Energy management in municipal solid waste treatment: a case study of a mechanical biological treatment facility

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Abstract

Over the last few years, mechanical biological treatment systems for municipal solid waste have been introduced in many European countries. In most cases, this was driven by the European Union Landfill Directive, which requires the diversion of biodegradable municipal waste from landfill to alternative processes. Although this type of treatment allows energy recovery from municipal solid waste, the process of mechanical biological treatment appears to be an intensive energy consumer, due to high demand of electricity consumed by process equipment.

This paper presents the main results of an energy audit performed to a Mechanical Biological Treatment facility in Portugal, which due to the amount of energy consumed must comply with the Portuguese Program called Intensive Energy Consumption Management System – *SGCIE*. The program was created in 2008 to promote energy efficiency and energy consumption monitoring in intensive energy facilities (energy consumption higher than 500 toe per year). Facilities operators are required to perform energy audits and take actions to draw up an action plan for energy efficiency, establishing targets for energy consumption reduction and greenhouse gases emissions indexes.

To implement actions that improve energy efficiency, it is necessary for the facilities operation to be associated with an effective energy management methodology, as well as an efficient facilities management procedure. The implementation of any energy management system should start with an energy audit, which was carried out to identify potential energy conservation measures for improving energy efficiency, and also typical energy consumption patterns and sector/equipment load profiles. This tool gives managers the information to support decision making on improving energy performance and reducing greenhouse gas emissions.

Results shown that there is a considerable potential for reducing energy consumption and greenhouse gases emissions on Mechanical Biological Treatment units. Here, as elsewhere in the industrial sector, energy efficiency can only be achieved through a continuous energy monitoring and management system.

Introduction

Mechanical Biological Treatment (MBT) has been established as state of the art in the field of waste treatment in many European countries. In Germany more than 70 MBT plants treat over 7 million tons of waste per year (Gandolfi 2008). The European Union Landfill Directive especially restricts the landfilling of biodegradable waste and stipulates a pre-treatment of municipal solid wastes (MSW) (DEFRA 2013). In terms of this type of treatment, MBT technology is currently the only alternative to waste incineration, which in many cases is not politically accepted. Therefore, environmental or socio-economic impacts and other consequences of implementing these different strategies must be taken into consideration to support the decision of choosing the technology to use (Cimpan & Wenzel 2013).

There is a large amount of equipment required to perform the waste treatment in the process of an MBT plant, which results in a significant overall energy consumption and associated high financial costs; as well as high emissions of greenhouse gas emissions (GHG) and its associated consequences to the environment. Good energy management practices result in facilities with better energy performance. In order to implement actions that improve energy efficiency, it is necessary for the plant operation to be associated with an effective energy management methodology, as well as an efficient facilities management procedure. One of the ways to achieve this is through monitoring and targeting of energy consumption, which mainly consists of using management techniques to control energy consumption and cost.

The ISO standard 50001:2011 intends to provide organizations with a recognized framework for integrating energy performance into their management practices, giving requirements for implementation of energy management systems (EnMS). This ISO Standard is based on the Plan-Do-Check-Act (PDCA) continual improvement framework and incorporates energy management into everyday organizational practices, as illustrated in Figure 1.

According to the proposed framework, organizations shall always seek ways to improve their energy usage, and thus perpetually reducing the operating costs. When organizations start seeing the financial returns from energy management they shall continuously strive to improve their energy performance. The key issue is regularly assessing energy performance and implementing measures to increase energy efficiency.

Moreover, the implementation of any energy management system should be based on an energy audit (Turner & Doty 2004), which consists of a detailed examination of the energy usage conditions in an installation – the vital tool that gives the managers the information to support decision making on improving energy performance (Thumann & Younger 2003). Energy audits are not only essential for improving energy efficiency and performance, but also represent a key step in the process of reducing GHG emissions from buildings, facilities, industrial processes and transport systems.

