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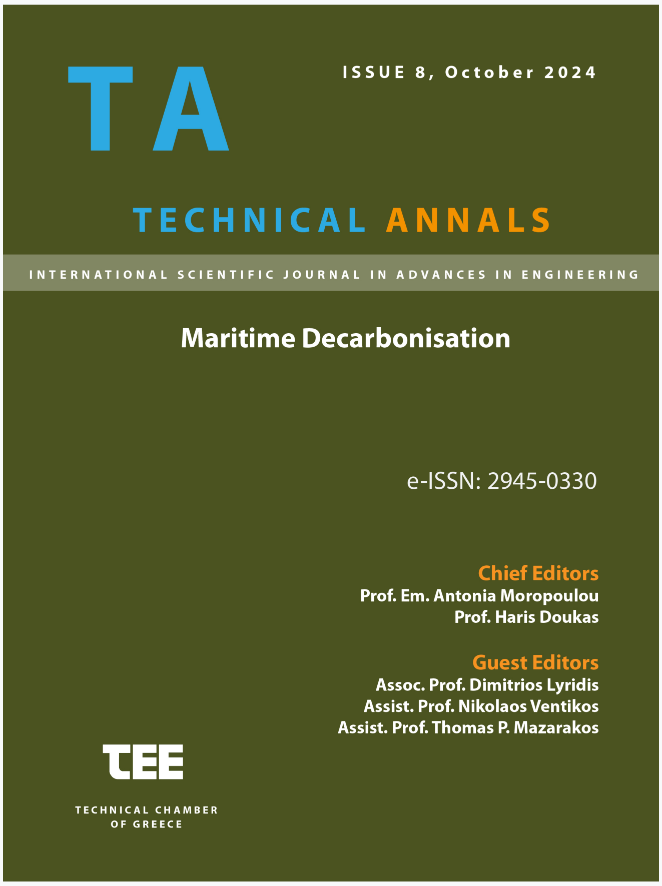

White paper on Biogas Upgrading Economics – Comparison between biogas upgrading and electricity co-generation: Greece

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White paper on Biogas Upgrading Economics – Comparison between biogas upgrading and electricity co-generation: Greece

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Abstract. The present study intents to compare the existent Biogas usage options, currently used in Greece for electricity generation using co-generation engines (COGEN), and comparing it to the current trends in biogas purification, either from Anaerobic Digestion (AD) or from Landfill (LF) , for production of Biomethane, for Natural Gas (NG) grid injection or Compressed Natural Gas (CNG) for fleet fueling. The study also presents the current feed-in tariffs in place for electricity production in Greece, as a function of feedstock used to produce biogas. Study shows a better overall energy recovery from all biogas upgrading solutions – from AD and LF – than the equivalent co-generation options, by at least 2-fold. Economic yield comparison is highly dependent on the "feed-in" tariff that may be in place at each given time. In addition to land-usage of Biomethane, and analysis of possible impact in the usage of Liquefied Biomethane (Bio-LNG) in the shipping industry, given the impact of the latter in Greek economic activity.

Keywords: Biomethane, RNG – Renewable Natural Gas, Biogas Upgrading, CNG – Compressed Natural Gas, LNG – Liquid Natural Gas

Abbreviations

AD	Anaerobic Digestion (biogas)
Bcm	Billion cubic meters
CAPEX	Capital Expenditure (Cost)
CHP	Combined Heat and Power (units)
CNG	Compressed Natural Gas
COGEN	Cogeneration Unit
EC	European Commission
EP	Environmental Protection Agency
FiT	Feed-In Tariff
GHG	Greenhouse Gas
IEA	International Energy Agency
IMO	International Maritime Organization
LF	Landfil (biogas)
LNG	Liquid Natural Gas
NG	Natural Gas
OPEX	Operational Expenditure (Cost)
SDS	Sustainable Development Scenario
STEPS	Stated Policies Scenario
USDA	United States Department of Agriculture

1 Introduction

Biogas upgrading leads to Biomethane which can play an important role in meeting the European Union (EU) 2030 greenhouse gas (GHG) reduction target by at least 55% by 2030 compared to 1990 levels. This reduction is a key step towards achieving climate neutrality by 2050. The EU's current national climate plans, when combined, are projected to lead to a 2.6% decrease in global GHG emissions by 2030 compared to 2019 levels. To limit global warming to 1.5°C, as outlined in the Paris Agreement, global emissions need to be reduced by 43% by 2030 and reach net zero by 2050. Additionally, biomethane increases Europe an energy security by reducing the dependency on Russian natural gas and can alleviate part of the energy cost pressure on households and companies.The European Commission fully recognises these benefits and thus set a target of 35 billion cubic meters (bcm) of annual biomethane production by 2030 in its recent REPower EU plan 2050 [1] . Up to 2022 [2] , 3 bcm of biomethane and 15 bcm of biogas are produced in the EU-27. Gas for Climate 2050 [2] estimation shows that up to 41 bcm of biomethane in 2030 and 151 bcm in 2050 could be available. This is significant as the current (2020) EU natural gas consumption is 400bcm (of which 155 bcm was imported from Russia).

REPower EU plan 2050 [1] propose doubling the objective of Fit for 55 for biomethane to lead to the production of 35 billion cubic metres (bcm) per year by 2030. To do so, Member States' energetic strategic plans should channel funding to biomethane produced from sustainable biomass sources, including in particular agricultural wastes and residues.

Gas for Climate 2050 [3] proposes the following actions to accelerate biomethane as renewable and low-carbon gas, but still need to be fully addressed in the EU or Members States policy framework:

- Assess, through the national energy and climate plans (NECPs), the Member States' biomethane strategies to determine whether together they meet the 35 bcm 2030 target
- Continue to work through the Biomethane Industrial Partnership (BIP) to ensure that Member States'exchange of best practices leads to increased ambitions on biomethane production and feedstock mobilisation
- Provide clear guidance on the definitions of intermediate cropping, and abandoned, marginal, severely degraded lands, to give certainty to the market on how to develop these feedstock streams
- Ensure open access to infrastructure where biomethane plant operators have the right to connect and inject their production directly into the grid, thus providing secure offtake for plant operators
- Open access to the hydrogen infrastructure has been mentioned in the Hydrogen and Decarbonised Gas Package, and the EC should ensure that Member States introduce a "right to inject" policy for biomethane

Gas for Climate, has produced a Manual for National Biomethane Strategies [4] with 10 steps guide to support stakeholders in the development of their national biomethane strategies.

