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The Economics and Policy of Biomethane: A Pragmatic Approach to Renewable Energy and Waste Valorization

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ABSTRACT

Biomethane, also known as green gas, contributes to urban sustainability and decarbonisation by valorising waste such as the Organic Fraction of Municipal Solid Waste (OFMSW). This study assesses the economic feasibility of a biomethane plant, using discounted cash flows in a medium-sized plant located in Rome using OFMSW as a substrate. The results confirm the project's feasibility, with the following key indicators: a Net Present Value (NPV) of 1635 k€, an Internal Rate of Return of 46%, and a Discounted Payback Time of 3 years. Subsidies account for approximately 60% of revenues and therefore have a significant impact on the project's economic viability. It emerges that at an incentive of 0.732 €/m³, the NPV is positive in 86% of simulated cases; if reduced to 0.627 €/m³, the probability of profitability drops to 27%. Break-even is reached at 0.623 €/m³ for a 250 m³/h plant. Stability of incentives and the development of a national supply chain are essential to ensure pragmatic and long-term sustainability and reduce reliance on public support. Biomethane supports SDGs 7-12 by providing renewable energy, promoting a circular economy, improving waste management, and contributing to more sustainable and inclusive cities.

Keywords: Biomethane, Economic Analysis, Subsidies, Sustainable Development, Waste Management
JEL Classifications: O44, Q20, Q40, Q57

1. INTRODUCTION

The energy transition is a vital component for Europe's goal of achieving carbon neutrality by 2050. The Repower EU plan outlines urgent actions to diversify the European Union's gas supply and speed up the shift toward sustainable energy sources. By 2030, the European biogas industry is projected to produce around 35 billion m³ of biomethane annually (Sulewski et al., 2023). This growth highlights the increasing importance of green gas in supporting the energy transition (Giocoli et al., 2023; Singlitico et al., 2019). In the context of a global energy crisis, the exploration of alternative energy solutions has become imperative to promote energy security. Historically, fossil fuels have underpinned human energy consumption, significantly contributing to climate change. As a result, countries around the world are actively working to implement solutions that meet international greenhouse gas reduction targets, encourage sustainability, and drive economic development (Nastasi et al., 2022; Qyyum et al., 2022). Biomethane, as a renewable energy carrier, emerges as a promising green alternative with the capacity to decarbonize sectors that are traditionally difficult to abate (Bose et al., 2022a). More specifically, biomethane contributes to emission reductions while facilitating the valorisation and management of increasing volumes of organic waste. This aligns with policies related to energy, waste management, and the circular economy (Bose et al., 2022b; Lombardi et al., 2021; Ozturk et al., 2025), thereby positioning biomethane as a viable solution to contemporary societal challenges. Nevertheless, the broader adoption of biofuels remains constrained by the reliance on suboptimal feedstocks (Dessi et al., 2022; Rehman et al., 2022). Although environmental awareness has increased, a significant gap remains between public support for biofuels and their actual usage (de Paula Leite et al., 2025). This needs a robust collaboration among stakeholders throughout the local value chain (D'Adamo et al., 2025).

In the biogas and biomethane sectors, public acceptance is generally higher when facilities are situated in proximity to biomass sources, thereby minimizing transportation requirements (Lubańska and Kazak, 2023). Additionally, the development of decentralized facilities—particularly in rural or agricultural settings—can enhance public support (Lisiak-Zielińska et al., 2023) and promote socio-economic development in depressed regions (Guerra-Mota and Aquino, 2024). In the end, achieving sustainable transformation requires active participation from citizens, supported by education and effective communication efforts (Carbonell-Alcocer et al., 2021).

Despite growing support for biomethane, environmental concerns remain, such as odor emissions and poor integration with the local landscape (Bourdin et al., 2020). Social justice issues also arise, especially when economic benefits are seen as unevenly shared (Bourdin and Chassy, 2023). Other challenges include potential declines in property values near production sites (Zemo et al., 2019) and the NIMBY ("Not In My Back Yard") effect (Mancini and Raggi, 2022; Mazzanti et al., 2021). However, generating renewable energy locally is vital for increasing regional energy independence (Lyytimäki et al., 2021). Encouraging open dialogue and inclusive governance at the local level can help reduce opposition and boost social acceptance (Niang et al., 2022). Therefore, community consultations are essential to ensure the successful adoption of biomethane projects (Bourdin and Delcayre, 2024).