Methodology

The work performed during the energy audit required a coordinated, phased approach to identify, evaluate and recommend energy conservation measures (ECM). The energy audit started with collecting and gathering preliminary data on the facility; afterwards a facility inspection and the installation of energy monitoring equipment took place, in order to identify and evaluate potential ECMs; finally, an energy audit report was written, integrating an action plan for energy consumption reduction, establishing targets for energy consumption reduction and GHG emissions indexes. Figure 2 illustrates a schematic representation of the different stages of the energy audit performed to the MBT facility.

The preliminary data collection and analysis consisted in a review of the facility energy bills and monthly production data, along with other current and historical energy and production related data. The architectural and engineering plans of the plant and its systems in conjunction with data inventory of the different energy related systems (pump, fan, compressed air, process heating, etc.) were assessed in detail to identify the potentially major energy consumers in the facility. At this stage, general information about the facility (year of construction,

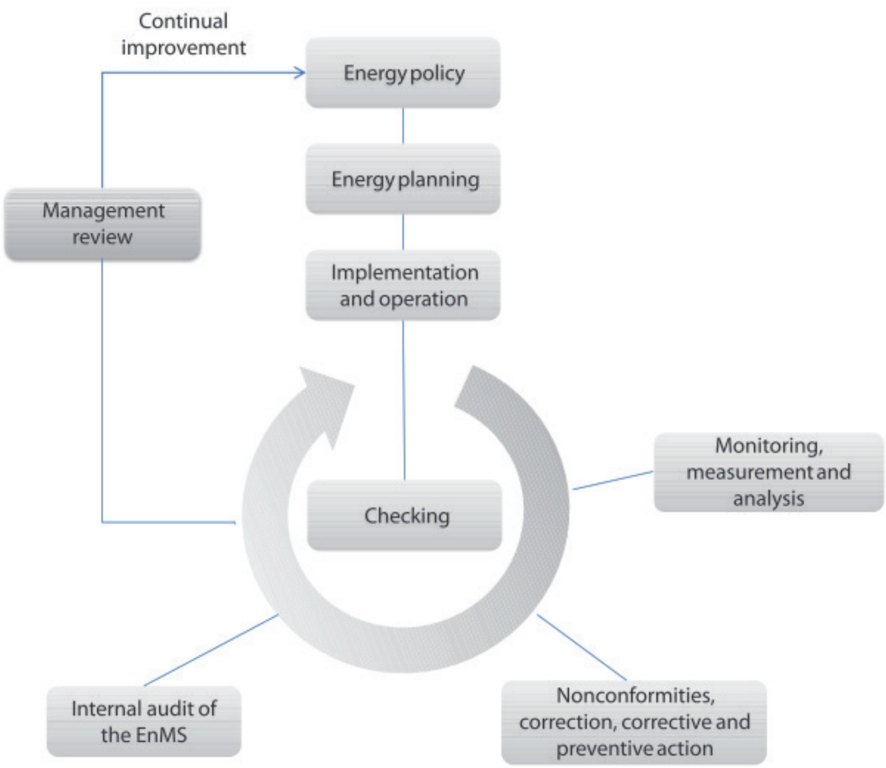

Figure 1. Energy management system model for ISO 50001:2011 (ISO 2011).

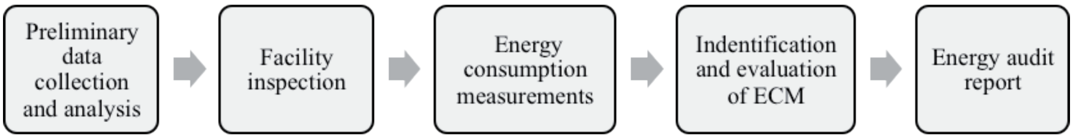

Figure 2. Energy audit phases.

upgrades, types of products, operation schedule, operating hours, scheduled shut-downs, etc.) was also collected.

This information was useful for the planning of the facility inspection, identifying the main issues to be discussed and analysed during the on-site visit.