To achieve the biomethane targets set in the REPowerEU plan, EC launched the Biomethane Industrial Partnership (BIP) [5] on 28 September 2022 which aims to support the achievement of the EU's 2030 target of 35 bcm annual production and use of sustainable biomethane and to create the conditions for a further ramp-up of its potential by 2050. It will promote active engagement between the Commission, EU countries, industry representatives, feedstock producers, academics and NGOs. The Commission will work closely with EU countries to support them in their development of national strategies on biomethane production and to promote cooperation on biomethane with neighbouring countries, including Ukraine.

Since biomethane is indistinguishable from natural gas, it can reach any grid-connected residential or commercial building, industrial facility, or power plant and can provide energy services to a broad spectrum of sectors and end users. To be injected, biomethane has to comply with the gas grid specifications originally planned for natural gas.

Viewed through the lens of decarbonisation, the optimal uses of biomethane are in end-use sectors where there are fewer low-carbon alternatives, such as high-temperature heating, petrochemical feedstocks, heavy-duty transport and maritime shipping. But there are other motivations that can play into the uses of biomethane, including rural development, energy security (where biomethane is used instead of natural gas transported over long distances or imported, or where it is used flexibly to complement electricity from variable wind and solar PV), and urban air quality.

Several countries have already introduced production and/or consumption targets for various timelines [4] . In parallel, many European countries have assessed the benefits of using biomethane in the different sectors (industry, transport, building, power) to target its consumption towards highly beneficial use cases [4].

For example, Denmark has chosen to prioritise the use of biomethane to be injected in the grid for decarbonising hard-to-abate sectors such as industry and transport. On the other hand, Italy had initially supported the use of biomethane only in the transport sector (this has changed with the new policy measures adopted in July 2022). The Netherlands prioritises the use of biomethane in the built environment.

Each European country exercises its right to establish natural gas quality parameters, employing diverse methods such as national regulations, standards, gas company requirements, and specific contracts with biomethane producers.

Traditionally, gas standards on grid injection and transport use are defined by natural gas properties. Those standards are not always 100% suited to biomethane and may vary across countries. Differentiating between natural gas and biomethane and meticulously defining parameters such as heating value and maximum contaminant levels such as oxygen, sulphur, and carbon dioxide will facilitate biomethane uptake and cross-border trade in the coming years, enabling the sector to deploy 35 bcm by 2030.

A full analysis on the specifications of different standards related to biomethane was carried out in the framework of the GreenMeUp project [6].

Specifications for biomethane grid injection in Greece taking into account regulatory hurdles, ensuring gas quality, optimizing grid infrastructure, and promoting cost-effective solutions, is under developemnet.

Biomethane is procuded by purifying the Biogas, by removing its main contaminants: CO2, N2, O2, H2S, Siloxanes. This prufication process is refered as Biogas Upgrading.

2 Biogas Production and Upgrading Options

Biogas is produced by anaerobic degradation of organic matter. Typical sources of organic matter for biogas production are wastewater treatment sludges, livestock waste, crops and food waste. This organic matter can be degraded in Anaerobic digestors (Fig. 1) or can occur naturally in landfills.

Fig. 1. Anaerobic digestors and gas holder in a farm [16]

Biogas originated from digestion has typically a high methane concentration (50% - 70% vol/vol) and very low Oxygen and Nitrogen contamination levels (>2% O_2,>1% N_2) , whilst biogas from landfill is characterized by lower Methane concentration levels (40%-60% vol/vol) and much higher Oxygen and Nitrogen levels (N_2 > 10%).

2.1. Biogas to Electricity - CHP

Biogas has been used since the 80's for energy production. In these cases, and after a pre-treatment for H_2S and Siloxanes removal, a combustion engine is used to burn the biogas and convert it to electricity and heat. These units are commonly called CHP – Combined Heat and Power units, as they produce both electricity and heat.

The main back draw of this technology is low energy recovery obtained, usually in the range of 30-40%. Additionally, operation costs are high, namely because of the H_2S and Siloxane levels, that usually increase the wear in the engines and causing maintenance costs to be higher those in operation with similar equipment using Natural Gas as fuel source.

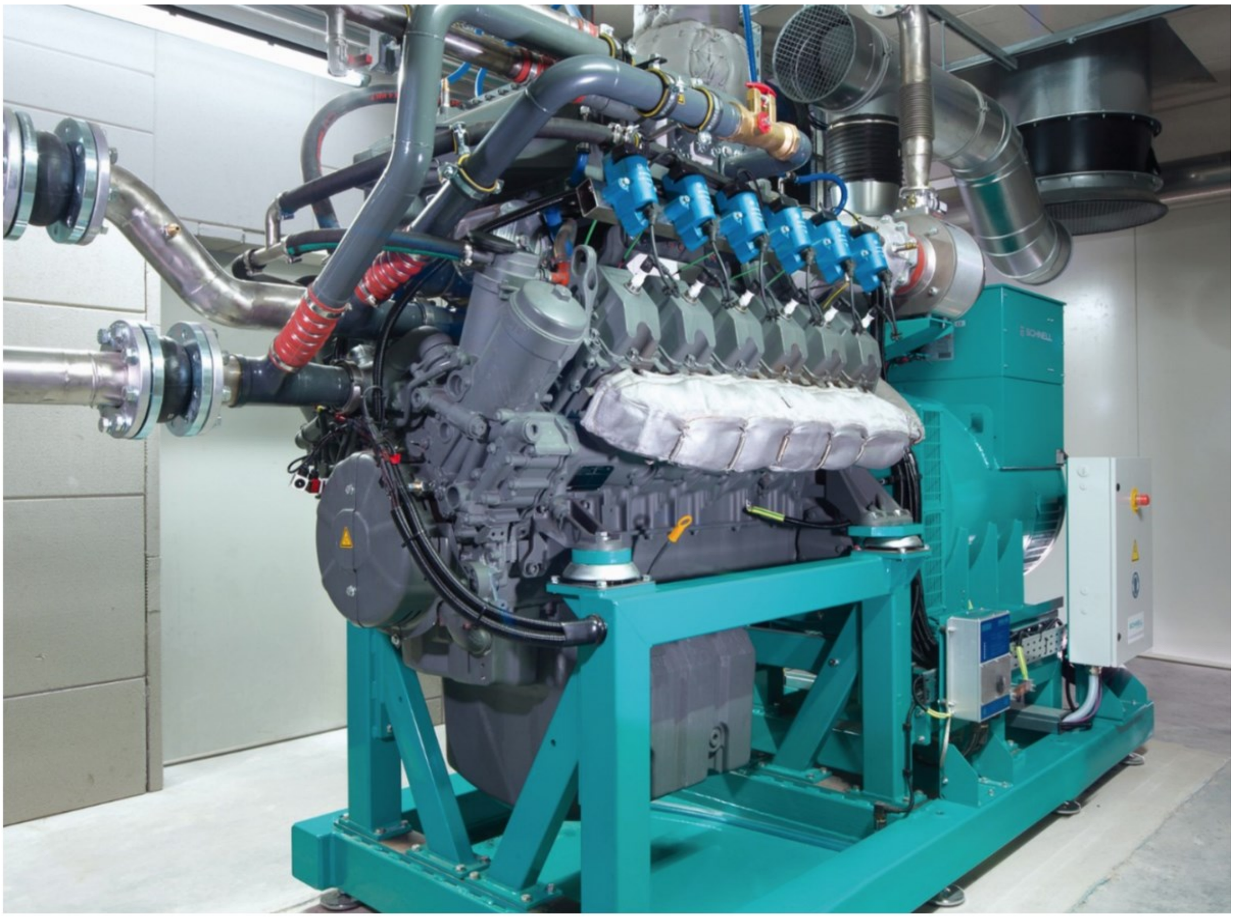

Fig. 2. PlanET CHP Unit [17]