Global guidelines for waste reduction emphasize improved management of recyclable waste and aim to achieve no landfill disposal. Anaerobic digestion (AD) for bioenergy recovery has emerged as an attractive waste management approach within modern industrial settings, providing environmental benefits and generating clean biogas (Haider et al., 2022; Volpi et al., 2023). Biomethane contributes to the circular bioeconomy by enhancing resource efficiency, minimizing waste, and creating economic value through innovative business models. This transition addresses both resource depletion and climate change challenges (Le Pera et al., 2022). Moving from a linear "take-make-waste" paradigm towards a circular bioeconomy necessitates coordinated efforts across the supply chain and consideration of regional technical, cultural, and political contexts (Dees et al., 2023). This is especially encouraging for the agricultural sector, where large amounts of waste can be transformed into energy and fertilizers, helping to reduce pollution while creating additional value for farmers and other stakeholders (Feng et al., 2023). The creation of new jobs, reduced health care costs, and improved quality of life in communities represent additional benefits that this approach can bring about (Cucchiella et al., 2019; Ruiz-López et al., 2022). Notably, biomethane can stimulate economic growth in rural areas by converting organic waste into marketable products, thus creating employment opportunities and increasing agricultural incomes. Furthermore, it enhances energy security by reducing dependence on foreign energy sources (D'Adamo et al., 2023). This can help to achieving global sustainability objectives, as Sustainable Development Goals (SDGs) 1-2-3-7-8-9-12 (Solarte-Toro and Cardona Alzate, 2021). Several studies concentrate on Italy, which is often regarded as a benchmark for the biogas-biomethane value chain (Bux et al., 2023; Calise et al., 2024; Sica et al., 2023; Valenti et al., 2023). Biomethane thus clearly emerges as a key energy source for sustainable production (D'Adamo et al., 2023). Previous assessments of profitability have indicated a strong dependence on incentive mechanisms (D'Adamo et al., 2023; Naquash et al., 2022), with growing emphasis on small and medium-sized plants to promote decentralized energy systems (Catalano et al., 2024; O'Connor et al., 2021). Some analysts suggest that the European biogas-biomethane market is substantially influenced by policy frameworks (Sesini et al., 2024), highlighting the need to evaluate the potential impact of new incentive decrees to sustain the sector in a mature market. Despite progress, significant untapped potential remains (Noussan et al., 2024), underscoring the importance of assessing the interplay between plant profitability and the prevailing market and regulatory environments (Catalano et al., 2024). The analysis of the biomethane chain requires an assessment of the prospects in local areas. For example, the social context in the city of Rome shows how biomethane can support sustainable development (D'Adamo et al., 2025) going beyond perspectives that contrast NIMTO (Not In My Term of Office). There is a need to formulate profitability analyses for the various incentive mechanisms in place (Catalano et al., 2024). This work aims to fill this gap.

This study assesses the economic and financial feasibility of OFMSW treatment and biomethane production projects, emphasizing their profitability and potential contribution to sustainable development. It evaluates a medium-sized plant (250 m^3/h) located in Roma. The analysis integrates economic considerations and situates the biomethane sector within the broader waste management context providing policy implications. The structure of the paper is as follows: following this introduction, Section 2 presents the economic model; Section 3 provides a descriptive analysis of the results across various scenarios; and Section 4 concludes with relevant policy implications.

2. METHODOLOGY

This section provides a description of the relevant policy framework (section 2.1), followed by a description of the economic model (section 2.2) and a presentation of the input data (section 2.3).

2.1. Policy Framework

The new Italian incentive decree (Ministerial Decree of September 15, 2022) targets an additional biomethane production of at least 2.3 billion m^3 by June 30, 2026. The decree primarily supports the integration of biomethane into the natural gas grid through two key incentives: (i) A capital grant covering up to 40% of eligible costs, and (ii) an energy account incentive, which provides a tariff applied to net biomethane production for 15 years. These incentives apply to newly built biomethane plants used for agricultural purposes or fueled by waste, as well as to the conversion of existing agricultural plants into biomethane production facilities. For plants with a capacity up to 250 m^3/h, an all-inclusive tariff is offered - a single payment encompassing both the economic value of the natural gas sold and the guarantee of origin. The reference tariff is set at 69 €/MWh. This tariff is adjusted based on any percentage reductions made during the application process, and further reductions may also apply.

2.2. Economic Model

In carrying out this analysis, the discounted cash flow method was used, which considers the time value of money, allowing the aggregation of cash flows through the application of an appropriate discount rate. The Net Present Value (NPV) quantifies the wealth generated by the project (D'Adamo et al., 2023; Gupta et al., 2022; Silagy et al., 2024). In this study, an economic evaluation methodology was adopted to determine the financial sustainability of the investment through the application of various analytical tools. In conjunction with the NPV, other indicators were used, such as the Discounted Break-Even Point Time (DBPT), which identifies the period of time required for the discounted and cumulative cash flows to reach the initial value of the investment, thus indicating the moment when there is a return on the investment related to the project in question. In addition, the IRR (Internal Rate of Return) is used to assess the profitability of an investment and is the discount rate that makes the NPV equal to zero, and the PI (Profitability Index) indicates the profits obtained for each euro invested.

The economic model used is in line with that proposed in the reference literature (D'Adamo et al., 2023):

$$NPV = \sum_{t=0}^{n} (I_t - O_t)/(1+r)^t \quad (1)$$

$$NPV/Size = (\sum_{t=0}^{n} (I_t - O_t)/(1+r)^t)/S_{biomethane} \quad (2)$$

$$I_t = R_t^{subsidies} + R_t^{selling} + R_t^{CO_2} + R_t^{compost} + R_t^{OFMSW} \quad \forall t=1 \ldots n \quad (3)$$

$$R_t^{subsidies} = Q_{biomethane} * AIT_u \quad \forall t=n_r \ldots n_s \quad (4)$$

$$R_t^{selling} = Q_{biomethane} * p_{biomethane} \quad \forall t=n_s+1 \ldots n \quad (5)$$

$$R_t^{CO_2} = Q_{CO_2} * p_{CO_2}^u \quad \forall t=n_r \ldots n \quad (6)$$

$$R_t^{compost} = Q_{compost} * p_{compost}^u \quad \forall t=n_r \ldots n \quad (7)$$

$$R_t^{OFMSW} = Q_{OFMSW} * \left(R_{gross,t}^{OFMSW} - C_t^{OFMSW}\right) \quad \forall t=n_r \ldots n \quad (8)$$

$$0_t = C_{lcs,t}^{1°s} + C_{lis,t}^{1°s} + C_{lcs,t}^{2°s} + C_{lis,t}^{2°s} + C_{lcs,t}^{3°s} + C_{lis,t}^{3°s} + C_{lcs,t}^{dig} + C_{lis,t}^{dig} + C_{l,t} + C_{s,t} + C_{ts,t} + C_{mo,t}^{1°s} + C_{df,t}^{1°s} + C_{e,t}^{1°s} + C_{i,t}^{1°s} + C_{mo,t}^{2°s} + C_{df,t}^{2°s} + C_{e,t}^{2°s} + C_{i,t}^{2°s} + C_{z,t}^{2°s} + C_{o,t}^{dig} + C_{o,t}^{com} + C_{o,t}^{dis} + C_{tax,t} \quad \forall t=0 \ldots n \quad (9)$$

