# Analysis of Alternative MSW Treatment Technologies with the aim of Energy Recovery in the Municipality of Vari-Voula-Vouliagmeni

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**Abstract** The design and implementation of flexible plants with thermal or biological waste treatment methods are significantly important in conjunction with European and National environmental legislations. Alternative Municipal Solid Waste (MSW) management is directly linked to the reduction of the biodegradable fraction and total waste mass disposed to landfill sites. This paper focuses on the techno-economic analysis of a small scale waste management project through an integrated mechanical-biological treatment scheme which includes the technology of anaerobic digestion (AD) for combined heat and power (CHP) production. Additionally, the main technical and design parameters of the digesters are also reviewed. The goal is to investigate the economic viability of the integration MSW concept by comparing it to the current practice of waste disposal.

**Keywords:** municipal solid waste, mechanical biological treatment, waste treatment products, dry anaerobic digestion, composting

## 1. Introduction

A legislative framework on the MSW management field has been drawn up for all the countries-members of European Union. The" landfill directive" (1999/31/EC) in combination with Waste Framework Directive (2008/98/EC) are the main legal tools in which detailed objectives and priorities as well as an indicative timetable for their implementation are specifying. The standard outline of the hierarchy ranks 6 approaches to waste management. In order (most preferable to least preferable) these are: prevention, minimisation, reuse, recycle, energy recovery and disposal (Official Journal of the European Communities, 16/07/1999 & 22/11/2008).

Anaerobic digestion (AD) is one of the most mature MSW technologies. Specifically in Europe alone, more than 250 installations dealing with the organic fraction of MSW as a significant portion of the feedstock have been constructed or are permitted and contracted to be constructed. (Luc De Baere and Bruno Mattheeuws 2015; California Integrated Waste Management Board 2008). The dominant MSW treatment method in Greece remains the landfill disposal (80%), while only the 4% of the produced MSW is fed to composting systems (Eunomia 2009).

The scope of this study is to investigate the financial sustainability of the erection of a small-scale Mechanical Biological Treatment (MBT) plant for treating biowaste combined with biogas production in the Municipality of Vari-Voula-Vouliagmeni (VVV), located in the department of Attica, Greece. Hence, a detailed techno-economic analysis is carried out, including the investment costs, the operational costs and the revenues from the electricity and recyclables sale in the local market.

## 2. Methodology

The proposed system involves the development of a MBT plant which operates in two stages. The first stage, involves the mechanical pre-processing of the entire waste stream in a Mechanical Treatment Facility (MTF). The second stage includes the AD of the separated Organic Fraction of MSW (OF-MSW) in a Biological Treatment Facility (BTF). Regarding the post-treatment of the digestate, a Composting Treatment Facility (CTF) with open windrows is considered.

A dry-batch system with garage-shaped digesters at mesophilic temperatures (35-38°C) is selected as an AD system, since it combines a modular and compact structure with high energy efficiency and maximum process water savings (T.Z.D. de Mes et. al 2003; RIS International LTD. 2005; Bekon Brochure; Herhof GmbH Brochure), while also being the most applicable at small scale (Luc De Baere and Bruno Mattheeuws 2015; Adriana Perez Garcia 2014).

The capacity of mechanical treatment stage was estimated in accordance with the annual production of mixed waste in the Municipality of VVV. As far as mechanical and biological processes are concerned, a mass balance was carried out where specific recovery rates for the different recyclable materials of the household waste were considered.

The recovery rates were obtained by other similar MSW mechanical separation processes which were detected in a variety of literature sources. More specifically the recovery rates assumed are: 35% for paper/cardboards, 55% for plastic, 90% for Ferrous metals, 85% for non-ferrous metals and 40% for glass (Tonini D. and Astrup T. 2012; Combs A. 2012; N. Pressley *et al*. 2014). The recovery of organic matter of household waste is carried out via an 80 mm trommel and it is considered to be on a rate of 90% (Cristina Montejo *et al*. 2011 Papageorgiou George 2016).

For the techno-economic assessment, indicative capital and operational costs are used, based on the literature and data from existing plants.

## 3. Case study: Municipality of VVV

The Municipality of Vari-Voula-Vouliagmeni is located in the south suburbs of Athens and its population is 48.817 citizens. A total of almost 35.000 tn of MSW is annually generated in the wider region, a number that corresponds to 706.62 kg/citizen. It is assumed that the production of mixed waste (containing household waste, green waste and bulky waste) approaches a quantity of 32.000 tn/year, whereas the amount of recyclable waste is nearly 3.000 tn/year (Local action plan for MSW management in municipality of Vari-Voula-Vouliagmeni, 2014).

