POTENTIAL AND COSTS ESTIMATION OF BIOMETHANE IN CROATIA: URBAN WASTE TO GRID INJECTION AND USE IN TRANSPORT SECTOR

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Summary

Croatia became the 28th Member State of European Union on 1 July 2013 and has to have legal framework harmonized with EU acquis as well as to fulfill related obligations in practice. What is of relevance for this work: waste treatment is defined by Directive 1999/31/EC on the landfill of waste and Directive 2008/98/EC on waste, while the share of Renewables in transport, according to Directive 2009/28/EC, has to be minimum 10% in 2020.
Biomethane could be a solution for obligations in both sectors: as a positive valuable result of organic urban waste treatment and as a fuel contributing to increase of RES share in transport sector.
There is a legal framework in Croatia transposing related directives, as well as strategies and plans for both areas at the state and some local levels, but a general overview of potential for biomethane production is missing. Thus, an assessment of biomethane potential for feed into the grid and use by transport sector, with the focus on municipal solid waste, is a core topic of this presentation.

Key words: Biomethane, Municipal Solid Waste, Biogas, Biogas Upgrade, Injection into Gas Grid, Transport

1. STRUCTURE OF THE WORK

The scope of this work is the potential of biomethane production in Croatia from the biodegradable part of municipal solid waste only, i.e. excluding energy crops, agricultural and industrial waste, as well as sewage. Furthermore, the usage side of biomethane is limited to the transport sector and injection to the gas grid, without consideration of electricity and heat production. It has to be noted that this source – MSW - has not been considered at the state level so far as a source of biomethane in Croatia.

The first step of the work was an assessment of the annual quantity of municipal solid waste produced in Croatia using national statistics, published by the Bureau of Statistics and by the Environment Agency. All data and assessment were done for 2011, the last year for which real data have been published by the Bureau of Statistics and the Environment Agency (at the time of writing this thesis). Keeping in mind the fact that the separation of municipal waste is still not very developed in most of the counties and that it has to be introduced to fulfill the obligations imposed by Directive 2008/98/EC, not all amounts of biodegradable MSW were taken into account as potential sources of biomethane production. To be more precise: plastics, paper and cardboard were deducted from the overall MSW quantity.
An exact structure of MSW is publicly available for the City of Zagreb, and this structure was used for the assessment of the MSW structure for other counties. It has been considered as adequate, since the City of Zagreb contributes with 20% to the total MSW of Croatia, which corresponds to 18% of the Croatian population living in Zagreb. According to this assessed MSW structure, 36,1% of municipal solid waste has been considered as a source for biogas production and biomethane production respectively.

The potential of biogas production, including assessment of relevant costs, has been calculated based on the type of waste (as defined according to the MSW structure), given the correlation between the type of waste and biogas yield (as given by Wellinger (2012)) and taking into account the most applicable technologies. Using the same source (Wellinger (2012)), a share of biomethane in biogas was assessed as of 61%, i.e. 61% of biogas potential has been taken as biomethane potential.

The next step was an elaboration on biogas upgrade (i.e. biomethane production): why and how it can be done – in line with the requirements for gas grid injection and vehicles from one side and with upgrade technologies from another side. The characteristics of the transport sector and the natural gas network in Croatia were briefly described, and the requirements, possibilities and barriers for further use of biomethane – directly in the transport sector and in the natural gas grid – have been considered within this work.

The data on the existing natural gas network have been found at the Transmission System Operator, Plinacro (for transmission grid) and at the Croatian Gas Association (for distribution grids). Taking into further consideration population data, as given by the Bureau of Statistics after the last Consensus in 2011, an assessment of the population with access to transmission natural gas network and distribution networks respectively, has been done. In other words, it was assessed how much biomethane produced from MSW can be easily injected into the natural gas network – from "the population covered by the natural gas network" point of view.
The data for the transport sector, i.e. vehicles in Croatia using natural gas, were found at NGVA and HSUP. The same sources were used for natural gas prices, in order to make a price comparison of methane produced from MSW and the existing methane (natural gas) on the Croatian market.

Investment costs were assessed according to the technology (appropriated for this type of waste as input material), quantities of biodegradable waste (as assessed per county for an estimated MSW structure) and investment costs for certain biogas technology and quantity (as given by Kovacevic (2010)).

The counties have been grouped in different groups – according to geographical and traffic configurations – to apply the economy of scale principle, i.e. to try to find a more economical solution for biogas production from MSW (not 1 plant in each county, then other configurations downsizing to only 3 plants in the entire country). Additional costs – to upgrade biogas to biomethane – have been calculated using the results of "Bio-methane Regions" project (Biomethane Calculator) and according to the gas requirements in the case of injection to the natural gas grid and in vehicle use. Those upgrading costs have been added to biogas plant costs, following the same grouping of counties (from one plant per county to the grouping where 3 plants can cover the MSW of entire country).

