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Industrial Urban Symbiosis: A Solution to Transform Waste into Resources

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Abstract
The Greek EcoSite, located in Western Achaia, exemplifies the benefits of industrial-urban symbiosis (I-US) through its innovative waste treatment processes and integrated approach. By promoting collaboration between industries and urban areas, the EcoSite optimizes resource use and minimizes waste, addressing critical waste management challenges in the region. The Greek EcoSite demonstrates a viable, circular approach to waste management, aligning with broader environmental and economic sustainability goals. It showcases potential for replication across different industrial and urban landscapes aiming to close material loops and produce high-value resources from waste.

Keywords: I-US, industrial- urban symbiosis, methane, AnMBR

1. Introduction

Many regions—particularly urban areas—rely heavily on external resources to sustain their economies (Wiedmann et al., 2015). These resources are often sourced from hinterlands located thousands of kilometers away from the point of consumption. As a result, urban regions are increasingly vulnerable to disruptions in resource availability, especially in the face of global challenges such as climate change and geopolitical or economic instability. To address these risks, urban areas must adopt strategies that enhance their resilience in resource supply chains while also minimizing their environmental impact. One such opportunity is urban-industrial symbiosis (I-US), which has been recognized as a promising approach. I-US builds upon the concept of industrial symbiosis (van Berkel et al., 2009) and is considered a key strategy within the circular economy framework (Murray et al., 2017). Industrial symbiosis involves networks of diverse organizations that exchange materials, energy, and/or water within a shared geographic area. The term "symbiosis" draws inspiration from natural ecosystems, where different species exchange resources such as materials, energy, or information. In this context, industrial partners can collectively enhance their competitiveness through mutual exchanges, rather than acting independently.

This work has been carried out as part of the Horizon Europe SYMSITES project. The SYMSITES initiative focuses on implementing industrial-urban symbiosis strategies to convert waste and by-products into environmentally sustainable value-added products. The project has tested innovative technologies, methodologies, and stakeholder engagement approaches across four EcoSites located in different European regions, each characterized by distinct socioeconomic and environmental conditions—ranging from northern Europe (Denmark), through central Europe (Austria), to southern regions (Spain and Greece). At the Greek EcoSite, an anaerobic membrane bioreactor (AnMBR) has been employed for the production of methane, water for irrigation and compost. In addition, the prospect of producing biohydrogen and biopolymers from specific food waste streams is also explored.

2. Greek EcoSite

The increasing demand for sustainable waste management has led to the integration of mixed waste valorization in decentralized treatment systems. A dark fermentation (CSTR1) system was piloted at the Greek EcoSite to explore hydrogen production using the Liquid Fraction of Food Waste (LFFW), obtained using a screw press, as the feedstock. The Greek EcoSite investigates the performance of anaerobic digestion for different feedstock combinations of municipal wastewater (MWW), Olive industry wastewater (OIWW), and the liquid condensate of food waste obtained upon drying food waste in a dryer/shredder . In an Anaerobic Membrane Bioreactor (CSTR2) system, the organic load reduction was evaluated—quantified as COD—and the methane potential of was assessed, across different experimental phases, simulating real operational scenarios.

The Greek EcoSite is located at the wastewater treatment plant (WWTP) in the municipality of Western Achaia. This urban-industrial symbiosis extends over a larger area of approximately 13.5 km^2, encompassing Ano Alissos, the industrial zone, and the WWTP. The EcoSite focuses on waste from olive industry and is designed to treat industrial and urban wastewater as well as food waste. The overall flow diagram of the Greek EcoSite is presented in Fig.1 and the operational parameters of the AnMBR and are given in Table 1.

The operation of the AnMBR system was divided into four distinct periods:

- Period 1: Municipal wastewater (MWW) treatment under varying hydraulic retention times (HRTs), starting from 4 d and reducing to 1 d.
- Period 2: Co-digestion of municipal wastewater (MWW) and Olive industry wastewater (OIWW) and gradually increasing concentrations of OIWW moving from weak to strong feed organic load. The HRT was 2d.
- Period 3: Further co-digestion including the three waste streams using municipal wastewater (MWW), Olive industry wastewater (OIWW), and liquid fraction of food waste (LFFW) at an HRT of 4d
- Period 4: The liquid fraction (condensate) generated from the dryer /shredder replaced the LFFW in the buffer tank, while the solid fraction so-called FORBI (food residue biomass) may be used for compost production.

Table 1. AnMBR operational parameters

Parameter	Unit	Target/Range	Notes
Anaerobic Membrane Bioreactor (AnMBR)			
Hydraulic Retention Time (HRT)	days	1–4	Adjusted based on feed composition
Organic Loading Rate (OLR)	g COD/L/day	0.8–2.0	Increased OLR improved methane yield
pH	pH units	7.1–7.5	Maintained for methanogenic activity
Temperature	°C	Mesophilic conditions (35°C)	No additional heating applied
tCOD Removal Efficiency	%	≥90	Demonstrated effective organic removal
Effluent TSS	mg/L	≤10	Well below directive limit (35 mg/L)
Effluent Total Nitrogen	mg/L	68 (target <10)	Requires tertiary treatment or agricultural reuse
Effluent Total Phosphorus	mg/L	15.7 (target <0.7)	Also requires improvement for discharge compliance
Biogas Composition	% CH_4 (v/v)	≥70	Efficient methanogenesis confirmed

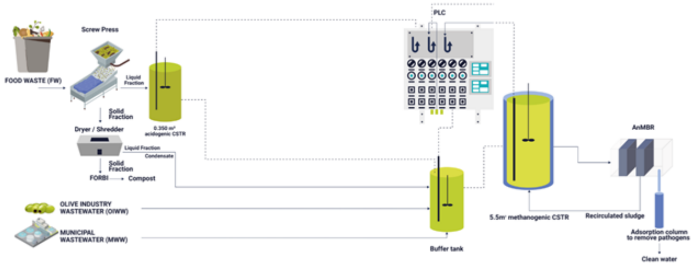

Figure 1 Flow diagramm of the Greek EcoSite

3. Conclusion

The anaerobic membrane bioreactor system may treat effectively the municipal wastewater at a low HRT (1d) leading to significant energy and sludge management cost reduction if it replaces the existing aerobic treatment process. The results validate the feasibility of co-digesting MWW with high-strength industrial effluents and the liquid fraction of municipal solid waste, if appropriate acclimation and operational adjustments (e.g., buffer volumes, pH control) are applied albeit at high retention times. The progressive increase in methane potential across periods highlights the synergistic effect of feed complexity. Co-treatment of industrial and urban wastewaters leads to high methane production.

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