**Table 1.** The composition of mixed waste in municipality of VVV

| Type of waste | Annual amount (tn) | Percentage (%) |
|---|---|---|
| Household waste | 18.997,52 | 59 % |
| Green waste | 10.110,17 | 32 % |
| Bulky waste | 2.794,03 | 9 % |
| Mixed waste | 31.763,18 | 100 % |
| Recyclable waste | 2.732,00 | |
| Total MSW | 34.495,18 | |

Based on the data given by the Municipality, the overall MSW management cost was 5.691.156€ or 165 €/tn in 2014. The annual operating costs are divided into direct and indirect expenditures arising from sectors concerning the waste collection, the transportation via refuse vehicles and the disposal at the sanitary landfill area situated in west suburbs of Athens (Ano Liosia).

The national landfill gate fees for the Municipalities are expected to highly increase until the year of 2020 in accordance with L. 4257/2014 and L. 4042/2012. This legislative imposition of penalties for waste disposal practices provides motivations for the development of alternative waste management plans and Municipality of VVV seems to be pioneer of finding the most sustainable solution.

The proposed plant incorporates a CHP facility for implementing electrical and thermal energy recovery via the biogas utilization into an internal combustion engine. Hence, revenues from the energy production are considered according to the feed in tariff prices given by the national legislative framework, L. 4414/2016 (129 €/$MWh_{el}$ for $P_{el}$<=2 MW).

## 4. Results

The nominal input for the MBT plant is 35.000 tn/year while the BTF is designed to receive 18.500 tn/year of organic waste. Additionally, the total plant is considered to contain several areas and facilities, each contributing differently to the Project objectives of recovery and recycling, residual treatment and energy cogeneration.

### *4.1 Basic project description*

The mixed MSW is delivered to a concrete deep bunker, contained within an enclosed building of the mechanical pre-treatment area of the plant. The waste is fed from the reception bunker to the MTF via a walking floor, while a crane and a grab mechanism are also used for transportation. The manually sorted stream of household waste passes through a horizontally laid down 80mm rotary trommel where fine materials fall and larger materials spiral through, leaving it toward following separation processes in which both partial recovery of recyclables and production of Refuse Derived Fuel (RDF) are carried out.

The mechanical equipment used in this section is shredders, drum screens, an air classifier, eddy current separators, magnetic separators and balers (Papageorgiou George 2016; Enzo Favoino *et al*. 2013).

The recovered organic fraction is mixed with the shredded in a diameter of almost 60 mm green waste fraction, composing a homogenized and biodegradable mixture almost equal to 18.500 tn/year. The organic feedstock with basic substances food and garden waste is stored within bunkers into a tipping building of the BTF before moving by a wheel loader within the garage-shaped digesters. Inoculation takes place by mixing the fresh substrate with material that has already been fermented. It is then filled into each cell and digested under airtight conditions for 20 days. Once the fermentation process is completed, each fermenter is emptied (Adriana Perez Garcia 2014; Bekon Brochure; Herhof Gmbg Brochure). The generated biogas is dried in a gas-processing chamber, where gas quality and flow rate are measured. It is then pumped through a gas-regulating device with the respective safety installations into the biogas CHP unit (Bekon Brochure & spin-project.eu).

Finally, 50 % of the dry fermentation residue (digestate) is separated and mixed with new materials to be processed in the AD digesters while the rest 50 % is optionally composted via an enclosed tunnel composting process. The last composting stage generally takes the form of windrow composting where the retention time in each cell is estimated at 30 days. The final compost is a valuable organic quality fertilizer used in agriculture and gardening, possibly generating additional revenue (Adriana Perez Garcia 2014; Bekon Brochure; spin-project.eu).

