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Technical and economic analysis of biomethane: A focus on the role of subsidies

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ABSTRACT

Biomethane is a renewable energy useful to encourage the transition to a sustainable energy future. Incentive policies favour its development and consequently this paper evaluates the economic performance for use of biomethane fed into the grid, destined for cogeneration or sold as vehicle fuel. A mathematical model is proposed and the indicators used are Net Present Value and Discounted Payback Time. This paper aims to evaluate the financial feasibility of biomethane plants in function of the plant size (100 m^3/h, 250 m^3/h, 500 m^3/h, 1000 m^3/h) and the feedstock used (organic fraction of municipal solid waste and a mixture of 30% maize and 70% manure residues on a weight basis) for each final destination of biomethane. Furthermore, a sensitivity analysis on the critical variables is conducted and 356 case studies are overall assessed. The results of the paper demonstrate that the profitability of biomethane plants is verified in several scenarios and it is strongly linked to the subsidies. Biomethane used as vehicle fuel presents greater financial results favouring the increase of share of renewable energy in transport sector and environmental improvements are obtained.

1. Introduction

Policies and management practices of renewable energy systems (RESs) can encourage a green revolution in the energy context of XXI century. RESs provide important benefits compared to fossil fuels, in particular regarding greenhouse gas (GHG) emissions, but also economic opportunities are very interesting [1–3]. Furthermore, European Union (EU) aims to develop the circular economy based on the exploitation of resources recovered by wastes [4,5].

Biogas is produced by anaerobic digestion (AD) beginning from a range of feedstocks, particularly agricultural residues (e.g. manure and crop residues), energy crops, organic-rich waste waters, organic fraction of municipal solid waste (ofmsw) and industrial organic waste [6,7]. Mediterranean products and by-products are widely available and the usable matrices change the economic feasibility due to their yields and costs [8,9]. Biomethane is obtained from properly treated biogas through the process of purification. Its properties are similar to those of natural gas, making it suitable for be used as a vehicle fuel, distributed in the main gas supply or used to generate green power [10,11].

The use of biomethane is mainly spread in the EU, because it enables European countries to reduce their reliance on natural gas imports [12]. According to the latest data, Europe has 367 biomethane by the end of 2014, 23% increase compare to 2013. Germany leads the ranking in terms of number of plants (equal to 178), followed by Sweden (no. 59), the UK (no. 37), Switzerland (no. 24) and the Netherlands (no. 21). In 2014, about 12% of all biomethane produced in Europe was used in the transport sector and it is expected to grow further in the future [13].

The biogas-biomethane chain is a carbon-negative substitute for consumption of fossil gas and its use achieves a reduction of greenhouse gases amounting to the equivalent of 200 g of CO_2/kW h of generation (200 gCO_2eq/kW h) [14]. In the transport sector, a mixture of 20% biomethane provides a reduction of 24 gCO_2/kW h than methane and using 100% biomethane this reduction is estimated equal to 119 gCO_2/kW h. The use of methane as fuel for a given vehicle currently achieves emissions savings of 21–24% compared to diesel and petrol [15]. Consequently, the policy makers can support biofuels, because they are characterized by lower emissions compared to ones produced by diesel and petrol [16].

The upgrading of biogas to biomethane is more environmentally sustainable, in terms of GHG emissions and reduction of NOx and particulate matter (PM) local emission, than combustion of biogas in a combined heat and power unit [17]. Giant reed, that is a good alternative to energy crops, is recently included among crops