2.2. Biogas Upgrading – Biomethane

The usage of biogas for CHP has been declining in Europe and USA, due to the end of subsidized tariff contacts as well as the high cost of maintenance associated with CHP engines, as well as the net production of CO2 in the combustion process.

Since the beginning of the millennium, a new biogas usage has been gaining traction, which consists of performing the biogas upgrade, or, the removal of the gaseous contaminants – CO_2, N_2 and O_2 – with an increase of the CH_4 concentration. When the resulting gas – Biomethane – reaches a concentration that equals the heating value of natural gas on a given Natural Gas Grid, it can be either injected into the local pipeline, becoming a renewable source of natural gas – or Renewable Natural Gas (RNG), or can it be used as fuel in vehicles, in the compressed (Compressed Natural Gas - CNG) form of in the liquid form (LNG – Liquid Natural Gas). Biomethane is therefore a renewable energy source by its origin in waste degradation.

2.2.1 Biomethane in Europe

Biomethane production in Europe has been led by Germany, being the leading producer of biomethane in Europe. UK, France and the Nordic countries have been following this path since 2010. France is currently the most active country in Europe promoting the installation of biomethane production plants, followed by Italy and Spain.

Data presented in this section has been extracted from two extensive reports, elaborated by REGATRACE [7] and the European Biogas Association [8]. These two reports are extensive and quite complete, so only a short summary data is presented in this paper.

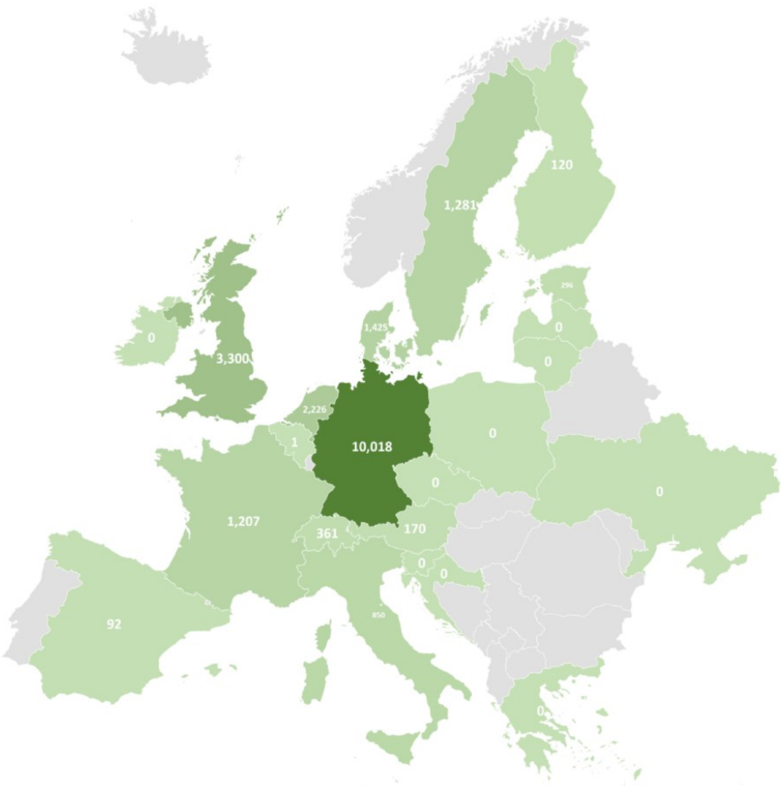

Fig. 3. Biomethane production in Europe per country (GWh/yr) – 2020 data from REGATRACE [7]

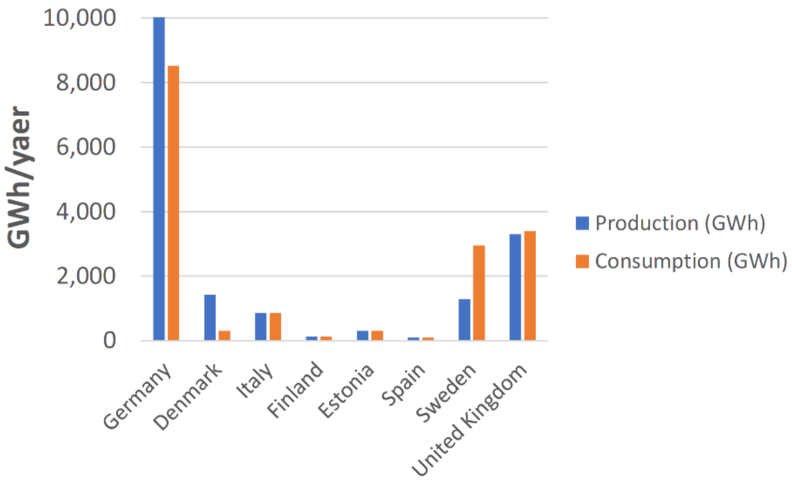

Fig. 4. Production and consumption of biomethane per country – REGATRACE Data 2020 [7]

The Biomethane production has been subject to different incentive programs depending on the host country. The most common program is based on Feed-in-Tariffs (FiT) on a long-time basis. France, UK and Italy are amongst the ones promoting biomethane. Italy is known to have also a combined scheme, with FiT and Investment co-investment programs, namely for the promotion of Liquid Natural Gas (LNG) for transportation.

LNG ships would account for 38% of the 298 vessels built in 2022, with the trend to increase in the coming years. [9].

In the case of Greece, the production of Liquified Biomethane for use as shipping fuel could benefit its maritime transport industry, helping the shipping industry to reduce its CI (Carbon Intensity) score up by more than 20%, as well as stongly reduce NOx and SOx emissions. [10].

IMO (International Maritime Organization) set an ambitious target of decreasing GHG emissions within the industry by 40% until 2030 [11].

This ambitious target require the adoption of alternative renewable shipping fuels with the potential of reduction of the GHG emissions. Biomethane, by itself, is considered reduce up to 80% the GHG as compared to maritime fuel [9].