After the preliminary analysis, a facility inspection was performed, which consisted of an on-site visit to inspect actual systems and answer questions from the preliminary review. The audit team also met with the operation and maintenance staff to obtain an introduction and to establish a common understanding of the audit process. At this stage it is important to get a deeper insight on the processes and utilities of the facility, so comments from the facility staff were also taken into consideration and some readily-available data was collected. The electrical load and thermal energy use inventory was completed with the identification of major energy consumption systems and equipment. Some data were available and collected from the staff of the plant being audited, while other data was collected through measurement and recording. During this visit the existing measurement instrumentation and the type of recorded data was also verified, in order to identify what additional measurements would be required.

The on-site energy consumption measurements were performed on specific equipment and systems to evaluate its load profile and identify if there are any potential ECM. Gathering data through measurement is one of the main activities of energy auditing, because without adequate and accurate data, an energy audit cannot be successfully accomplished. This stage was very important to establish the quantification of energy flows and assess the energy performance of the facility.

The information gathered during the facility inspection and the energy consumption measurements should be reviewed and organized. Along with this, a set of opportunities to improve the energy efficiency should be studied to estimate the energy savings potential and the implementation cost. Measures with a lack of potential or without cost effectiveness were disregarded. The simple payback method was used to assess the cost effectiveness of each ECM.

The energy audit report was prepared taking in consideration the interest of the stakeholders in each section. Therefore, there was an effort to customize each section in order to give a rich picture of the work developed and the proposed ECMs to improve the performance and reduce the energy bills of the facility. The report includes an action plan for the implementation of each ECM, with a description in a simple way with clear goals, saving targets, and definitions of roles and responsibilities for its execution.

The conversion factors to primary energy used were the following, according to Portuguese norm (*Despacho n.º 17313/2008*): 0.000215 toe/kWh for electricity and 1.01 toe/ton for diesel, parameters defined due to the energy mix of the country. To compute the GHG emissions, the factors used were the following, also according to the previously referred Portuguese norm: 0.47 $kgCO_2$/kWh for electricity and 3,098.2 $kgCO_2$/toe for diesel.

Brief description of the facility

The energy audit was performed to a MBT facility, located in Portugal. Figure 3 shows the MSW treatment process flow diagram implemented.

Trucks unload MSW in the waste reception area and it is loaded into a device for opening and disintegrating the waste bags for easier further processing. After this, disaggregated MSW is separated in two fractions in a sieve drum. By means of a magnetic separator and a manual sorting line, recyclable materials are recovered from the sieve overflow and the rejected material is sent to landfill. The sieve underflow is conducted to hydromechanical pre-treatment ('pulpers') where a homogenous mixture is obtained, and impurities from the organic fraction are removed before the digestion process.

The anaerobic digestion is executed in mesophilic temperature conditions (*i.e.* 34 ºC to 36 ºC) in two digesters, 2,000 m^3 each. The resultant biogas is used for electricity generation, from which heat is partially recovered and used in the process. The digested substrate is then dewatered, and the remaining solid phase is stabilized in two-stage composting: firstly mixing with structure material and treated in closed forced ventilation boxes, and then in piles with forced ventilation in a covered, but not closed space. After a total of twelve weeks the remaining structure material is sieved out to obtain the final compost. The liquid phase is largely recycled back into the process as process water.

Energy consumption analysis

The first step of the energy audit performed consisted in the compilation and quantification of the facilities current and historical energy usage and associated utility costs in order to establish the energy consumption baseline. For this study, baseline energy use was established from the monthly utility bills of 2012. In Figure 4 the energy consumption, in terms of final energy and primary energy, and GHG emissions for the baseline year are shown.

It is important to establish the existing patterns of energy usage, disaggregating the energy consumption by each sector or end-use. This will help to identify the sectors where the energy consumption reduction could be more significant. Figure 5 shows the estimated breakdown of primary energy consumption per year.

