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Economic analysis of biomethane and bioelectricity generation from biogas using different support schemes and plant configurations

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A B S T R A C T

Commercial renewable energy projects are sensitive to policy instruments that shape the rate of deployment of renewables and affect their technological evolution. This study evaluates the economic performance of biogas projects under policy involving two novel instruments: (i) BFP (biomethane feed-in premium) and CMP (carbon mitigation premium) able to shape economic attractiveness and future technological evolution of biogas. The study reveals that only conventional biogas CHP plants are likely to be profitable under current policies. Biomethane plants require incentives e.g. from BFP, but interestingly the sufficient incentive can be more than 50% lower than the current incentive for electricity. The study also finds that innovative pressurised anaerobic digestion that can achieve direct carbon intensity of 13 tCO_2 per GWh_f (compared with about 168 tCO_2 per GWh_f for conventional biogas upgrading) can be very economically attractive, if policy combining BFP and CMP is implemented. The total support required from governments under the policy combining BFP and CMP instruments is similar or even lower than that currently available for bioelectricity. In addition, carbon mitigation benefits are achieved. Policy instruments and technological innovations are therefore critical for ensuring high energy outputs from biogas at a minimal economically justified carbon footprint.

1. Introduction

Renewable electricity from biogas is today incentivised by means of various policy instruments such as feed-in tariffs, quotas or auction systems. These usually attractive economic incentives make most biogas based electricity projects fully commercial today. However, the current incentives are relatively expensive to governments and hence applied to different extents across various European countries with only a few countries applying aggressive support schemes for biogas, e.g. Germany. In contrast, in recent years economic incentives have been rarely applied to support biomethane production and hence biogas technology has developed mainly in the direction of power production.

Therefore, the most widely used biogas related power technology in Europe is CHP (combined heat and power). Unfortunately, one of major deficiencies of distributed CHP systems [1] is their limited electrical efficiency (typically 35–40%). Another part of biogas energy content is converted to the form of renewable heat (about 40%), but with the exception of digester thermal control or optional digestate drying, a great amount of cogenerated heat is dissipated and wasted. The remainder of up to about 25% of biogas energy is dissipated due to the limited efficiency of CHP units. Distributed CHP plants with good access to cheap digestible biomass have usually poor access to heating infrastructures and opportunities for selling the cogenerated heat are limited. Hybrid CHP plants that involve the use of heat for digestate drying provide a new market product (dry organic fertiliser) but fail to provide additional renewable energy.

An alternative technological option to CHP is biogas upgrading to biomethane which is today gaining attention and incentivisation in Europe, e.g. in Italy, France, Germany, Denmark, UK, Sweden or the Netherlands. The major advantage of biomethanation is spatial and temporal decoupling of biogas production from utilisation that leads to increased energy efficiency and improved sustainability [2]. The energy cost of biogas upgrading by capturing CO_2 (about 0.2–0.5 kWh/Nm^3 raw biogas) can be less than 10% of raw biogas energy content (6 kWh/Nm^3 raw biogas, at 60% CH_4 content) and hence the energy conversion efficiency of about 90% can be attained. BM (biomethane) can substitute natural gas [3] thus

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serving local transport needs as a vehicle fuel [4,5] or being injected into natural gas grids. BM from gas grids can be further utilised in flexible power plants for generating back-up power thus stabilising power systems with a significant share of naturally fluctuating wind and solar power sources [6,7]. BM also greatly enhances energy storage potentials since methane can be stored in salt caverns, aquifers and depleted natural gas reservoirs in quantities up to 10 TWh_f per one storage site [8]. Most European countries already have natural gas storage infrastructures which can be used for BM without modification.

Specific raw biogas production costs range from 0.046 $€_{2013}/kWh_f$ for manure dominated feedstock mixtures to 0.065 $€_{2013}/kWh_f$ for a feedstock mixture dominated by maize silage. Specific biogas upgrading costs add on average 0.017 $€_{2013}/kWh_f$ leading to total costs of 0.063–0.082 $€_{2013}/kWh_f$. This is greater than the price of natural gas for industrial users of 0.037 $€_{2013}/kWh_f$ [8] emphasising the need for support schemes if biomethane industry is to become economically viable.

Support schemes for BM that are currently exploited in certain European countries include [8]: (1) feed-in tariff for electricity (with a BM bonus), (2) direct feed-in tariff for BM (supporting injection in the natural gas grid or direct delivery to a fuel station), (3) feed-in tariff for heat (the provision of BM for heat is supported with a feed-in tariff on top of the gas price), (4) tax exemption (allowing for exempting BM from a tax or applying a reduced tax rate), (5) investment incentive (investors benefit from a reduced interest rate for a loan or a fixed share of the investment cost), (6) fee for avoided network tariffs (rewarding for lower costs of local BM use compared to the transportation of natural gas over long distances), (7) biofuel quota in transport (existence of fixed targets or quotas for a certain amount of biofuels in conventional fuels increases demand for renewable BM) and (8) renewable energy quota (existence of an obligatory share of renewable electricity sold by the suppliers if not met by own generations requires purchase of certificates for example from BM).