Biomethane produced by anerobic digestion of manure, considering the additional reduction of CH4 emission is considered to reduce GHG in shipping up to 188% [9].

Liquified Biomethane is in fact considered the most economically viable biofuel to reduce GHG emissions in shipping industry, when compared to Biomethanol, Hydrogen or e-amonia [9].

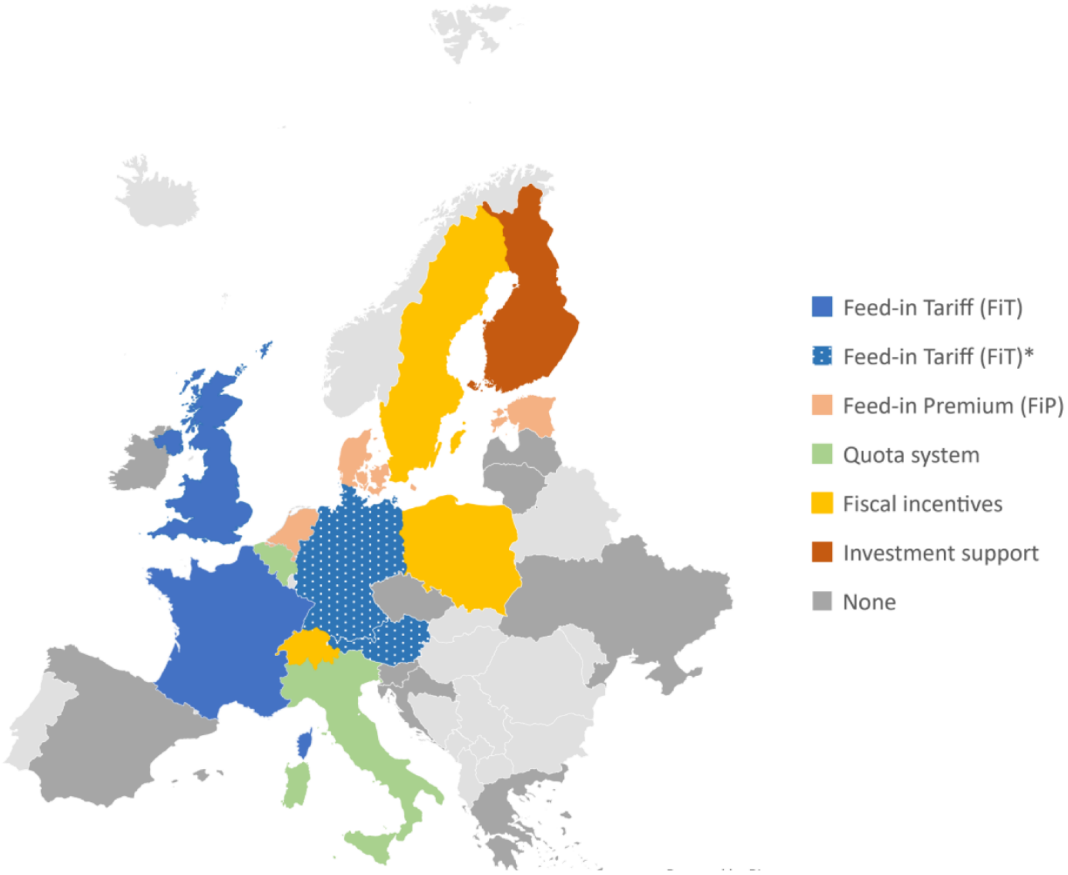

Fig. 5. Biomethane Support Scheme by Country – REGATRACE Data 2020 [7]

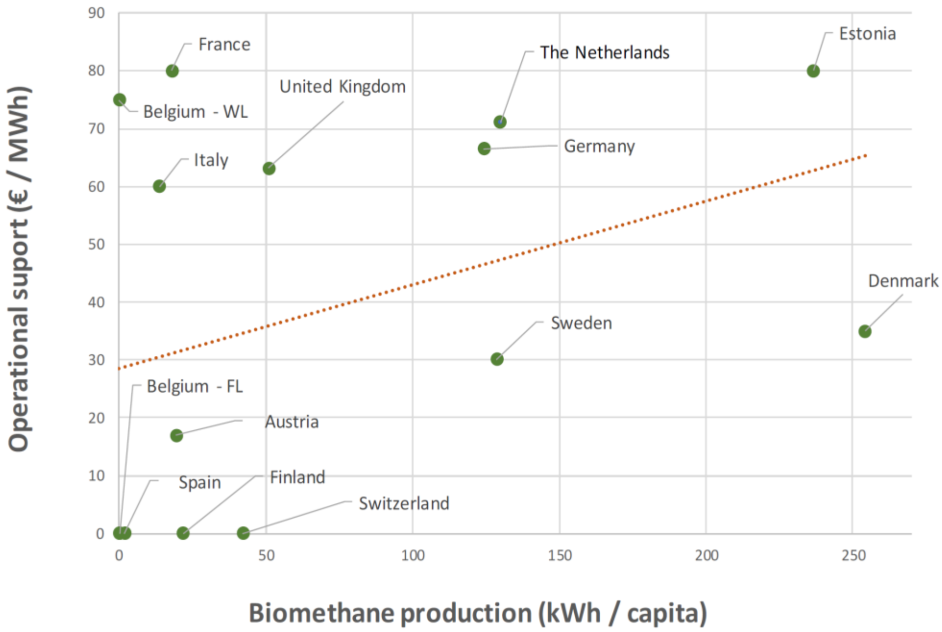

Fig. 6. Operational Support for biomethane per country as a function of production per capita. REGATRACE Data 2020 [7]

Investment in Biomethane production has been increasing steadily throughout Europe, having the number of biomethane production plants increased close to 400% between 2011 and 2019.

