SusNisia: Circular economy for biogenic residues for the North Aegean – case studies for Islands of Chios and Lesvos

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Abstract
The North Aegean Islands of Chios and Lesvos set recycling goals for organic residues from Municipal Solid Wastes (MSW). Both islands, in line with the National and Regional Plans for Municipal Waste Management, are discussing the approach of mechanical-biological stabilization MSW in combination with separated collection of biowastes and municipal pruning. The SusNisia-project, funded by BMU[1], adds Anaerobic Digestion (AD) to both approaches to demonstrate the added-value by production of biogas for energy purposes or as fuel for e.g. garbage trucks. The advantages of separated collection of organic input materials are the production of high quality and multi-purpose end-products to serve the goal of local nutrient recycling. As refinement, SusNisia applies digestate or compost from Biowaste-AD and char coal from municipal pruning for production of specific soil enhancement products e.g. for olive tree cultivation, vegetable farming and greenhouse applications. The char coal, as activated char, absorbs pollutions, provides a sink for carbon dioxide and delivers extended water storage capabilities. The paper focus on dry fermentation option with German technology for islands of Lesvos and Chios to demonstrate added value by sectoral coupling to integrated waste management systems.
Keywords: Anaerobic Digestion, Biogas, Biomethane Biowaste, Combined-Heat and Power, Organic-Rankine-Cycle, Municipal Solid Waste

1. Introduction

Greece currently produces about 5.2 Mt of municipal waste in 2010 [EIB 2010], equivalent to a per capita waste generation rate of 460 kg/capita. According to OECD, in 2017 ca. 80 % of MSW was landfilled, contrary to the expectations of the EU landfill directive 1999/31/EC. In this respect, Greece was among the EU countries which missed the diversion target of 75% since then, the country has continued to struggle in achieving the minimum targets of the landfill directive. Greece introduced therefore in 2015 the national waste management plan of Greece [Harocopou & Trichilis 2016]. In the frame of the SusNisia project, the Greek islands of Lesvos and Chios are showcases for transformation to sustainable waste management system which meets EU-legislation. The Island's initiatives focus on reduction of organic fraction within the MSW by a) introduction of separated bio-waste collection and production of compost and b) Aerobic biological treatment (ABT) of MSW to reduce organic fraction by composting. In a first step Lesvos will introduce a separated collection of biowastes and treatment within an ABT for the capital of Mytilini. The island of Chios will introduce an ABT and incineration plant for MSW and introduce separated collection of biowastes on a later stage. Within the SusNisia-project, the University of the Aegean, the German partner Bekon GmbH and IZES gGmbH (Institute for Future Energy and Material Flow Systems) demonstrated the potential added-value to the Island's initiatives by application of intermediate anaerobic digestion step. The project investigated the economic and technical feasibility of such a project in the context of the Islands.

2. Added-Value of Biogas from AD-plants

Within the objective to reduce the organic fraction within the MSW, the production of biogas from waste can generate added-value in the field of energy supply. Biogas has a heating value of 6 kWh/m^3. This energy can be used to cover self-supply of electricity, heat or fuel for the waste management facilities or even sold to the market. This advantages are accompanied by higher efforts of technical management of the anaerobic process and higher costs for investment (CAPEX) and operation (OPEX). The specific economic feasibility is highly depending on factors like energy revenue schemes, investment funding schemes and legal specifications. Major advantage is the mitigation of GHG emissions in compare to ABT [Phong 2012] and know-how transfer of technology. There are different possible utilisation options of biogas which have been considered in SusNisia: Removal of CO_2 and upgrading to 100% methane as CNG[2]. Utilisation of the resulting biomethane for fuel purposes for municipal transport or feed-in into a natural gas grid. The untreated biogas can be used directly within a CHP unit, consisting of combustion engine and power generator. The produced electricity can be used to substitute costs for supplied energy or can be fed into the power grid within a feed-in scheme or based on market conditions. The produced heat,

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[2] Compressed Natural Gas

about 40 – 45% of the total energy, can be used to provide heat up to 80°C for process or building heating. If a heat demand will not be possible as third option an ORC system can be attached to use the heat energy for production of additional power, increasing the electric efficiency. The feasibility of each options has to be considered within additional effects. The utilisation of CNG as fuel needs investments in upgraded vehicles and a distribution logistic. Waste heat could be used for heating purposes within a district heating network which needs investments for infrastructure and sufficient heat consumer.

3. Status-Quo of Organic Residues on the Islands

Table 1 shows 4 major organic residues on the islands including suitable treatment options and energy content. Based on this this analysis MSW, Biowastes and municipal pruning were selected as input material for the AD-plants. Overall for Chios ca. 20,000 – 22,000 t/a MSW and for Lesvos ca. 40,000 t/a MSW and ~9,000 t/a pruning were stated. For the SusNisia-Showcases, for Chios 10,000 t/a
MSW and for Lesvos 4,000 t/a biowastes and 4,500 t/a pruning were selected.