The mechanical pre-treatment (dry and hydro-mechanical pre-treatment) bin in the chart comprehends the separation in two fractions in a sieve drum, magnetic separation and manual sorting of selected waste, the conveyor belts and "pulping",

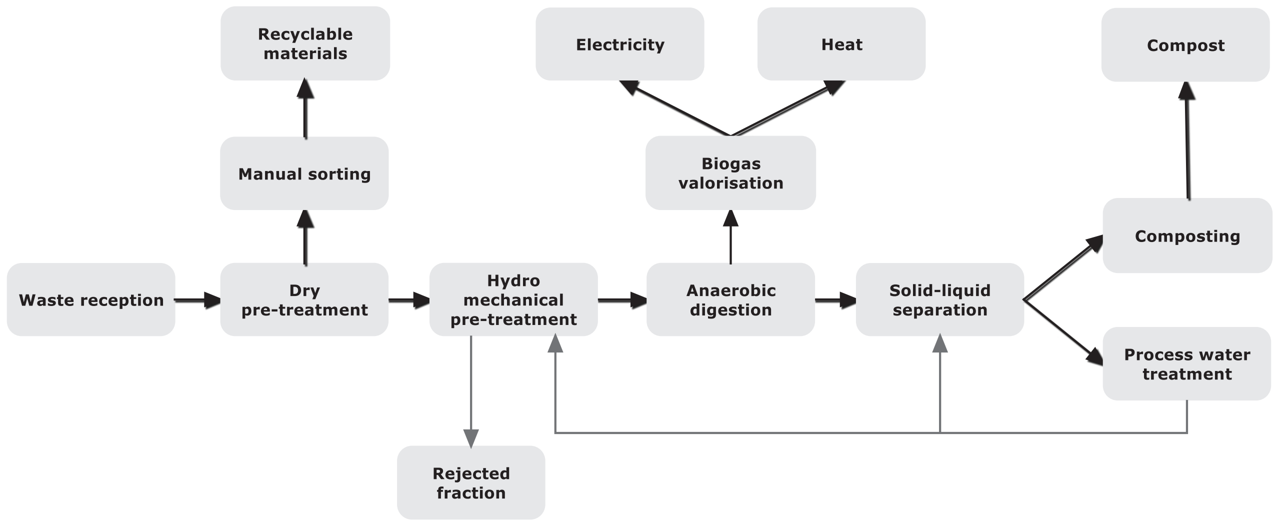

Figure 3. MBT plant process.

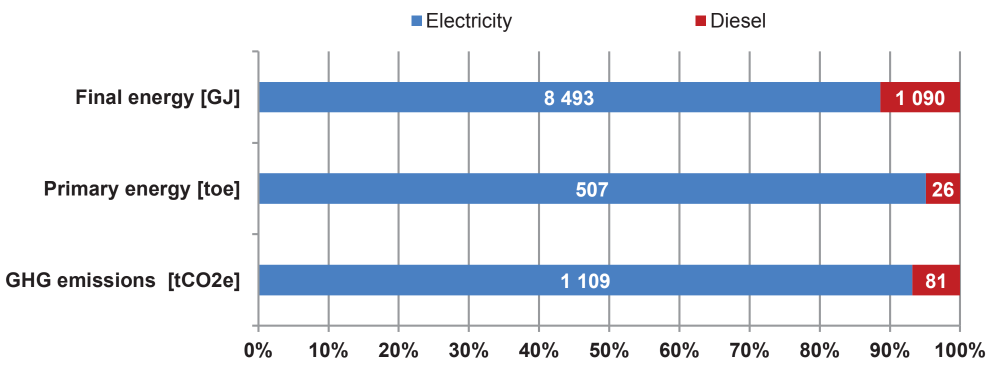

Figure 4. Baseline energy consumption and GHG emissions.