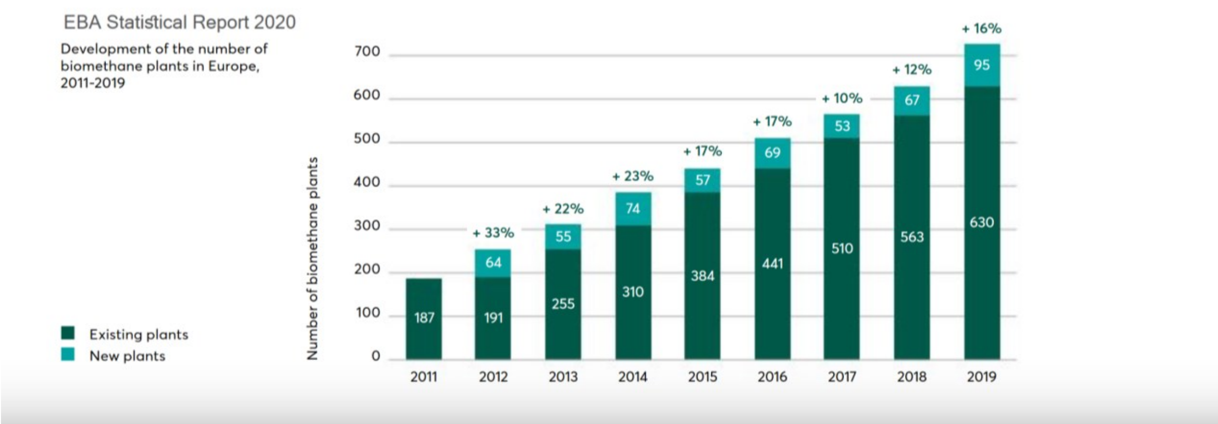

Fig. 7. Evolution of Biomethane production plants in Europe – EBA Data 2020 [8]

2.2.2 Biomethane in word level

Whichever way the energy system evolves over the coming decades, biomethane is on a growth trajectory wordwide. Currently around 3.5 Mtoe of biomethane are produced worldwide. The vast majority of production lies in European and North American markets, with some countries such as Denmark and Sweden boasting more than 10% shares of biogas/biomethane in total gas sales. Countries outside Europe and North America are catching up quickly, with the number of upgrading facilities in Brazil, China and India tripling since 2015. [12]

The United States has implemented a program mandated by the Environmental Protection Agency (EPA) and US Department of Agriculture (USDA) called AgSTAR, designed to enable the uptake of anaerobic digestion [4]. The program assesses the biogas feedstock availability and emissions reduction potential on national, state and county levels combining USDA livestock data and EPA emissions inventory data. Through this, the top ten states for biogas recovery and methane reduction potential in the US are identified, and criteria for profitable biogas projects by waste management method, size of operation and energy costs defined.

The International Energy Agency (IEA) has implemented an analysis for future trends referening to two scenarios, the Stated Policies Scenario (STEPS) and the Sustainable Development Scenario (SDS). [12] The **STEPS** represents the IEA's assessment of the implications of today's energy and climate policies, including those policies that have been announced (for example, as part of the nationally determined contributions under the Paris Agreement). This gives a sense of the direction in which the global energy system is heading, based on the latest available market and technology data and a defined set of starting conditions and assumptions. The **SDS** takes the opposite approach. It fixes the end point, in this case full achievement of various energy-related sustainable development goals, and then works out a feasible pathway to reach them. Most significantly, it charts a pathway for the global energy sector to be fully aligned with the Paris Agreement by holding the rise in global temperatures to "well below 2°C and pursuing efforts to limit [it] to1.5°C". It also meets goals relating to universal access to modern energy, including access to both electricity and clean cooking fuels, as well as a dramatic reduction in emissions of the pollutants that cause poor air quality.

Motivations like rural development, energy security (where biomethane is used instead of natural gas transported over long distances or imported, or where it is used flexibly to complement electricity from variable wind and solar PV), and urban air quality, are visible in IEA scenarios, notably in developing economies in Asia (including China, India, Southeast Asia and other developing economies in Asia Pacific) that account for the bulk of the growth. China produces over 30 Mtoe of biomethane by 2040 in the STEPS, which is injected into its expanding natural gas grid, while India's consumption grows to 15 Mtoe, in part to support the expansion of gas use in the transport sector.

In the case of China, biomethane largely substitutes for domestic coal and imported natural gas (biomethane provides a much greater reduction in CO2 emissions than switching from coal to natural gas). In India, it substitutes for the traditional use of solid biomass and for oil products, where import dependence stands at around 80% of total demand. Projected consumption growth in STEPS is more limited in countries with mature gas markets. Consumption in North America increases to just under 10 Mtoe. European biomethane use reaches 12 Mtoe in 2040, accounting for 2.5% of the gas used in natural gas grids. At the moment, 70% of the biomethane used in Europe comes from energy crops. The share of waste and residue feedstocks is set to rise, though, as policies seek to encourage bioenergy that avoids competition with food or feed production, and industry initiatives (such as the Biogas Done Right concept developed by the Italian Biogas Association) gain traction. In the SDS, the production and use of biomethane accelerates in all regions, a consequence of strengthened efforts to lower the carbon footprint of gas and ensure energy access across the developing world.

The Asia Pacific region sees by far the largest growth, driven in large part by China and India, but gains are also visible elsewhere: by 2040, there is a 10% blend of biomethane in gas grids in Europe and a 5% blend in North America. This represents a step change in the role of biomethane in global energy.

The Figure 8 presents the future trends for biomethane in two IEA scenarios, STEPS and SDS with developing countries in Asia to lead the way for biomethane.

