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Electricity and substitute natural gas generation from the conversion of wastewater treatment plant sludge

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HIGHLIGHTS

- A comparative energy generation assessment from WwTP sludge was conducted for Chile.
- Economic potential and generation cost of electricity and Bio-SNG were evaluated.
- The representative generation cost of electricity was estimated at 21.5 ct € kW h_e^{-1}.
- The representative cost of Bio-SNG was estimated at 43 € $MMBTU^{-1}$.
- Electricity offers both economic and environmental benefits in a larger extent.

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ABSTRACT

In Chile, the energy that can potentially be obtained from the digestion of sludge generated from wastewater treatment processing (WwT) was calculated using a holistic approach. The different pathways of electricity generation via the direct combustion of biogas and upgraded biogas produced as bio-substitute natural gas (Bio-SNG) for injection into the gas grid were assessed and compared. Information such as the served population, WwT technology employed and geographical distribution of the sludge sources was gathered to estimate energy potential; additionally, technical and economic information was collected from the literature. Furthermore, economic modelling was employed for the purpose of comparing the two end-use alternatives.

The results were presented by using supply-cost curves and then integrated into a geographical information system (GIS), the latter of which shows the distribution of energy potential nationwide. A comparison with a reference market price of the corresponding secondary energy type, electricity or natural gas, was conducted to elucidate the economic attractiveness of the two assessed options. From the assessment, it was concluded that the economic potential for the injection of Bio-SNG into the grid is 19 MM $Nm^3\,y^{-1}$ at a representative generation cost of approximately 43 € $MMBTU^{-1}$, whereas biogas for the electricity generation pathway has an economic potential of 75 GW $h_e\,y^{-1}$ at a representative generation cost of 21.5 ct€ kWh_e^{-1}. In view of these results, it can be observed that the electricity generation pathway may offer more major economic and environmental benefits than the Bio-SNG pathway, despite both options being hardly competitive without subsidies. Additionally, it can be observed that the Bio-SNG route is not competitive in most cases, and it is economically attractive solely under restricted conditions, principally those established by plant capacity. Furthermore, steadily increasing electricity prices over time suggests that the biogas-to-electricity option will become progressively more competitive. These results can be considered as outcomes to elaborate a national macro-policy to tackle the sludge issue under a waste-to-energy approach.

1. Introduction

Adequate water and sanitation services are crucial for the protection of public health, the maintenance of basic conditions of living and the protection of biota and natural resources. Despite the outstanding advances in wastewater treatment technologies in recent decades, the universalisation of water and sanitation services remains a major challenge for the 21st century [1].

Under a modern perspective, a centralised municipal wastewater treatment (WwT) programme was set up in Chile, thanks to a large-scale water reform policy started in the late 1990s, leading toward the privatisation of this service sector, which was previously managed by the state. In parallel with this

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Nomenclature

Bio-SNG	substitute natural gas from biomass
MMBTU	one million British thermal units, 1 MMBTU = 293.29 kW h_{th}
WwT	wastewater treatment
WwTP	wastewater treatment plant
CHP	combined heat and power
ct €	euro cent
MM	abbreviation of one million (10^6)
GIS	geographical information system
GW h_e	gigawatt-hour electric
GW h_{th}	gigawatt-hour thermal
hab	inhabitants
VS	volatile solids
TS	total solids
t	metric tonne (1000 kg)
FM	fresh matter
θ_H	mean hydraulic retention time (h)
θ_c	mean cell retention time (h)
MLVSS	mixed liquor volatile suspended solids
VSS	volatile suspended solids
BOD	biochemical oxygen demand
CAS	conventional activated sludge
COS	carbonyl sulphide
AD	anaerobic digestion
$y_{i,j}$	index i and j of a variable y
π_f	physical limit (theoretical potential)
π_g	geographical limit (geographical potential)
π_t	technical limit (technical potential)
π_e	economic limit (economic potential)
$A_{i,j}$	restriction on source j of limit i
i	capital cost (%)
γ, δ	correlation factors

restructuring, emissions standards for municipal sewage discharge were developed when the General Environmental Law was enacted (1997). With the advent of these standards, water supply companies have the obligation to treat polluted water after discharging it into the surface-water environment for the purposes of preserving biota, avoiding detrimental effects, improving the value of tourism sites and protecting human health. According to the World's Water Report [2], Chile has 922 billion cubic metres of total renewable freshwater. Furthermore, by 2010, 87% of the urban population was connected to wastewater treatment plants (WwTPs) [3], a share that is in line with OECD countries [4]. This figure is expected to reach 98% and then 99% by the present year (2013) and 2015 respectively (see Fig. 1).