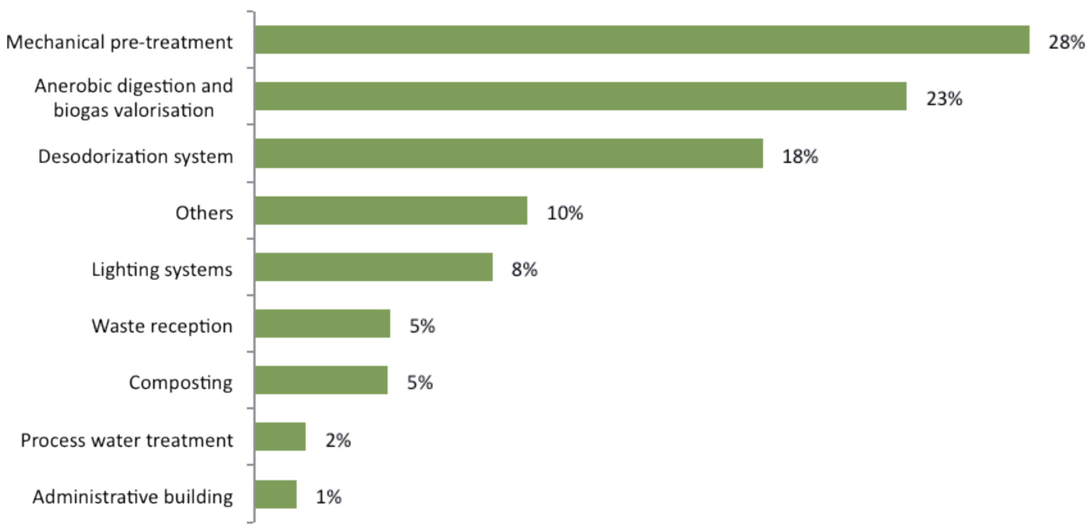

Figure 5. Breakdown of primary energy consumption by sector/end-use.

Table 1. Reference energy usage indicator.

Energy consumption [toe]	Energy consumption [GJ]	Business activity [ton]	EUI [kgoe/ton]	EUI [GJ/ton]
533	9,584	37,316	14.3	3.9

which is mostly performed in large tanks called "pulpers", in which the lighter fraction of waste is mixed with water and stirred to obtain an homogenous mixture, and impurities from the organic fraction such as grit are removed before the digestion process. Anaerobic digestion and biogas valorisation includes all the pumps and compressors necessary to maintain the anaerobic digestion process in biodigesters and posterior storage. Deodorization consists mostly of an air pumping system removing contaminated air from the facility, filtering and scrubbing, and finally injecting the air into a biofilter. Waste reception includes the first disaggregation of solid waste, including the wheel loader used for loading of the waste bags into the disaggregation (shredding) machine. The composting bin includes a number of ventilators used to ventilate compost piles.

In order to define targets to reduce energy consumptions it is necessary to establish a metric to compare the energy efficiency of the facility and report potential improvements, over the years. In the present study the index used is based on the ratio between energy consumption and business activity ratio, which is measured in tons of MSW treated per year. Thus, the energy usage indicator (EUI) computed is as follows in Table 1.

Energy conservation measures

During the energy audit several ECM were identified and its savings potential was estimated. The energy consumption in the year 2012 was considered as the baseline to study the savings potential of energy and cost, and the payback time was used as economic criteria to determine the cost effectiveness of each measure, due to its simplicity. The different ECM analysed and proposed for the MBT facility are described in the following subsections.

ENHANCEMENT OF COMPRESSED AIR SYSTEM PERFORMANCE

The compressed air system is a significant electrical energy consumer, with a large improvement potential. A package of three integrated interventions are proposed, in order to improve the overall performance of the system: a) replacement of existing compressors by a new, more efficient one; b) mending existing leaks and implementing a leak prevention to detect and fix new air leaks sooner; and c) reducing the operating pressure of system, which is made possible by the previous measure, leading to a decrease in the energy demand without the risk of occurring an excessive pressure drop. The estimated total annual savings due the enhancement of the compressed air systems are 8.7 toe.

IMPROVEMENT OF LIGHTING SYSTEMS

The improvement of lighting systems consists in a maximization of the daylight utilization due to translucent tiles application and the reconfiguration of the indoor lighting systems and their controls. Also, the outdoor lighting system will be interventioned, replacing 150 W high-pressure sodium (HPS) lamps with 100 W lamps. This ECM leads to an estimated overall reduction in the total annual energy consumption of 14.0 toe.