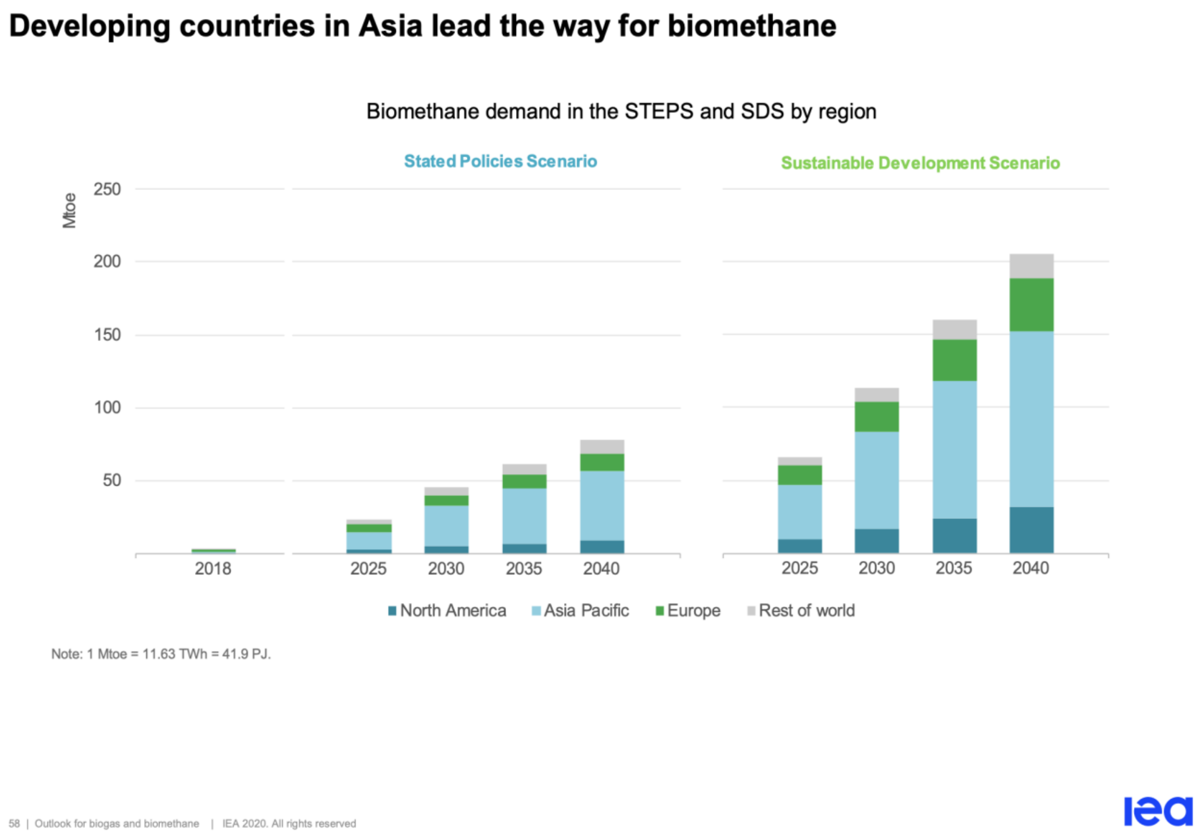

Fig. 8. Future trends for biomethane in two IEA scenarios, STEPS and SDS [12]

3 Methodology

This study intents to compare a better overall energy recovery from all biogas upgrading solutions – from AD and LF – than the equivalent co-generation options, by at least 2-fold. Economic yield comparison is highly dependent on the "feed-in" tariff that may be in place at each given time. To this scope, an overview over practices, polices and technologies in Europe and other regions is examined and taking into account global experience and industrial know-how of authors, a case study with economical data and a Comparison of CHP biogas and Biomethane Production with scenarions (injection to grid, CNG, LNG) for Greece is developed. Environmental data from Biogas upgrading are also presented as well as future applications in addition to land-usage of Biomethane, like the usage of Liquefied Biomethane (Bio-LNG) in the shipping industry, given the impact of the latter in Greek economic activity in terms of economic value and jobs created.

In Greece, biogas usage has been regulated by law 4414/2016, which sets the Feed-In tariffs (FIT) depending on the biogas source and plant capacity.

Table 1. – Feed-In tarif for biogas CHP plants[5]

	<2 Mwatt (€/KWh)	> 2 Mwatt (€/KWh)
Fermentable waste and organic sewage sludge	0.1229	0.106
	<3 Mwatt (€/KWh)	> 3 Mwatt (€/KWh)
Organic residues and wastes from livestock and agriculture: For power plants with an installed electrical capacity of less than three megawatts, the tariff is 22.50 cents each kilowatt hour. Power plants with more than three megawatts capacity get 20.40 cents per kilowatt hour.	0.225	0.20401

As of 2023, Greece accounted for 83 biogas plants, to a total energy production capacity of 1300 GWh, all dedicated to CHP.

As of the end of 2024 no Biomethane plant has been put in operation in Greece, inspite of the National Energy and Climate Plan (NECP) had set the target for the production of Biomethane 21TWh by 2030 and 9.7 TWh in 2050. [13] For achieving these targets a set of legal actions and documents needed in Greece like the determination of specifications for biomethane grid injection in Greece taking into account regulatory hurdles, ensuring gas quality, optimizing grid infrastructure, and promoting cost-effective solutions.

4 Available Technologies for Biogas Upgrading

Along the years, several technologies were developed to perform the removal of gaseous contaminants from biogas. This contaminant removal is the core of the Biogas Upgrading activities required to produce Biomethane. The comparison is performed towards the removal of the main contaminants required for Biomethane production –

CO2, N2 and O2 reaching the 40-60% of biogas composition. Other secondary contaminates may exist in biogas in very low percentage (or ppm level) like H2S, Siloxanes, NH3, VOCs and additional technologies may will be required.

The most adopted technologies, their advantages and drawbacks are described below:

Water Wash

Based on the principle of gas dissolution in water - CO_2 is soluble in cold water - whilst it can be released if water temperature is risen. Using this principle, a counter-current wash tower is used to “wash” the biogas, using cold water, being the resulting water collected at the tower rich in dissolved CO2, and the gas exiting from the top of the tower rich in CH4. Water is heated in a flash tank, where CO2 is released, and the water is re-introduced in the process.

This technology has an advantage of removing H_2S along with CO_2, but it will not remove Oxygen or Nitrogen, thus being unsuitable for modern high-grade Biomethane projects, where high CH_4 concentration is required. Additionally, it is not suitable to locations where water supply is in shortage, reason why this technology is declining.

Amine scrubbing

In this process, a scrubbing solvent - MDEA (mono di-ethanol amine) is passed through the gas phase, where CO_2 is reacting with MDEA, therefore being removed from the gas stream. In a second stage, the liquid solvent is heated and the CO_2 is released. After, the solvent stream is returned to the stripping tower.

This process has an advantage of allowing a high-level purification of CH_4 – up to 99,9%, but it will not remove Oxygen or Nitrogen. Additionally, a heat source is required to regenerate the solvent, reason why this process is considered to have a high operation cost.

This technology is not suitable for LF gas, where high concentrations of N_2 are usually found.

Membrane

This technology uses his technique uses polymeric membranes to separate the CO_2 from the CH_4 in biogas. Membranes are produced in long, thin fibers with a hollow center core.

Separation is achieved by Molecular diameter as the hollow fiber have nanopores with a defined diameter, that will allow the passage for the smaller molecules – permeate – and other bigger molecules will stay inside the core of the nanofibre – retenate. The control of the speed and gas pressure inside the nano-fibers will determine the separation capacity.

For high purity CH_4, multiple steps of membranes, with re—pressurizing between the steps and needed.

This technology allows the removal of CO_2 and in some extend, Oxygen, but does not allow N_2 to be removed from the gas stream, not being suitable for LF gas upgrading.

This technology has been widely used for AD gas upgrading, but growing concerns have been raised in the last years due to the tendency of irreversible bridging and clogging of the polymeric nano-holes by Volatile compounds.

PSA/VPSA

One of the most flexible technologies available today, PSA is the acronym o Pressure Swing Adsorption. This technology is based on properties of some materials that, under pressure, are capable of promoting a physical connection of some compounds inside its nano-structure, where some others do not make a connection, or can make but will take a long time for that connection to happen. The “VPSA” stands for Vacuum PSA, where vacuum is used to help clean the adsorbent material.

In the VPSA technology, no water or chemicals are used for the separation of the gas components. VPSA technology is the only upgrading technology that allows for the separation of O_2 and N_2, as well as CO_2, from CH_4, making it suitable to application both to AD and LF biogas. For these reasons is becoming today one of the preferred technologies for biogas upgrading.