WwT constitutes a set of physicochemical processes employed to remove pollutants, which can be physical, chemical or biological substances. WwT is normally divided into primary, secondary and tertiary treatment and is designed according to the environmental regulations governing the treated water. While primary systems (also known as mechanical treatment) entail the removal of suspended solids, floating materials and scum from raw sewage, commonly by sedimentation or flotation, secondary treatment (also known as biological treatment) aims to remove dissolved organic matter by anaerobic or aerobic biochemical processes. In tertiary systems (also called advanced treatment), the organic matter remaining after secondary treatment is removed, along with phosphorous and nitrogen, to control nutrient levels. Disinfection may subsequently be conducted eventually to meet the standards of effluent regulations.

As Fig. 2 shows, the most common primary treatment technology employed in Chile is sedimentation, which accounts for 5% of the total. In some particular cases, it is followed by disinfection, and this two-step treatment is sufficient to meet environmental regulations. The most heavily employed system in secondary treatment is activated sludge, which includes conventional activated sludge (CAS), extended aeration, oxidation ditches or sequential batch reactors, and makes up 54% of the total technology employed. The stabilisation pond is the second most commonly used technology in secondary treatment at 6% of the total and entails wastewater treatment in large surfaces, with or without aeration. The remaining 12% of the total number of running WwTPs are wastewater emissaries (outfalls), which collect wastewater and then dispose of it in the ocean. The introduction of tertiary systems is practically nonexistent, mainly as a consequence of current environmental observances.

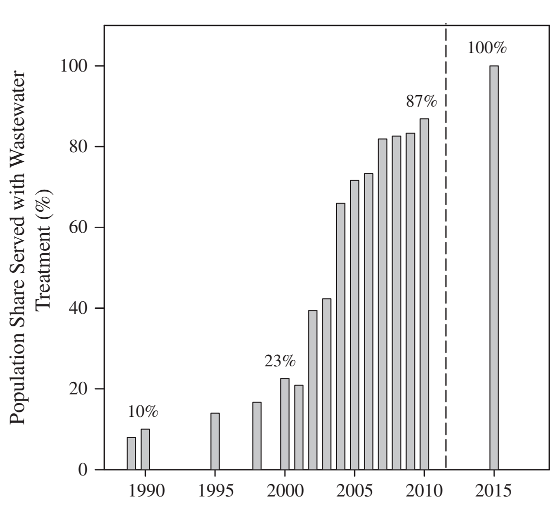

Fig. 1. Share of population served with public wastewater treatment in Chile 1990–2010.

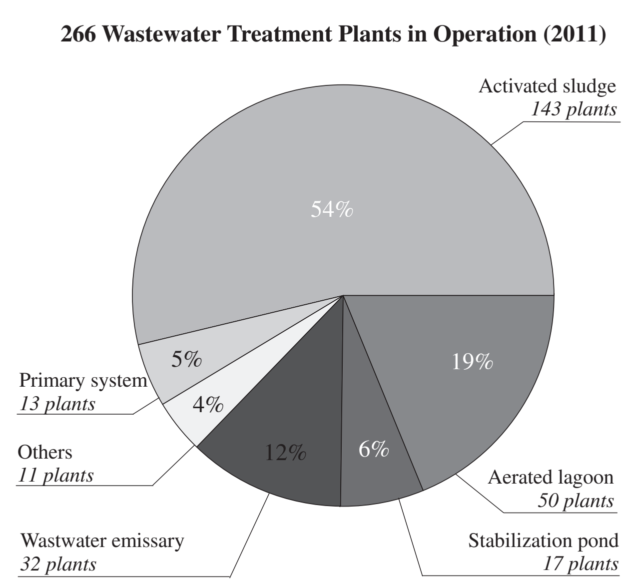

Fig. 2. Wastewater treatment technologies used in Chile.