REPLACEMENT OF STANDARD-EFFICIENCY MOTORS AND INSTALLATION OF VSD

In order to reduce the energy consumption related to electric motors, six electric motors are planned to be replaced with higher efficiency equivalents. Most of these motors are associated with pumps or fans. Also, a variable speed drive (VSD) is to be installed driving the motor of the device responsible for opening and disintegrating the MSW bags. The annual amount of energy savings in the motor systems is expected to be 8.0 toe.

IMPROVEMENT OF REJECTED FRACTION TRANSPORTATION

As the transportation of the rejected fraction to landfill is performed by a truck, with high fuel consumption, a smaller and more efficient alternative vehicle (tractor-trailer) solution was devised, which can replace the truck in some of its routes. This is expected to result in an energy consumption reduction of 3.7 toe per year.

SUMMARY OF ENERGY AND COST SAVINGS

The feasibility of each ECM was measured through a simple payback analysis. Table 2 summarizes the potential energy and cost savings, investment and payback time computed, for each of the previously presented ECMs. The unitary cost of energy was determined from the monthly utility bills.

According to the values presented in Table 2 it is patent that the total amount of energy savings is 34.4 toe, corresponding to a reduction of 6.5 % in annual energy consumption of the facility, thus allowing the compliance with SGCIE. The total investment to implement the proposed ECMs is an estimated 111,180 EUR, with an overall payback time of 4.6 years.

Conclusions and outlook

This paper presents the main results of an energy audit performed to a MBT facility for MSW. Some sectors and equipment with significant energy consumption were found to have a potential for improvement through the implementation of ECMs, and the energy audit was an effective tool to identify the potential volume and the priority actions to be taken. The proposed ECMs will allow energy consumption to be reduced by 6.5 %, resulting in a total cost saving of 24,252 EUR per year, and 6.6 % reduction in CO_2 emissions.

Despite these energy savings, this waste treatment technology has additional energy consumption when compared to conventional mass grate combustion facilities without pretreatment, which is straightforwardly explained by the energy

Table 2. Summary of potential energy and cost savings, investment and payback.

ECM	Energy savings [GJ]	Energy savings [toe]	GHG savings [tCO_2e]	Cost savings [€]	Investment [€]	Payback [years]
Enhancement of compressed air system performance	146.3	8.7	19	4,501	12,270	2.7
Improvement of lighting systems	234.9	14.0	31	7,230	36,620	5.1
Replacement of standard efficiency motors and installation of VSD	134.4	8.0	18	4,107	17,490	4.3
Improvement of rejected fraction transportation	154.1	3.7	11	8,414	44,800	5.3
Total	669.7	34.4	79	24,252	111,180	4.6

necessary to the pre-treatment processes. However, usually MBT anaerobic digestion technology is associated to the production of electricity and heat from recovered biogas, which may compensate, at least partially, for the increased energy costs in MBT anaerobic digestion units.

Since the main goal of these facilities is the adequate treatment of waste, a balance of energy consumed and produced on site, as well as a comparison with other types of treatment, was considered beyond the scope of this work, but constitutes an interesting possible future work.

Energy audits provide the information that energy managers need to identify energy consumption patterns and components of a facility and document existing conditions. ECMs can be identified and prioritized. By taking an open-minded and methodical approach to the audit process, it is possible to identify and avoid unnecessary expenditures in most facilities while improving the operation and production.

While the results obtained and presented here are only valid for this particular facility, they can be used in comparison when addressing other very similar facilities in layout and process, the methods used here can be applied, with the adequate adjustments, to other audits to very different facilities.

Acronyms

ECM Energy conservation measure
EnMS Energy management system
EUI Energy usage indicator
GHG Greenhouse gas
HPS High pressure sodium
MBT Mechanical biological treatment
PDCA Plan-do-check-act
VSD Variable speed drive

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