VPSA processes can also achieve 98-99% CH4 concentration, and some have near-zero methane losses.

2-stage VPSA

The removal of Nitrogen in Landfill gas may require a specific VPSA process, with 2 sequential separation processes. SYSADVANCE METHAGEN LF, a patented process, removes N_2 in the first stage, where O_2 and CO_2 are removed in the second stage. N_2 levels can be drawn down from 22% to 2% with such process. CH_4 purity can be as high as 98%, with residual O_2 levels around 0.2%.

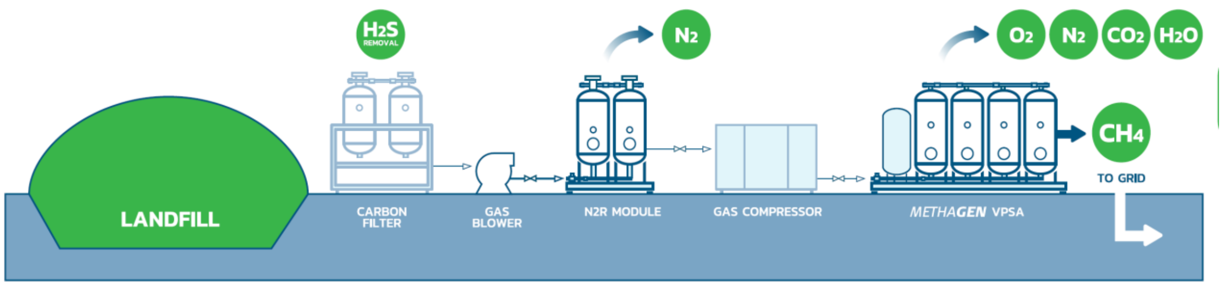

Fig. 9. METHAGEN LF system schematics for Landfill gas upgrade - SYSADVANCE

Fig. 10. METHAGEN LF system schematics for Landfill gas upgrade - SYSADVANCE

A detailed description of each biogas upgrading can be found in [14].

5 CASE STUDY – Comparison of CHP biogas and Biomethane Production – Greece

As in most European countries, biogas in Greece has been used for several years for electricity production in CHP units. The FiT are regulated by law 4414/2016. So far, no specific regulation was issued for Biomethane production, either for NG grid injection nor for CNG or LNG fleet fueling. In the present study, a comparison is made from the energy recovery and economical value points of view, of both CHP and Biomethane production. The cases of both AD biogas and LF biogas upgrading are presented in comparison with CHP.

In CHP projects, it is common to rate the energy recovery and values based on the MW.hr injected on the electrical grid or on the NG grid/CNG fueling.

Biogas composition has been considered to contain 55% CH4 in the AD case, and 50% in the LF case.

As there are no FIT published for Biomethane in Greece, its value was considered within the scope of this work between the public bulk NG price (aprox. 45€/MW.hr) or equivalent on fleet CNG price for fleet fueling, and the equivalent

for energy value FIT for COGEN systems. The trend is analyzed from public NG price or equivalent on fleet CNG price for fleet fueling.

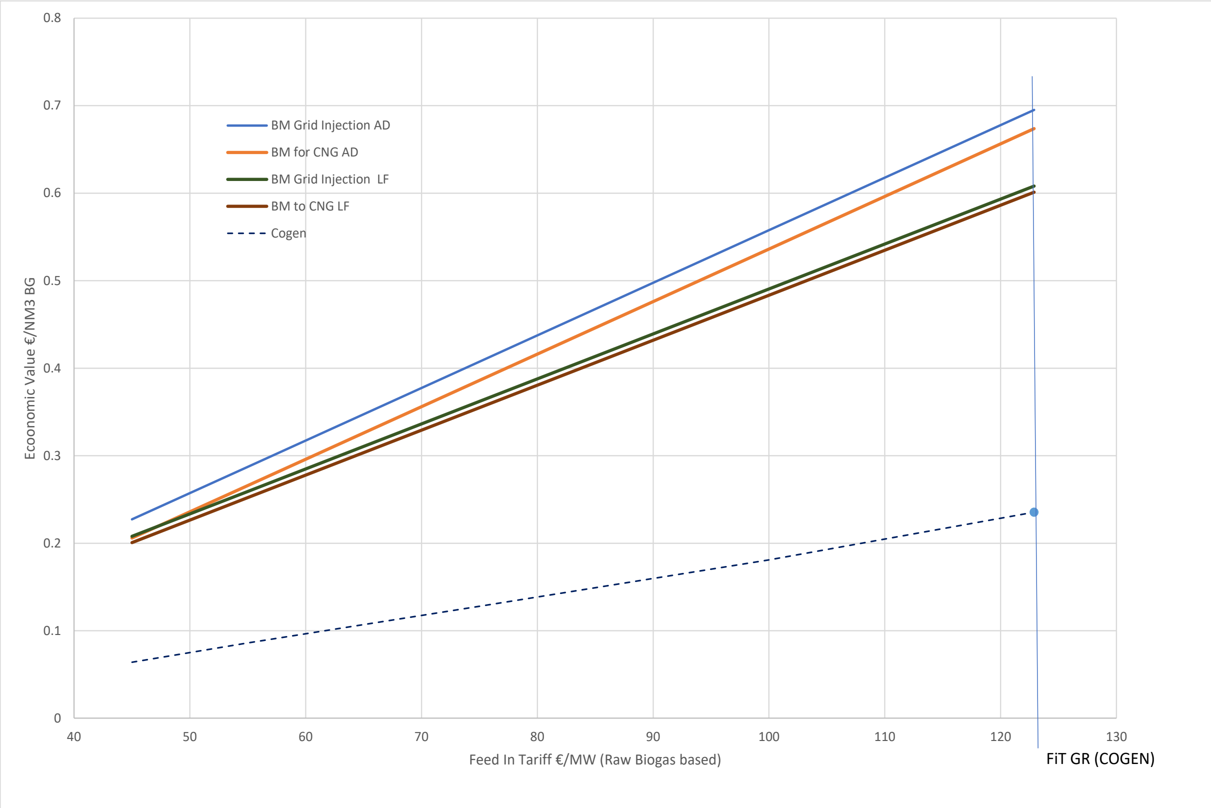

Fig. 11. Comparison of Economic Value between COGEN and Biomethane production, for CNG or Grid Injection

Figure 11 shows clearly the enhanced economic value of all Biomethane production, against COGEN option, for the same FiT. This effect is derived directly from the energy recovery efficiency of the biomethane production option, when compared against the less efficient COGEN technology.

Figure 11 also shows that Biomethane productions can yield the same economic value (0.2€/Nm3BG) to the operator with a FiT equal to a market value of NG or CNG than COGEN operation yields for a high FiT value (aprox 125€/MW.hr).