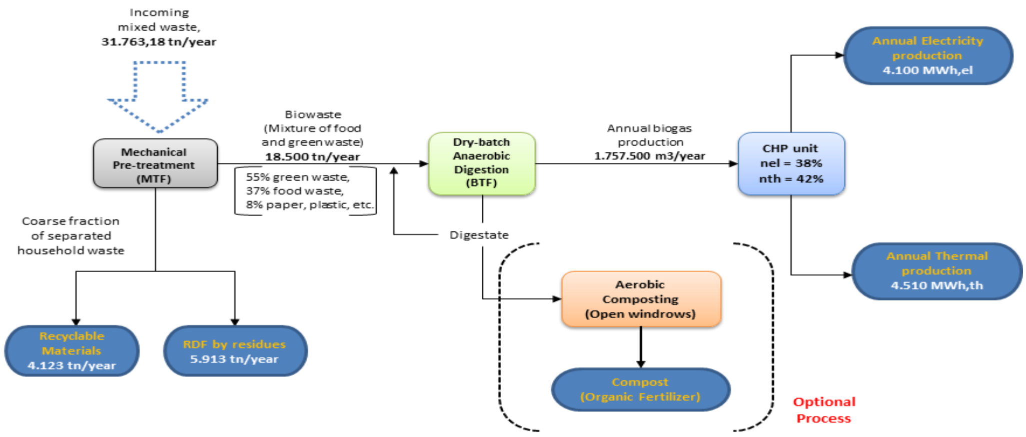


**Figure 1.** Simplified flow diagram of the designed waste infrastructure network H for the removal of Pb (II) onto diatomite

**Table 2.** Basic technical characteristics for the MBT plant

| Technical aspects | Assumed values | Value range | Literature sources |
|---|---|---|---|
| Biogas yield value | 95 Nm3/tn | 80-125 Nm3/tn | James Browne *et al.* 2013; Adriana Perez Garcia 2014; RIS International LTD. 2005 |
| Annual biogas production | 1.757.500 Nm3/year | - | - |
| Lower Calorific Value (LHV) | 22 MJ/m3 | 19-26 MJ/m3 | T.Z.D. de Mes et. al 2003 ; Adriana Perez Garcia 2014 |
| Electrical efficiency rate (nel) | 38% | 30-40% | Tonini D. and Astrup T. 2012; James Browne *et al.* 2013; T.Z.D. de Mes et. al 2003 |
| Thermal efficiency rate (nth) | 42% | 35-45% | Tonini D. and Astrup T. 2012; James Browne *et al.* 2013; T.Z.D. de Mes et. al 2003 |

**Table 3.** Specific net annual costs for the designed MBT plant

| | |
|---|---|
| Total annual investment cost (annuity) | 2.202.355 € |
| Total operational cost | 2.050.000 € |
| Collection and Transportation cost | 4.064.117 € |
| Revenues from electricity sale | 476.010 € |
| Revenues from recyclable materials sale | 815.860 € |
| Specific net annual costs | 7.024.602 € or 200,7€/tn MSW |

*4.2 Technoeconomic evaluation*

The small scale MBT plant operates for 8.200 hours/year, corresponding to an annual production of electricity and heat of 4.100 $MWh_{el}$ and 4.510 $MWh_{th}$, respectively. The evaluation of energy production levels is based on the assumptions summarized in Table 3.

The investment costs for both Mechanical and Biological Treatment stages are estimated to be 11.000.000 € and 6.752.500 € while the annual operating costs are 1.200.000 € and 850.000 €, respectively. Including the CHP plant, the total capital cost is 17.752.500 €. The annual operational cost is estimated equal to 2.050.000 €. It is assumed that the energy required for running the plant is covered by electricity produced from the CHP unit. Additionally, costs for refuse collection and transportation to the proposal MBT plant are calculated to be 4.064.117 €/year (Sotirios Karellas *et al*. 2009; RIS International LTD. 2005).

The revenues from selling the generated electricity (90%) to the national electricity grid are 476.010 € or 13,6 €/tn of waste. Next, the revenues from the sale of the recovered recyclable materials are calculated equal to 815.860 € or 23.3 €/tn. The net annual specific costs, including capital and operational costs, waste collection and transportation costs, revenues from the sale of electricity and recovery materials, are approximately 201 €/tn. The individual specific annual costs for the designed MBT plant in VVV are presented in Table 3. For the economic analysis, an interest rate of 9 % and a project life of 15 years have been assumed.

The scenario involving the development of the MBT plant is compared with the existing scenario of waste disposal. By estimating the annual savings occuring in the MBT scenario, it estimated that the NPV of the investment is equal to 3.856.299 €. Meanwhile, an interest rate of 12.3 % is calculated. The payback period is equal to 6,47 years. Considering the above economic indexes, the investment is profitable.

## 5. Conclusions

The integrated Mechanical Biological plant can be a reasonable suggestion towards the realization of a proper Municipal Solid Waste management in municipality of VVV. The provided possibility for disengagement from biodegradable waste landfilling practices in combination with material recovery, biogas production and energy cogeneration are the key factors which encourage the examination of such a kind of project. In addition, as national landfill gate fees for the Municipalities are increasing till 2020, the implementation of an AD-MBT for CHP is an economically appealing alternative to the current waste disposal scheme. The results from the economic analysis indicate that the development of the MBT is economically favorable, apart from its environmental advantages.

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