$$C_{inv}^{1°s,*} = C_{inv}^{u,1°s} * S_{biogas} \quad (10)$$

$$C_{inv}^{1°s} = C_{inv}^{1°s,*} * p_{capital\ grant} \quad (11)$$

$$C_{lcs,t}^{1°s} = C_{inv}^{1°s} / n_{debt} \quad \forall t=0 \ldots n_{debt}-1 \quad (12)$$

$$C_{lis,t}^{1°s} = \left(C_{inv}^{1°s} - C_{lcs,t}^{1°s}\right) * r_d \quad \forall t=0 \ldots n_{debt}-1 \quad (13)$$

$$C_{inv}^{2°s,*} = C_{inv}^{u,2°s} * S_{biomethane} \quad (14)$$

$$C_{inv}^{2°s} = C_{inv}^{2°s,*} * p_{capital\ grant} \quad (15)$$

$$C_{lcs,t}^{2°s} = C_{inv}^{2°s} / n_{debt} \quad \forall t=0 \ldots n_{debt}-1 \quad (16)$$

$$C_{lis,t}^{2°s} = \left(C_{inv}^{2°s} - C_{lcs,t}^{2°s}\right) * r_d \quad \forall t=0 \ldots n_{debt}-1 \quad (17)$$

$$C_{inv}^{3°s,*} = C_{inv}^{com} + C_{inv}^{dis} \quad (18)$$

$$C_{inv}^{3°s} = C_{inv}^{3°s,*} * p_{capital\ grant} \quad (19)$$

$$C_{lcs,t}^{3°s} = C_{inv}^{3°s} / n_{debt} \quad \forall t=0 \ldots n_{debt}-1 \quad (20)$$

$$C_{lis,t}^{3°s} = \left(C_{inv}^{3°s} - C_{lcs,t}^{3°s}\right) * r_d \quad \forall t=0 \ldots n_{debt}-1 \quad (21)$$

$$C_{lcs,t}^{dig} = C_{inv}^{dig} / n_{debt} \quad \forall t=0 \ldots n_{debt}-1 \quad (22)$$

$$C_{lis,t}^{dig} = \left(C_{inv}^{dig} - C_{lcs,t}^{dig}\right) * r_d \quad \forall t=0 \ldots n_{debt}-1 \quad (23)$$

$$C_{l,t} = C_l^{u,a} * n_{op} \quad \forall t=n_r \ldots n \quad (24)$$

$$C_{s,t} = C_s^u * Q_S \quad \forall t=n_r \ldots n \quad (25)$$

$$C_{ts,t} = C_{ts}^u * Q_S \quad \forall t=n_r \ldots n \quad (26)$$

$$C_{mo,t}^{1°s} = p_{mo}^{1°s} * C_{inv}^{1°s} \quad \forall t=n_r \ldots n \quad (27)$$

$$C_{df,t}^{1°s} = p_{df} * C_{lcs,t}^{1°s} \quad \forall t=n_r \ldots n \quad (28)$$

$$C_{e,t}^{1°s} = c_e^{u,1°s} * Q_{biogas} * p_e \quad \forall t=n_r \ldots n \quad (29)$$

$$C_{i,t}^{1°s} = p_i * C_{inv}^{1°s} \quad \forall t=n_r \ldots n \quad (30)$$

$$C_{mo,t}^{2°s} = p_{mo}^{2°s} * C_{inv}^{2°s} \quad \forall t=n_r \ldots n \quad (31)$$

$$C_{df,t}^{2°s} = p_{df} * C_{lcs,t}^{2°s} \quad \forall t=n_r \ldots n \quad (32)$$

$$C_{e,t}^{2°s} = c_e^{u,2°s} * Q_{biogas} * p_e \quad \forall t=n_r \ldots n \quad (33)$$