If a FiT for Biomethane is implemented, similar to the one current in place for COGEN (aprox 125€/MW.hr), the economic value of such Biomethane operation (0.6 – 0.7 €/Nm3BG) will be 3.5 times higher than the COGEN operation (0.2€/Nm3BG).

Another aspect to consider is the unit cost, both in Investment (CAPEX) and running costs (OPEX).

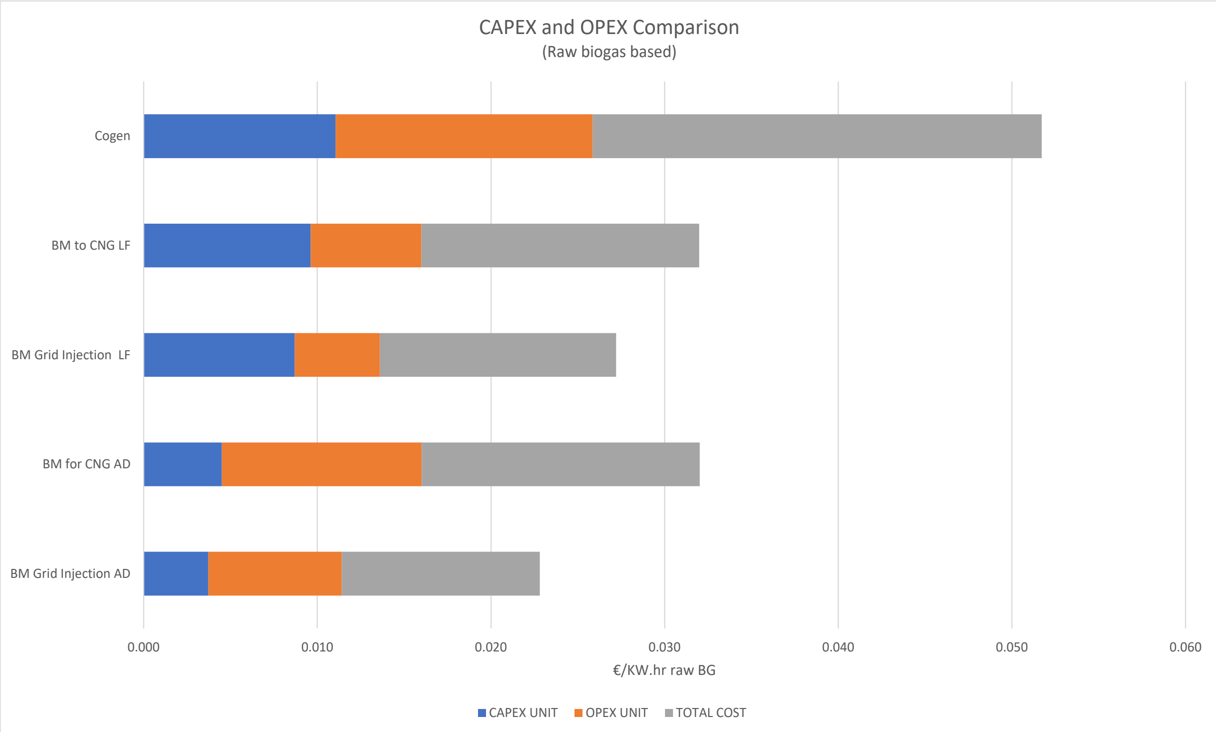

Fig. 12. CAPEX and OPEX value comparison for Biomethane production options and COGEN

Again, COGEN option presents itself as a higher investment option, as well as to having significantly higher running costs, when compared to all biomethane options. CAPEX and OPEX condition the economic value of the COGEN unit, reducing the operators profit margin.

An additional note should be added regarding the CAPEX and OPEX between the biomethane production options, Investment and operational costs:

Gas Origin – Landfill gas projects require higher investment and incur in higher OPEX costs due to the additional requirement of having a Nitrogen removal system, thus increasing both cost factor.

Gas Destination – CNG projects require higher investment and incur in higher OPEX costs due to the fact that a high-pressure gas compressor, high-pressure storage tanks and filling station add to the invest cost, and incur in OPEX values due to maintenance and power costs, when compared to NG grid injection projects.

Data used for COGEN calculations has been extracted from [15].

A 10-year amortization time was used to calculate unitary CAPEX.

6 Environmental factor – De-carbonization

The Biomethane option constitute a better option when compared to COGEN systems from an environmental point of view. When operation COGEN systems, CO_2 is generated by the combustion of the biogas. Additionally, energy recovery is low, thus adding to an increased environmental foot print.

Biomethane has a positive impact as far as environmental footprint is concerned, as it will replace NG from fossil origin, and will not produce CO_2 in its production, except the one naturally existing in biogas, which is also released during COGEN option.

Biomethane presents itself as having a positive impact on the de-carbonization efforts, by substitution of a fossil fuel gas by a renewable gas. In addition, for countries that do not produce NG, Biomethane can increase the energy independence resilience and energy source diversification.

7 Conclusions

COGEN energy production from biogas has been the valuation path since mid-70's. Currently, most European countries are phasing-out COGEN units, as FiT contracts are reaching their termination, and shifting the support incentives to Biomethane production, both for Grid Injection and Mobility (CNG).

As of the end of 2024 no Biomethane plant has been put in operation in Greece, inspite of the National Energy and Climate Plan (NECP) had set the target for the production of Biomethane 21TWh by 2030 and 9.7 TWh in 2050. [13] For achieving these targets a set of legal actions and documents needed in Greece like the determination of specifications for biomethane grid injection in Greece taking into account regulatory hurdles, ensuring gas quality, optimizing grid infrastructure, and promoting cost-effective solutions.

The present white paper intents to present the Biomethane production from biogas as a more efficient from recovery point of view.

Several technologies are presented and their advantages/shortcomings are presented. VPS technology presents itself as the technology showing more compatibility with multiple biogas upgrading scenarios.

Biomethane from Landfill gas and CNG application require a higher investment effort that from Digestion biogas, and for NG grid injection.

Data show that **Biomethane production from biogas allows for a better overall economic value for the operator, at least by two-fold, when compared to COGEN units at the same FiT**, as a result of the higher energy recovery capacity of Biomethane production technologies and lower CAPEX and OPEX.

Biomethane production costs are compatible with NG market prices given its low OPEX and CAPEX values. FiT tariffs should be in place in order to allow the biomethane production investments to be economical viable.

The adoption of the Liquefaction of Biomethane could have further positive effects in Greece´s shipping industry, supporting the adoption of this Renewable fuel as LNG shipping fuel., helping Greeck shipping industry to sustainably meet the IMO 2030 target of 40% GHG emissions reduction.

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