation is always a facility of great importance and must be prepared to deal with sudden energy failures. If measures are taken to overcome these shortcomings and at the same time contribute to a more environmentally friendly and efficient installation, it will add value to the military installation itself, to the country and to the environment.

### References

1. Pordata. Produção de energia elétrica a partir de fontes renováveis. [Online] 2017 [Access date: 01/05/2017]; Available from:
   http://www.pordata.pt/Portugal/Produ%cc%81cia%cc%81l%cc%81ctica+a+partir+de+fontes+renov%cc%81veis+(per+centagem)+2012.

### Table VII

<table>
<thead>
<tr>
<th>Item</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_I$</td>
<td>410 kW</td>
<td>Installed Capacity</td>
</tr>
<tr>
<td>$I_{inv}$</td>
<td>3 050 €/kW</td>
<td>Specific Investment</td>
</tr>
<tr>
<td>$I_{pp}$</td>
<td>1 250 500 €</td>
<td>Total Power Plant Investment</td>
</tr>
<tr>
<td>$F_{IRP}$</td>
<td>30%</td>
<td>Percentage of the investment funded by european funds.</td>
</tr>
<tr>
<td>$n_{E}$</td>
<td>25%</td>
<td>Electric Efficiency</td>
</tr>
<tr>
<td>$n_{T}$</td>
<td>55%</td>
<td>Thermal Efficiency</td>
</tr>
<tr>
<td>$O_{M}$</td>
<td>6%</td>
<td>O&amp;M (% of L) expenses</td>
</tr>
<tr>
<td>$a$</td>
<td>7 013 h (80%)</td>
<td>Annual Utilization of $P_I$ (Utilization Factor)</td>
</tr>
<tr>
<td>$LHV$</td>
<td>3.8 MWh/tn</td>
<td>LHV of the biomass</td>
</tr>
<tr>
<td>$E_{elec}$</td>
<td>2 875 MWh</td>
<td>Annual electric energy produced by the power plant</td>
</tr>
<tr>
<td>$E_{ther}$</td>
<td>6 325 MWh</td>
<td>Annual thermal energy produced by the power plant</td>
</tr>
<tr>
<td>$E_{CM}$</td>
<td>2 630 MWh</td>
<td>Annual electric energy consumed by CSM</td>
</tr>
<tr>
<td>$E_{CM}$</td>
<td>1 097 MWh</td>
<td>Annual thermal energy consumed by CSM</td>
</tr>
<tr>
<td>$P_{IC}$</td>
<td>18.5 €/tn (0.019 €/kWh)</td>
<td>Biomass price</td>
</tr>
<tr>
<td>$P_{PC}$</td>
<td>84.3 €/MWh</td>
<td>Feed-in Tariff</td>
</tr>
<tr>
<td>$P_{PR}$</td>
<td>100 €/MWh</td>
<td>Electricity price</td>
</tr>
<tr>
<td>$n$</td>
<td>20 anos</td>
<td>Power plant lifetime</td>
</tr>
<tr>
<td>$a$</td>
<td>6%</td>
<td>Discount Rate</td>
</tr>
<tr>
<td>$i$</td>
<td>0.0872</td>
<td>i factor</td>
</tr>
<tr>
<td>$k_a$</td>
<td>11.47</td>
<td>ka factor</td>
</tr>
<tr>
<td>$I_{IP}$</td>
<td>204 500 €</td>
<td>Forestry equipment investment</td>
</tr>
<tr>
<td>$I_{AA}$</td>
<td>600 000 €</td>
<td>Investment in the secondary hot water network</td>
</tr>
</tbody>
</table>

### Table VIII

<table>
<thead>
<tr>
<th>Item</th>
<th>Value (with financing of 30%)</th>
<th>Value (without financing)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Capacity</td>
<td>410 kW</td>
<td>410 kW</td>
</tr>
<tr>
<td>LCOE</td>
<td>0.083€/kWh</td>
<td>0.083€/kWh</td>
</tr>
<tr>
<td>Investment in the Power Plant</td>
<td>875 350 €</td>
<td>1 250 500 €</td>
</tr>
<tr>
<td>Annual Cash Inflow</td>
<td>393 374 €</td>
<td>393 374 €</td>
</tr>
<tr>
<td>Annual Cash Outflow</td>
<td>164 314 €</td>
<td>164 314 €</td>
</tr>
<tr>
<td>Net Cash Flow</td>
<td>229 060 €</td>
<td>229 060 €</td>
</tr>
<tr>
<td>Total Investment</td>
<td>1 715 350 €</td>
<td>2 090 500 €</td>
</tr>
<tr>
<td>NPV</td>
<td>947 473 €</td>
<td>572 323 €</td>
</tr>
<tr>
<td>IRP</td>
<td>10 years</td>
<td>13,3 years</td>
</tr>
</tbody>
</table>

lifetime of the power plant is 20 years. If the power plant was considered to be a biomass power plant, instead of a renewable cogeneration, the NPV would be higher and the IRP would be lower, due to the fact that the feed-in tariff would be considerably higher (from 84.3€/MWh to 119.07€/MWh). If the investment in the hot water primary distribution network had been considered, the final value for the NPV would be negative in both cases, so it was assumed here that this asset was already ready or was financed by an outside investor.

It is seen that a 30% financing in the initial investment reduces the IRP in 3 years, and substantially increases the NPV. Although a more detailed study of both consumption and technology is needed for a final project to be implemented, this work has attempted, with relative success, to show realistic and at the same time conservative results, based on existing cases and measurements taken at the CSMs.