$$C_{i,t}^{2°s} = p_i * C_{inv}^{2°s} \quad \forall t=n_r \ldots n \quad (34)$$

$$C_{z,t}^{2°s} = p_z^u * Q_z \quad \forall t=n_r \ldots n \quad (35)$$

$$C_{o,t}^{com} = C_o^{com} \quad \forall t=n_r \ldots n \quad (36)$$

$$C_{o,t}^{dis} = C_{o}^{dis} \qquad \forall t = n_r \ldots n \tag{37}$$

$$C_{tax,t} = CF_t * p_{tax} \qquad \forall t = n_r \ldots n \tag{38}$$

$$C_{gv,t+1} = C_{gv,t} * (1 + inf) \qquad \forall t = n_r \ldots n \tag{39}$$

$$Q_S = (n_{oh} * S_{biomethane}) / p_b^u \tag{40}$$

$$Q_{biogas}^{nom} = S_{biogas} * n_{oh} * \%CH_4 \tag{41}$$

$$Q_{biogas} = Q_{biogas}^{nom} * (1 - l_{bs}) \tag{42}$$

$$Q_{biomethane}^{nom} = S_{biomethane} * n_{oh} \tag{43}$$

$$Q_{biomethane} = Q_{biogas} * (\%CH_4) * (1 - l_{us}) * r_{bm}. \tag{44}$$

$$Q_{CO_2} = S_{biogas} * n_{oh} * (\%CO_2) * cf_{CO_2} * r_{CO_2} \tag{45}$$

The biogas-biomethane supply chain generally develops in three phases: the first phase involves the production of biogas through anaerobic digestion; the second phase involves upgrading, i.e., the purification process to obtain biomethane; and the third phase involves the compression and distribution of the final product. Equations (1) and (2) refer to the calculation of NPV and NPV/Size.n the revenue side (equations 3 to 8), the main sources include: economic incentives (subsidies), sale of biomethane, sale of digestate, sale of food-grade CO_2. If OFMSW is treated, additional net revenues are generated from the management of this waste. With regard to the cost structure (equations 9 to 39), the following items are considered: depreciation of mechanical and electrical components, energy consumption, insurance, initial investment, labor costs, maintenance and overheads, purchase of zeolite, substrates and transport. The economic and technical analysis is based on a number of fundamental assumptions, including: (i) The qualitative and quantitative specifications of the gas produced (such as composition and pressure), which must be appropriate to the needs of the end user, and (ii) the size of the biogas plant, optimized according to the maximum degree of saturation in the upgrading phase. It should be noted that the inflation rate applied to the cost components has not been applied to the revenue components in order to take a conservative approach from an economic point of view. Furthermore, it should be noted that the approach that distinguishes between the inflation rate and the opportunity cost of capital is consistent with that adopted in previous studies (Baena-Moreno et al., 2020b; Nazari et al., 2021). Finally, equations 40 to 45 provide technical data useful for the economic model, which are necessary for calculating the quantities of substrate, biogas, biomethane, and CO_2. Specific comparative parameters were used to assess the potential of biomethane from residues. For OFMSW, a value of 90 m^3 of biomethane per ton was considered, in line with the literature (D'Adamo et al., 2023).

2.3. Input Data

The data used for this model are shown in Table 1, supplemented by some considerations that emerged from discussions with industry experts.

Table 1: Input data

Variable	Value	Reference
Conversion factor (CO_2)	1.84 kg/m^3	De Clercq et al., 2017
Conversion factor (MWh/m^3)	0.0105 MWh/m^3	Catalano et al., 2024[&]
Cost of OFMSW	55 €/t	Cucchiella et al., 2019[&]
Interest rate on loan	3	Chinnici et al., 2018
Investment cost (anaerobic digestion)	4250 €/kW	Catalano et al., 2024[&]
Investment cost (compression)	58,000 €	Uusitalo et al., 2013[&]
Investment cost (digestate)	750,000	Hagman et al., 2018
Investment cost (distribution)	245,000 €	Smyth et al., 2010
Investment cost (upgrading)	4400 €/(m^3/h)	Catalano et al., 2024
Lifetime of investment	20 y	Catalano et al., 2024
Loan duration	10 y	Chinnici et al., 2018
Losses in the biogas system	6%	Smyth et al., 2010
Losses in the upgrading system	1.5%	Smyth et al., 2010
Number of operating hours	8000 hg	Chinnici et al., 2018
Number of operators	4	Ferella et al., 2017[&]
Operation cost (compression)	45,000 €/y	Uusitalo et al., 2013[&]
Operation cost (distribution)	15,000 €/y	Uusitalo et al., 2013
Operation cost (digestate)	180,000 €/y	Hagman et al., 2018
Opportunity cost	5%	Catalano et al., 2024
Percentage of capital grant	40%	Section 2.1
Percentage of carbon dioxide	47%	Morero et al., 2017
Percentage of depreciation fund	10%	Budzianowski and Brodacka, 2017
Percentage of insurance cost	2%	[&]
Percentage of maintenance & overhead costs (anaerobic digestion)	20%	Catalano et al., 2024[&]
Percentage of maintenance & overhead costs (upgrading)	10%	Catalano et al., 2024[&]
Percentage of methane	60%	Amato et al., 2023
Percentage of tax value	27.5%	Catalano et al., 2024
Period of realization	0.5 y	Catalano et al., 2024[&]
Period of subsidies	15 y	Section
Plant size (biogas)	750 kW	[&]
Plant size (biomethane)	250 m^3/h	[&]
Price of biomethane (after subsidies)	0.80 €/m^3	[&]
Quantity of compost	5555 t	De Clercq et al., 2017[&;]
Quantity of CO_2	4284 t	Catalano et al., 2024[&]
Quantity of substrate	22,222 t	Catalano et al., 2024[&]
Quantity of zeolite	42 t/y	Catalano et al., 2024[&]
Inflation rate	3	Catalano et al., 2024
Recovery rate (biomethane)	97	Catalano et al., 2024
Recovery rate (CO_2)	97	Ferella et al., 2017
Gross revenues from treatment of OFMSW	65 €/t	Catalano et al., 2024[&]
Unitary electric consumption (anaerobic digestion)	0.13 kWh/m^3	Bortoluzzi et al., 2014
Unitary electric consumption (upgrading)	0.29 kWh/m^3	Browne et al., 2011
Unitary labor cost	25,000 €/y	Catalano et al., 2024[&]
Unitary potential of biomethane	90 m^3biomethane/t	Catalano et al., 2024; Pierro et al., 2021
Unitary price of CO_2	12 €/t	De Clercq et al., 2017[&]

(Contd...)

Table 1: ***(Continued)***

Variable	Value	Reference
Unitary price of compost	50 €/t	Hagman et al., 2018[&]
Unitary price of electricity	0.25 €/kWh	[&]
Unitary price of zeolite	800 €/t	Catalano et al., 2024[&]
Unitary subsidy (biomethane)	69.74 €/MWh	Section 2.1[&]
Unitary substrate cost	0 €/t	Ferella et al., 2017[&]
Unitary transport cost of substrate	1 €/t	Ferella et al., 2017[&]

[&]Survey

The main cost and revenue items are calculated below.