The final part brings conclusions on the possible contribution of biomethane to the fulfillment of the RES transport target by 2020, as well as meeting obligations in regards to waste treatment and landfills.

2. LEGISLATIVE FRAMEWORK AS BACKGROUND

Legislative framework forms an important background to this work. On the one hand, the requirements towards waste in general, including municipal solid waste have been imposed; defining a scope of waste which can and has to be used for energy production, including biomethane. On the other hand, the compulsory targets for Renewables, including the transport sector, have to be fulfilled by 2020. Croatia transposed the relevant EU acquis into the national legislation, making an obligatory framework which is, in a way, an incentive basic for this work.

Waste management is one of the important issues interlinked with environmental protection. Several directives and regulations define the EU framework for waste management, but only the most relevant to municipal waste and, consequently, to this work, have been described within this sub-chapter.
Directive 1999/31/EC[1] stipulates an obligatory decrease of land filled biodegradable waste in all Member States. In concrete terms, for Croatia, the reference year is 1997. Biodegradable waste quantities at landfills have to be reduced to 75% of 1997 values by 31 December 2013, 50% by 31 December 2016 and 35% by 31 December 2020 respectively[2]. Absolute numbers are shown by Table 1:

Table 1 – Mandatory decrease of biodegradable waste disposal at landfills in Croatia

1997	by 31.12.2013	by 31.12.2016	by 31.12.2020
100%	75% of 1997' value	50% of 1997' value	35% of 1997' value
756.175 t	**567.131 t**	**378.088 t**	**264.661 t**

(Data source: Law on sustainable waste management, OG 94/13)

Directive 2008/98/EC[3] establishes mayor principles of handling waste in a way that does not have a negative impact on the environment or human health, at the same time imposing certain requirements to product producers and introducing a waste hierarchy and relevant treatment manners. For this work, recovery, i.e. energy recovery, is the most relevant.
Croatia has transposed both directives into its national legislation. A basic primary law, the Law on Waste (OG 178/04, OG 111/06, OG 60/08 and OG 87/09), has been complemented by secondary legislation: the Ordinance on Waste Management (OG 23/07 and OG 111/07); the Rulebook on Register of Environmental Impurity (OG 35/08) and the Rulebook on Manner and Conditions of Waste disposal, categories and work conditions of landfills (OG 117/07 and OG 111/11). A comprehensive Law on sustainable waste management (OG 94/13) was approved in July 2013, comprising definitions and requirements of the previous law and secondary acts.
The legislation defines waste and its categories, as well as the responsibility for waste management. Cities and municipalities are responsible for municipal waste management, which includes waste separation and set up of relevant containers. The counties and the city of Zagreb are responsible for managing all types of waste, except hazardous waste, which is the sole responsibility of the state. The legislation foresees, in line with the EU acquis, an increase of waste separation and re-use, as well as a decrease of landfills.
The Strategy of Waste Management in the Republic of Croatia (the Strategy in further text) describes the state of play in 2005 as the base line and ways to achieve mandatory goals. Two main issues have to be solved at the same time: the decrease of landfills and re-design of current waste separation and waste management.
The first step required in the direction of proper waste management and reduction of landfills is the separation of municipal solid waste. Only 16,3 % of MSW in Croatia was separated in 2011 (which is an increase in comparison to 10% in 2005). Glass, plastics, metals and paper are target materials of waste separation waste, but however, established systems and achieved results vary very much among the cities and counties in Croatia. The biggest shares of separated MSW (25,9 - 21%) have been achieved in Medjimurska County, the City of Zagreb and Primorsko-goranska County, while the lowest share – at the level of 2-3% - belongs to Licko-senjska and Vukovarsko-srijemska County.
According to the Report by the Environment Agency, 212 companies are involved in MSW collection in Croatia. 20 plants for the mechanical treatment of MSW, with a total capacity of 50.000 t/y, are in operation. There are also 3 plants for biological treatment, all of them located in the city of Zagreb. Zagreb is also the location of the single plant for landfill gas, used for further energy production, with the installed capacity of 2 MSW. Composting is organized at 7

[1] Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste
[2] Originally for EU MS, the reference year was 1995, and deadline years 2006, 2009 and 2016, while Croatia negotiated a certain postponement (to 2013, 2016 and 2020) during the Accession process to EU
[3] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

sites, with 14.000 t of MSW composted in 2011. Still, in 2011, 91% of municipal biodegradable waste (937.375 t) was deposited at landfills. As described in Table 1, by the end of 2013, the amount of deposited biodegradable waste had to be decreased to 75% of the quantity in 1997, i.e. to the level of 567.131 t.