Table 1. Status Quo Analysis for Organic Residues and Technologies (Source: University of the Aegean & IZES GmbH)

	Organic Residues	Quantities 2017	Technologies	Quantities for SusNisia	Biogas Output
Chios	MSW	~20.800 t/a	AD, ABT	10,000 t MSW/a for AD	1,200,000 m^3/a
	Fruit Peels from Fruit Juice Production	~1,100 t/a	AD, Compost		
	Whey from dairy farms	~895 m^3/a	AD		
	Pomace from olive oil production	~825 t/a	Pyrolysis, Composting		
Lesvos	Whey from dairy farms	~26,387 m^3/a	AD		
	Pomace from olive oil production	~18,901 t/a	Pyrolysis, Composting		
	MSW	~40,000 t/a	AD, ABT	4,000 t/a biowaste for AD	360,000 m^3/a
	Pruning from municipal greencut	~9,000 t/a	Compost, AD, Pyrolysis	4,500 t/a for AD	380,000 m^3/a

4. Costs-Benefits Analysis

Table 2 shows the products and possible revenues for the different utilisation options. The calculation for invest are based on assumption from BEKON GmbH, For CNG, the net average market price for Greek was used [CNG Europe 2019]. The feed-in tariff is defined art. 4 par.1b Law No. 4414/2016 with 129 €/MWh for installations with < 2 $MW_{el.}$ [European Commission 2016]. A typical end-consumer price for electricity can be stated with 180 €/MWh_{el} [Schälicke 2018].

Table 2. Technical and Economic Feasibility (Source: BEKON GmbH & IZES GmbH)

Island	Selected Quantities for Showcase	Biogas Output	Technology	Outputs[2]	Costs (OPEX and CAPEX)	Revenues
Chios	10,000 t $MSW_{50\% \text{ organic content}}$/a	1,200,000 m3/a	Biogas to Power and Heat via CHP with 360 kWel	Power: 2.6 GWh_{el}/a	CAPEX 3.3 Mio. € OPEX 0.13 Mio. €/a	~ 0.33 Mio. €/a with feed-in tariff ~ 0.47 Mio. €/a at 018 €/kWh
				Heat: 2.5 GWh_{th}/a		No utilisation
			Biogas to Power and Heat via CHP with 360 kWel + ORC-Plant	Power: 3.3 GWh_{el}/a	Not determined	~ 0.43 Mio. €/a with feed-in tariff 0.6 Mio. € at 0.18 €/kWh
				Heat: < 2 GWh_{th}/a		No utilisation
			Biogas to Methane Upgrader	CNG (99% CH_4): 678 t/a		~ 0.49 Mio. € CNG ~ 0.5 Mio. l/a vehicle fuel
Lesvos	4,000 t/a Biowaste + 4,5000 t pruning /a	740,000 m3/a	Biogas to Power and Heat via CHP with 220 kWel	Power: 1,54 GWh_{el}/a	CAPEX 2.8 Mio. € OPEX 0.1 Mio. €/a	~ 0.2 Mio. €/a with feed-in tariff ~ 0.28 Mio. €/a with 0.18 €/kWh
				Heat: 1.65 GWh_{th}/a		No utilisation
			Biogas to Power and Heat via CHP with 220 kWel + ORC-Plant	Power: 2.15 GWh_{el}/a	Not determined	~ 0.28 Mio. €/a with feed-in tariff ~0.39 Mio. €/a with 0.18 €/kWh
				Heat: < 1 GWh_{th}/a		No utilisation
			Biogas to Methane Upgrader	CNG (99% CH_4): 419 t/a		~ 0.3 Mio. € CNG ~ 0.34 Mio. l/a vehicle fuel

5. Summary and Conclusion

Beside direct financial effects by utilisation of biogas an intermediate AD step can add the following indirect positive effects:

- As the AD need a post-composting of digestate to inert remaining organic activity, the proposed size of ABT plant can be reduced, leading to less investment and operational costs.
- The AD-plant can use MSW and Bio-wastes without technical adjustments.
- Duo to similar pre- and post-treatment of wastes, mobile equipment such as sieving units, grinder, loader etc. can be used.
- The production of electricity from waste allows the substitution of electric energy from current fossil crude oil powered plants, leading to a greener power mix.
- Operation and optimisation of AD-plants increase of local know-how and provide best-practice example for other islands.
- Digestate from bio-wastes can be used as compost or as input for soil products to substitute mineral fertilizer.

AD-systems have higher investment and operational costs then ABT but generate direct revenues from biogas valorisation, such as biomethane fuel for operation of municipal vehicles or sales of electric and heat energy.

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