2.3.1. Investment costs

The construction of the plant involves specific investment costs, broken down by type of structure. In particular, as shown in Table 2, these costs relate to: the biodigester, the upgrading plant, the compression and distribution systems, and the compost treatment plant. In accordance with section 2.1, a capital grant of 40% of eligible costs is provided, which reduces the initial net investment incurred by the promoter. It is assumed that the initial net investment will not be incurred entirely in year 0, but will be financed through a ten-year loan with an annual interest rate of 3%. The loan will be repaid according to an Italian amortization plan, i.e., a method in which the principal repayments are constant, while the interest payments decrease over time, being calculated on the outstanding debt.

2.3.2. Operating costs

The project involves the commissioning of the plant in year 1, which will result in the related operating costs. Table 3 shows the annual operating costs of the plant, allowing the most significant items of expenditure to be identified immediately. Among these, the most significant is the maintenance costs for the first phase of production. This is followed by the cost of electricity for phases 1 and 2, calculated using expressions (29) and (33). These costs are determined by multiplying the amount of biogas produced by the specific electricity consumption of the phase in question and by the unit cost of energy and the operating cost of the digestate.

Additional expenditure items considered include: the cost of zeolite, calculated as the unit price for the quantity purchased; transport costs, obtained by multiplying the unit cost by the quantity transported; operating costs associated with the compression, distribution, and management of the digestate, defined within ranges identified in the literature; labor costs, calculated considering the number of operators involved and the average wage; finally, insurance costs, estimated as 2% of the initial investment for the upgrading plant and the biodigester.

Maintenance costs for both phases were quantified according to expressions (27) and (31). To simulate the trend of costs over time, an annual inflation rate of 2.5% was also considered.

2.3.3. Revenues

The economic analysis considers a time horizon of 20 years, during which revenues from various sources are expected (Table 4):

Table 2: Investment costs

Variable	Value
Biodigester investment cost (€)	1,912,500
Upgrading plant investment cost (€)	660,000
Compression investment cost (€)	34,800
Distribution investment cost (€)	147,000
Compost facility investment cost (€)	450,000
Total net investment (€)	3,204,300

Table 3: Operating costs

Variable	Value
Operating cost (compression) (€/y)	45,000
Operating cost (distribution) (€/y)	15,000
Operating cost (digested) (€/y)	180,000
Labor cost (€/y)	100,000
Substrate cost (€/y)	-
Substrate transport cost (€/y)	22,222
Electricity cost (1f) (€/y)	109,980
Electricity cost (2f) (€/y)	245,340
Zeolite cost	33,600
M&O cost 1f (€/y)	382,500
M&O cost 2f (€/y)	66,000
Insurance cost 1st year (€/y)	38,250
Insurance cost 2nd s (€/y)	13,200
Depreciation fund 1st (€/y)	19,125
Depreciation fund 2nd (€/y)	6600

Table 4: Revenues

Variable	Value
Revenues from subsidies (€/y)	1,420,564
Revenues from sales (€/y)	1,551,957
Revenue from CO_2 (€/y)	51,402
Revenue from compost (€/y)	277,778
Revenue from OFMSW (€/y)	222,222

- Sale of compost - Considering an annual production of 5555 tons of compost and a sale price of 50 €/t, annual revenues are estimated at 277,778 €.
- Sale of CO_2 - With an annual production of 4284 tons, determined using equation (45), and a sale price of 12 €/ton, annual revenues of 51,402 € are obtained.
- Delivery of OFMSW - The unit revenues from the treatment of OFMSW are calculated as the difference between the disposal fee (65 €/t) and the operating costs (55 €/t), for a net value of 10 €/t. Multiplying this value by the quantity of OFMSW treated annually, annual revenues of 222,222 € are obtained.
- Incentives for biomethane - In this case study, reference is made to an all-inclusive tariff for the promotion of biomethane, equal to 69.74 €/MWh (corresponding to 0.732 €/m^3 due to the conversion coefficient) pursuant to the decree and compatible with the size of the plant. Consequently, for the first 15 years of operation, the plant benefits from incentive revenues for an annual amount determined by multiplying the tariff by the total quantity of biomethane obtainable through expression (44).
- Sale of biomethane - Starting from the sixteenth year, the plant no longer receives incentives and must sell biomethane on the free market. A sales price of 0.8 €/m³ is assumed, which is in line with the value proposed in the literature, generating annual revenues of 1,551,957 € for the period between the sixteenth and twentieth years.

3. RESULTS

This section presents a description of the base scenario (section 3.1), followed by alternative scenarios (3.2). Finally, a discussion of the implications of this work is presented (section 3.3).

3.1. Base Scenario

In the context analyzed in this study, year 0 involves the construction of the plant and the payment of the first installment of the loan taken out to finance the investment. Starting from year 1, in addition to the repayment of the remaining installments (for a total period of 10 years), the operating costs and revenues already described in section 2 are recorded. The net cash flow is calculated for each year. All cash flows are discounted using a discount rate of 5% over a period of 20 years.

The results show high profitability (Table 5). The NPV is 1,635,551 €, or 6542 €/(m³/h), in order to facilitate comparisons between plants of different sizes. The IRR is 45.75%, significantly higher than the discount rate used, confirming the economic viability of the project. The DPBT also provides reassuring information for the promoter, as the investment is fully recovered within 3 years and 1 month. Among the other indicators analyzed, the Profitability Index (PI) is 0.63, measuring the relationship between the present value of future cash flows generated by a project and the initial investment required to implement it. This value indicates that, for every € invested, additional wealth of 0.63 € is generated. Finally, the Levelized Cost of Energy (LCOE) was calculated, which represents the average cost per unit of energy produced over the life cycle of the plant. Both the numerator and denominator are discounted. In this case, the LCOE is 0.39 €/m³, allowing the economic competitiveness of the project to be assessed compared to other production technologies.