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Nomenclature

1°s	biogas production
2°s	upgrading
3°s	compression and distribution
bm	biomethane
c_{c}^{chp}	corrective coefficient (chp)
c_{c}^{vf}	corrective coefficient (vf)
$c_{c,su}^{fitg}$	corrective coefficient – substrate (fitg)
$c_{c,si}^{fitg}$	corrective coefficient – size (fitg)
$C_{df}^{1°s}$	depreciation fund (1°s)
$C_{df,t}^{2°s}$	depreciation fund (2°s)
$C_{e,t}^{1°s}$	electricity cost (1°s)
$C_{e,t}^{2°s}$	electricity cost (2°s)
$c_{e}^{u,1°s}$	unitary electricity consumption (1°s)
c_{f}^{el}	conversion factor (electric energy)
c_{f}^{th}	conversion factor (thermal energy)
$C_{i}^{1°s}$	insurance cost (1°s)
$C_{i,t}^{2°s}$	insurance cost (2°s)
C_{inv}^{com}	investment cost (compression)
C_{inv}^{dis}	investment cost (distribution)
C_{l}	labour cost
$C_{l}^{u,a}$	unitary labour cost
C_{lcs}	loan capital share cost
C_{lis}	loan interest share cost
$C_{inv}^{u,1°s}$	unitary investment cost (1°s)
$C_{inv}^{u,2°s}$	unitary investment cost (2°s)
$C_{inv}^{u,2°s}$	unitary investment cost (3°s)
$C_{mo}^{1°s}$	mtz & overhead cost (1°s)
$C_{mo}^{2°s}$	mtz & overhead cost (2°s)
C_{o}^{com}	operative cost (compression)
C_{o}^{dis}	operative cost (distribution)
C_{s}	substrate cost
C_{s}^{u}	unitary substrate cost
C_{t}	discounted cash flow
C_{t}^{ofmsw}	cost of ofmsw
C_{tax}	taxes cost
C_{ts}	transport cost of substrates
C_{ts}^{u}	unitary transport cost of substrate
chp	combined heat and power
dtc	discounted total cost/m^{3}bm
dti	discounted total incentive for m^3 bm
dto	discounted total ofmsw for m^3 bm
dtsb	discounted total selling bm for m^3 bm
dtse	discounted total selling energy for m^3 bm
DPBT	discounted payback time
ebt	earnings before taxes
ftg	feeding into the grid
i_{aifit}^{u}	unitary incentive (chp)
i_{cic}^{u}	unitary incentive (vf)
I_{t}	discounted cash inflows
inf	rate of inflation
l_{bs}	losses in the biogas system
l_{f}^{el}	loss factor (electric energy)
l_{f}^{th}	loss factor (thermal energy)
l_{us}	losses in the upgrading system
mtz	maintenance
n	lifetime of investment
n_{debt}	period of loan
n_{oh}	number of operating hours
n_{op}	period of subsidies
n_{s}	number of operators
NPV	net present value
NPV/Size	ratio between NPV and size
O_{t}	discounted cash outflows
p_{b}^{u}	potential of biogas per unit of vs
p_{df}	% of depreciation fund
p_{e}	unitary price of electricity
p_{esc}	% of energy self-consumption
p_{i}	% of insurance cost
$p_{mo}^{1°s}$	% of mtz & overhead cost (1°s)
$p_{mo}^{2°s}$	% of mtz & overhead cost (2°s)
p_{ng}^{2012}	price of natural gas in 2012
p_{ng}^{c}	current price of natural gas
p_{sng}	selling price of natural gas
p_{tax}^{unit}	% of taxes cost
p_{u}^{th}	% of use of thermal energy
p_{z}^{el}	zonal price of electric energy
p_{z}^{th}	zonal price of thermal energy
R_{t}^{ofmsw}	revenues by treatment of ofmsw
$R_{gross,t}^{ofmsw}$	gross revenues by ofmsw
$R_{t,chp}^{selling}$	revenues by sell of bm (chp)
$R_{t,fitg}^{selling}$	revenues by sell of bm (fitg)
$R_{t,vf}^{selling}$	revenues by sell of bm (vf)
$R_{t,chp}^{subsidies}$	revenues by subsidies (chp)
$R_{t,fitg}^{subsidies}$	revenues by subsidies (fitg)
$R_{t,vf}^{subsidies}$	revenues by subsidies (vf)
$Q_{feedstock}$	quantity of feedstock
Q_{biogas}	quantity of biogas
Q_{biogas}^{nom}	nominal quantity of biogas
$Q_{biomethane}$	quantity of biomethane
$Q_{biomethane}^{chp}$	quantity of bm after conversion
$Q_{biomethane}^{el}$	quantity of electric energy
$Q_{biomethane}^{fitg}$	quantity of subsized bm (fitg)
$Q_{biomethane}^{nom}$	nominal quantity of biomethane
$Q_{biomethane}^{th}$	quantity of thermal energy
Q_{ofmsw}	quantity of ofmsw
r	opportunity cost
r_{d}	interest rate on loan
S_{biogas}	plant size (biogas)
$S_{biomethane}$	plant size (biomethane)
t	time of the cash flow
ts	total solids
vf	vehicle fuel
vs	volatile solids
ww	wet weight
%CH_4	percentage of methane
%ts/(ww + ts)	percentage of vs in the ww + ts
%vs/ts	percentage of vs in the ts

eligible for EU contributions, under the voice of environmentally beneficial practices [18].

From technological perspective, new solutions are proposed increasing the production of biomethane: a novel concept that combines AD and biomass gasification [19] and the use of polyetheretherketone (PEEK) membrane that obtains biomethane usable directly in the secondary grid injection with a pressure lower than 10 bar [20]. Manure separation technologies are