This study investigates the performance of a BFP (biomethane feed-in premium) instrument. In contrast to feed-in tariff instruments, premium based instruments can be applied to biogas plants as an additional element of normal market mechanisms and easily operate in parallel with other economic incentives. Moreover, the construction of BFP allows for its full or gradual withdrawal when market conditions and price relations no longer justify supporting biomethane industry by BFP and thus their costs for governments can be easily optimised. BFP is similar to direct feed-in tariffs for biomethane currently applied in France, Denmark, the UK, Italy and the Netherlands, but the major advantage of BFP is that it enables biomethane investors to participate in the gas market in a normal way since investors receive revenues from both BFP and contract prices.

Another problem of RES technologies in general and biogas technology in particular is associated with the lack of climate policy instruments rewarding for alleviated CO_2 emissions of various RES options [9–12]. Therefore, this study proposes, applies and evaluates the second instrument enabling to shape climate policy - CMP (carbon mitigation premium). The idea of rewarding biofuel plants for their GHG (greenhouse gas) efficiency has been previously proposed in the literature, especially in the case of bio-CCS (biological carbon capture and sequestration) [13–15]. Some authors have economically assessed the rewarding of bio-CCS incorporation into different plant configurations, but in most cases, the rewarding was via the sale of CO_2 allowances. However, such rewarding is not included in the EU-ETS (European Emissions Trading Scheme). Considering current regulation in the EU, an alternative reward for extra-avoided emissions is the co-feeding of a fossil fuel. However, it depends on the relation between fossil fuel price and biomass price and for most hybrid plants there is an adverse technological effect associated with biomass/fossil fuel co-feeding. Besides, fossil fuel co-feeding might lead to the dilution of CO_2-rich streams available in biogas or ethanol plants and thus increase the costs of CO_2 capture. Hence, there is an evident place for new climate policy instruments allowing for biogenic CO_2 emissions mitigation in a most cost-effective way without imposing unnecessary technological constraints such as co-feeding of fossil fuels. The primary objective of decarbonisation is to mitigate atmospheric CO_2 emissions at a minimal cost. Any economically feasible opportunity to mitigate CO_2 emissions should be thus enabled. It does not matter what is the origin of these emissions, biogenic or fossil, since both accumulate CO_2 in the atmosphere and both kinds of CO_2 are equally suitable for subsequent photosynthesis.

Within the current study the usefulness and impact of BFP and CMP policy instruments on biogas industry is investigated through the explorative economic analysis. The economic analysis is carried out for four different configurations of biogas plants in order to understand how BFP and CMP affect different biogas systems. Two investigated plant configurations involve conventional near-atmospheric anaerobic digestion, the first with CHP and the second with biogas upgrading to biomethane. The other two analysed plant configurations employ innovative pressurised anaerobic digestion delivering high purity methane followed by CHP or ending with biomethane as the final product. For a feedstock involving maize silage (40%) and cattle liquid manure (60%) the study provides technical parameters retrieved from a biogas plant model as well as economic parameters such as CAPEX, OPEX and income. NPV (net present value) and IRR (internal rate of return) are calculated for each plant configuration. Six scenarios are tested involving different combinations of supporting policy instruments.

2. Policy instruments incentivising biogas

2.1. BFP (biomethane feed-in premium)

BFP (biomethane feed-in premium) is an instrument offering economic incentive for biogas upgrading to biomethane. It takes the form of a premium rewarding for injection into gas grid or delivery to a fuel station. BFP can be implemented by means of an auction system to allocate it to a specific project owner. Alternatively, BFP can be implemented by means of a regulatory act and made available for broader groups of investors. Throughout this study BFP is understood as a policy instrument, premium associated with BFP is denoted as P_{BFP} and expressed in units $€/kWh_f$ (e.g. $P_{BFP} = 0.03\ €/kWh_f$) while incomes from BFP are denoted as I_{BFP} and expressed in units of €/yr.

2.2. CMP (carbon mitigation premium)

CMP (carbon mitigation premium) is an instrument aiming at rewarding for decarbonisation of fuel based plants, e.g. bioenergy plants. It can be easily adjusted to fit feed-in-tariffs, feed-in-premiums, quotas or contracts for difference based renewable energy support policies. CMP is constructed by specifying the reference level of CO_2 emissions intensity for a specific bioenergy technology. For simplicity reasons CMP is based on direct CO_2 emissions. The reference level of direct CO_2 emissions intensity is set in this study for biomethane (fuel) at 152 tCO_2/GWh_f and for electricity at 823 tCO_2/GWh_{el}. Plants generating biomethane and/or electricity from biogas with CO_2 emissions intensity lower than the reference level obtain premium per each tonne of mitigated CO_2 (P_{CMP} in units $€/tCO_2$). Incomes from CMP (I_{CMP} in units €/yr) are calculated from very simple formulas for biomethane (fuel) and electricity, respectively (eqs. (1) and (2)).