Table 5: Financial indicators

Indicator	Value
NPV	1,635,551 €
NPV/Size	6,542 €/(m³/h)
IRR	45.75%
DPBT	3 years and 1 month
PI	0.63
LCOE	0.39 €/m³

The revenues and costs are broken down below. As regards revenues, subsidies account for 59.3% of the total value and the other items relate to net revenues from the treatment of OFMSW (11.2%), sales on the biomethane market (13%), compost (13.9%) and CO_2 (2.6%). The sale of biomethane has a marginal impact on total revenues due to the incentive structure, in which this item has only been included in the last five years of the project and therefore had a reduced influence due to discounting.

On the cost side, in the context of debt, the weight of the investment cost has less impact due to discounting. In addition, the incentive system provides for a capital deduction that amplifies this effect. As a result, the investment costs of anaerobic digestion account for 16% and those of upgrading for 5.7%. As regards operating costs, maintenance costs during biogas production stand out, accounting for 21.7% of total costs. In addition, electricity costs in the first two phases account for 20.2% and operating costs related to compost for 10.2%. These three operating costs account for half of the total costs.

3.2. Alternative Scenario

Economic analyses are based on assumptions and estimates. Therefore, to strengthen the reliability of the results, an in-depth assessment of the critical variables emerging from the distribution of costs and benefits was carried out.

In the first phase, a sensitivity analysis was performed, varying each critical variable individually (Table 6). With regard to revenues, a deviation of ±0.10 €/m³ was assumed for the sale price of biomethane. With regard to the subsidy, only a reduction of 0.10 €/MWh was considered, as the value adopted in the reference scenario corresponds to the maximum allowed by the decree. With regard to other revenues, both positive and negative variations of 5 €/t were explored for the net proceeds from the treatment of OFMSW, and similar variations were applied to revenues from the sale of compost.

On the cost side, only conservative (pessimistic) scenarios were considered. These included a 5% rise in maintenance expenses during the anaerobic digestion phase, a 0.05 €/kWh increase in electricity prices for both process phases, an additional 200 €/kW

Table 6: Sensitivity analysis

Scenario	Critical variable	Base value	Modified value	NPV (€)	Var (%)	NPV/Size (€/m³/h)
optimistic	Biomethane sales price (€/m³)	0.80	0.90	1,928,454	17.9	7713
pessimistic	Biomethane sale price (€/m³)	0.80	0.70	1,320,931	−19.2	5283
pessimistic	Incentive tariff (€/MWh)	69.74	59.74	53,412	−96.7	2
optimistic	Net revenues from OFMSW (€/t)	10	15	3,643,352	122.7	14,573
pessimistic	Net revenues from OFMSW (€/t)	10	5	626,467	-	2505
optimistic	Revenues from compost (€/t)	50	5	1,886,526	15.3	7546
pessimistic	Revenues from compost (€/t)	50	45	1,384,576	−15.3	5538
pessimistic	Unit investment cost 1f (€/kW)	4250	4450	1,344,007	−17.8	5376
pessimistic	Unit investment cost 2f (€/(m³/h))	4400	4600	1,571,641	−3.9	6286
pessimistic	Unit price of electricity (€/kWh)	0.25	0.30	843,699	−48.4	3374
pessimistic	Percentage of M&A 1f (%)	20	25	562,097	−65.6	2248
pessimistic	Operating cost compost (€)	180,000	200,000	1,413,746	−13.5	5654
pessimistic	Opportunity cost of capital (%)	5	8	1,225,251	−25	490
pessimistic	Inflation rate (%)	2.50	3	1,012,032	−38.1	404
optimistic	Inflation rate (%)	2.50	2	2,208,354	35	883

in capital investment costs for the first phase, and 200 €/(m³/h) for capital costs in the second phase.

The results confirm the economic soundness of the project, which shows a positive NPV in all scenarios considered. However, consistent with the revenue and cost structure of the reference scenario, it should be noted that a reduction in the incentive tariff would cause the NPV to fall by 96%. Significant changes are also recorded following the increase in maintenance costs in the first phase and unit energy costs, which fell by 65% and 48% respectively.

The next phase of the analysis involved a simultaneous variation of the variables. The factors indicated were considered, with variations in the same range generating two alternative scenarios. With regard to revenues, a pessimistic scenario was considered for the critical variables (Table 7); the NPV obtained was -1846 k€, which is plausible as a negative change in the tariff set by decree was sufficient to significantly reduce profitability; in fact, restoring the tariff to the value set by decree, the NPV rose to -9 k€. The second scenario proposed is an increase in the critical variables relating to costs (Table 8). This pessimistic scenario proposes a 5% increase in maintenance costs for anaerobic digestion, a 0.05 €/kWh rise in electricity prices, an additional 200 €/kW in investment costs for the anaerobic digestion phase, a 200 €/(m³/h) increase in upgrading costs, as well as higher operating costs for composting. The NPV obtained from this simulation is -1063 k€.

Previous case studies did not assign probabilities to the occurrence of events. To address this, a risk analysis was carried out by modifying various critical variables and calculating the probability distribution of the NPV in each case. The subsidy value was held constant, as the high-tariff scenario already represented the maximum incentive level. To evaluate project risk, the Monte Carlo method was applied. This approach uses the cumulative distribution function associated with stochastic variables and simulates 1000 iterations. The mean value for each variable was set equal to its baseline value, while the standard deviation was assumed to match the range used in the earlier scenario analyses. The scatter plot below illustrates the distribution of NPV values across the 1000 simulations. The results indicate an 86% probability of achieving a positive NPV. Notably, 244 out of 1000 iterations yielded an NPV higher than that of the base scenario, as shown in Figure 1. A second simulation was conducted under an alternative policy scenario with a reduced incentive tariff (59.74 €/MWh), since this variable has the greatest influence on the NPV (Figure 2). In this case, only 27% of simulations produced a positive NPV, and just 9 iterations exceeded the NPV of the reference scenario.

The analysis concludes with an examination of the break-even point (BEP), which is essential for helping decision-makers identify the values of key variables at which the NPV become zero. Specifically, for the OFMSW substrate, the analysis considered the impact of the incentive tariff. The results indicated that, for the 250 m³/h plant under study, the break-even incentive value was 0.623 €/m³.

4. DISCUSSION

The contribution of renewable energy sources is crucial for achieving a sustainable energy transition (Bekun and Ozturk, 2025; Jabeen et al., 2021; Tutar and Atas, 2022). Within this framework, numerous studies emphasize the strategic importance of anaerobic digestion in the valorization of organic waste and the generation of renewable energy (Mizger-Ortega et al., 2022). In recent years, the discounted cash flow method - particularly the use of NPV - has become a fundamental tool for evaluating the economic feasibility of biogas and biomethane production facilities.

Numerous studies have shown that NPV varies significantly depending on several factors, including the type of substrate, the size of the plant, the presence of incentives, investment costs and the technological context. For example, NPV ranges from 8685 to 10,518 k€, depending on the percentage of biogas converted into biomethane (Pasciucco et al., 2023). Other studies have explored scenarios integrated with photovoltaics and solar collectors, with economic results ranging from 3 to 14 million € (Calise et al., 2023a) or NPV values between 19.6 and 29.5 k€, thanks to the recovery of residual heat from digestate (Calise et al., 2023b). More variable scenarios have been analysed in other studies showing an NPV ranging from -7.87 to 9.26 million $ depending on the mono- or co-digestion of residues (Volpi et al., 2023),

Table 7: Scenario analysis (revenues)

Scenario	Critical variable	Base value	Modified value	Modified NPV (k€)	NPV/Size (€/m³/h)
Pessimistic	Biomethane sale price (€/m³)	0.80	0.70	−1846	−738
	Incentive tariff (€/MWh)	69.74	59.74		
	Net revenues from OFMSW (€/t)	10	5		
	Revenue from compost (€/t)	50	45		

Table 8: Scenario analysis (costs)

Scenario	Critical variable	Base value	Modified value	Modified NPV (k€)	NPV/Size (€/m³/h)
Pessimistic	Unit investment cost 1f (€/kW)	4250	4450	-1063	-4242
	Unit investment cost 2f (€/(m³/h))	4400	4600		
	Unit price of electricity (€/kWh)	0.25	0.30		
	Percentage of M&O cost 1f (%)	20	25		
	Operating cost of compost (€)	180,000	200,000		

Figure 1: Risk analysis (base political scenario)

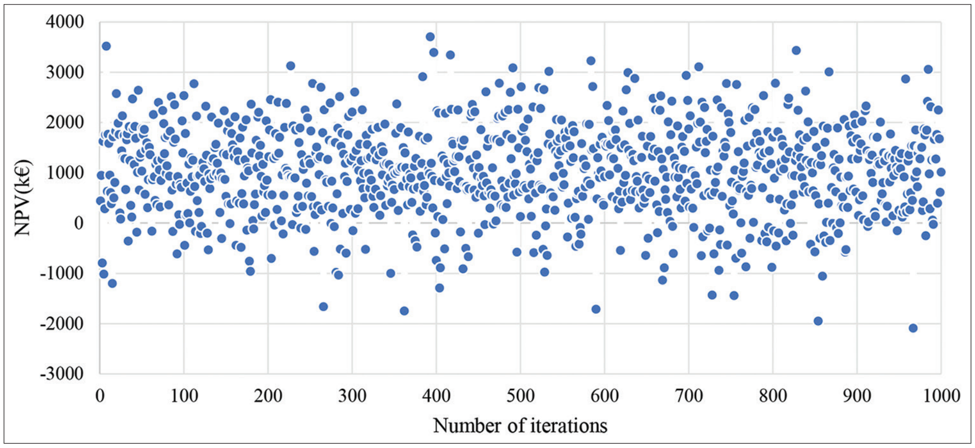
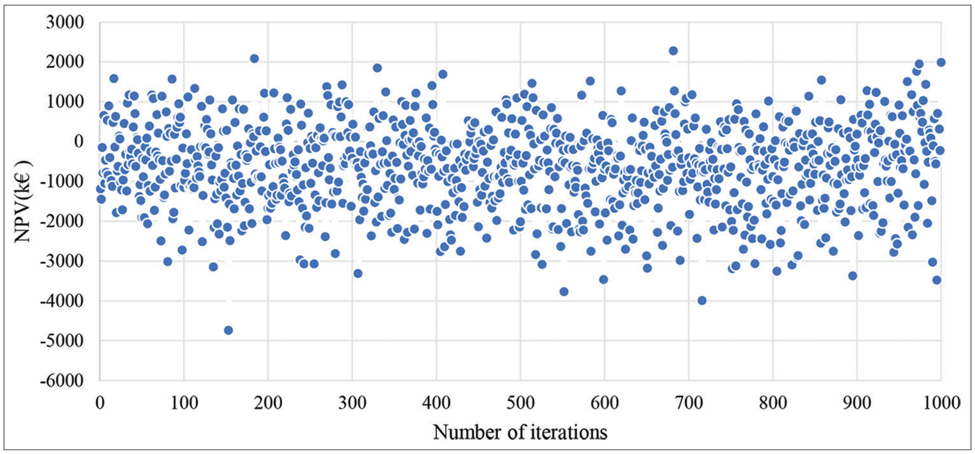


Figure 2: Risk analysis (alternative political scenario)



while wider ranges (23–40 M\$) are highlighted when considering multiple variables in integrated systems (Pan et al., 2023). In other cases, NPV estimates vary greatly from -125 to 949 k\$ (Pan et al., 2023). Further analysis confirms the critical impact of factors such as energy certificates, from -13.2 to 35.8 M€ (Calise et al., 2024), the sale price of biomethane, from -3.0 to 2.6 M\$ (Febijanto et al., 2024), the technologies adopted, from 1.4 to 33.4 million \$ (Pan et al., 2024) and emission certificates and the sale price, from -3897 to 6618 k€ (Cucchiella et al., 2017). Evidence of the role of public funds is confirmed in other analyses with an NPV between -1683 and 104 k\$USD (Kusz et al., 2024). Other key variables are the price of gas, where an economic loss is recorded when the price falls to 0.22 \$/m³ (Panda and Jain, 2025). Economies of scale, on the other hand, play a positive role with NPV values ranging from 1609 to 6462 €/m³ with Pressure Swing Adsorption technology and payback periods of between 3 and 10 years (Swinbourn et al., 2024). Another key variable is financing costs, with a payback period of between 5 and 6 years (Fava et al., 2025) or the sale of CO_2 and the presence of incentives with an NPV of -1325 k€ (Belinska et al., 2024). Finally, some economic and strategic analyses confirm how important it is to assess the weight of incentives in terms of profitability in order to provide guidance to investors and policymakers. In particular, some analyses have verified the profitability of 100 and 300 m³/h plants powered by by-products and OFMSW, with an NPV ranging from -2886 to 699 k€, showing that the break-even tariff depends on the size and substrate, and ranges between 0.61 and 0.95 €/m³ for OFMSW and between 0.76 and 1.01 €/m³ for by-products (Catalano et al., 2024). These aspects were confirmed in economic studies where baseline scenarios were compared with alternative scenarios with a NPV ranging from -3680 to 17,203 k€ (D'Adamo et al., 2023). The pragmatic sustainability model requires a variety of analyses that include the variation in the economic viability of a project in different considerations. It is essential to provide perspectives to the various stakeholders and show the different economic outcomes that emerge. However, it is essential to link the three dimensions of sustainability and involve all citizens in this decision-making process in order to achieve an ecological transition with them (D'Adamo et al., 2025).

5. CONCLUSIONS AND POLICY IMPLICATIONS

Biomethane is a virtuous example of the circular bioeconomy, in line with SDGs 7-12. Its ability to replace fossil gas makes it a key element in the shift to a low-carbon energy system. Within a well-organized supply chain, the use of specific substrates, such as OFMSW, allows for the production of renewable energy (green gas) and the valorization of by-products such as digestate and food-grade CO_2, with significant environmental benefits.

The analysis conducted confirmed the economic and financial soundness of the OFMSW treatment and biomethane production project, highlighting its high profitability in the reference scenario. The NPV of 1635 k€, the IRR of 46%, and a DPBT of just over 3 years indicate a financially advantageous investment. Sensitivity analyses show that, although the project remains generally profitable, its profitability is strongly influenced by the size of the incentive, which accounts for approximately three-fifths of total revenues.

The risk analysis confirms this dependence: with an incentive of 0.732 €/m³ in the base scenario, the NPV is positive in 86% of cases, while with a reduction to 0.627 €/m³, the probability of profitability drops sharply to 27%. In this context, however, it should be noted that in the reference scenario, the NPV is 53 k€. The BEP analysis estimated that for the plant in question (250 m³/h), the incentive value is calculated at 0.623 €/m³.

Biomethane is a strategic resource for the Italian energy system, as it enables the production of renewable energy from organic sources. In addition to gradually reducing the country's dependence on fossil gas imports, this supply chain is fully integrated into the existing natural gas distribution infrastructure, facilitating the transition to a more environmentally friendly energy model.

Biomethane contributes significantly to the decarbonization of energy consumption, promotes circular economy practices, and generates positive effects in terms of enhancing both rural and urban areas. The study presented here focuses on the city of Rome, an urban context with high OFMSW production, and aims to overcome a long phase of announcements and unimplemented plans by promoting a concrete action-oriented approach, i.e., a true "policy of doing." With this in mind, the objective is also to prevent NIMTO phenomena, i.e., the systematic postponement of decisions by politicians, through the promotion of sustainable, participatory, and immediately implementable solutions.

For the system to work effectively, it is essential to involve citizens, informing them about the concrete benefits of proper separate waste collection and encouraging virtuous behavior. The results of the analysis show that the plant remains profitable even with a reduction in revenues from OFMSW, thus opening up the possibility of redistributing part of the value generated as an incentive for more conscientious citizens.

Furthermore, the choice of a medium-sized plant should minimize opposition from the local population, even though the NIMBY phenomenon is still widespread according to recent analyses. On the political front, it is clear that the incentive tariff system continues to play a decisive role in the economic sustainability of the sector. Looking ahead, it will be necessary to move towards a context in which renewable sources are able to compete independently, without structural public support.

This requires the development of a national industrial supply chain capable of generating economies of scale and learning, reducing the initial costs of plants. In this context, the stability of the regulatory framework and incentives is a crucial factor in ensuring continuity and attractiveness for investment.

Biomethane, therefore, is emerging as a key energy carrier to accompany Italy's ecological transition, combining environmental, economic, and social benefits. The pragmatic sustainability model proposed encourages operational solutions, placing circularity as the guiding principle of new industrial policies.

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