Whereas municipal solid waste is the first pillar, the transport sector is the second pillar of this work; in particular transport fuels produced from renewable energy sources.
Directive 2003/30/EC[4] on the promotion of biofuels set up a general direction for transport sector – indicative renewable fuel targets (2% in 2005 and 5,75% in 2010), principles of support and promotion measures, as well as obligations on monitoring and reporting. One of the obligations was dedicated to monitoring the effects of the fuel mix with more than 5% biofuels, enabling the set up of a higher target. A higher target – as minimum of 10% fuels from renewable energy sources in transport by 2020 – has been set up by Directive 2009/28/EC[5] on renewable energy sources. The Directive unifies different sectors – electricity and transport, and recognizes the importance of heating and cooling in terms of energy consumption and consequently as a potential area of usage of renewable energy.
However, the most demanding requirements have been defined for Renewables in the transport sector, in particular towards liquid biofuels. Only biofuels produced in compliance with sustainability criteria, related to the types of land for crops production and CO_2 emission savings, can be calculated towards target fulfillment, regardless of the origin of production (i.e. by a Member State or imported).In addition, the contribution made by biofuels produced from waste, residues and non-food cellulosic material, as well as from ligno-cellulosic material, shall be considered to be twice that made by other biofuels. Both aspects – more strict requirements towards liquid biofuels than before and double counting of biofuels produced from waste (including municipal solid waste) – are very important for this work, and, in a way, they were the triggers for the chosen topic.
Additional requirements for the transport sector have been defined by Directive 2009/33/EC[6] on clean and efficient road vehicles. Special obligations have been placed on public authorities at state, regional and local levels regarding the general procurement of public vehicles. In this context, biomethane produced from municipal waste can play a significant role.
As well as waste management directives, the directives related to Renewables in the transport sector have been transposed by the Croatian legislation. The main document is the Law on Biofuels for Transport (OG 65/09 and OG 145/10), followed by several rulebooks and decrees, which define in more detail the support measures in production and usage of biofuels, eligibility conditions for support, sustainability criteria and its certification, energy content and fuel quality. The relevant framework was completed by strategic documents, such as the Energy Strategy and the Strategy of Sustainable Development, the National Renewable Energy Action Plan and the National Action Plan on incentives for production and usage of biofuels in the transport sector for the period of 2011-2020. Biogas has its place in all of these documents, although not a significant one.
It is important to emphasize that transport in Croatia is the sector with highest share in total final energy consumption since 2005 (30%) and has been growing continuously by 4,69% per year. Keeping in mind the consumption level in 2005 (80,02 PJ in transport sector), as the reference year for RES 2020 targets, the development forecast (128,54 PJ in transport sector in 2020) and the obligation by Directive 2009/28/EC (10% RES-T by 2020), renewable energy sources in transport must reach 10,05 PJ by 2020.
In 2011, bio-liquids contributed with only 0,16% of the total consumption of 84,97 PJ in the transport sector. Biogas has not been consummated in transport so far. The contribution of biogas (biomethane) has been foreseen from 2016 on; with 0,37 PJ in 2016, reaching 0,62 PJ by 2020. The National Action Plan on the incentives for production and usage of biofuels elaborates the potential for biomethane production, taking into account only livestock manure (2-2,6 PJ/y) and sewage waters in the 5 largest cities (0,31 PJ/y)[7]. The potential of biodegradable municipal waste, the topic of this work, has not been considered.

3. AN ASSESSMENT OF MSW AS A SOURCE FOR BIOGAS AND BIOMETHANE PRODUCTION

At the beginning of this chapter, in order to avoid possible misunderstanding, we should distinguish several terms, commonly used:
Natural gas is mainly composed of methane (CH_4), while ***biogas*** is the term used for balanced mixture of methane (CH_4) and carbon dioxide (CO_2). Thus, it is not appropriate to exchange the terms “natural gas” and “biogas” when applicable, as it can be done for example for diesel and biodiesel (equal in regards to composition and different only according to the origin). Keeping in mind gas compositions, the link between the terms “***natural gas***” and “***biomethane***” is more accurate.

Different wastes with an organic component can be an excellent source of biogas production: agricultural waste, manure, food & beverage industry waste, municipal waste. This work is focused solely on the biodegradable part of municipal solid waste, as the source whose potential Croatia has not comprehensively tapped yet, particularly not for the transport sector and grid injection.

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[4] Directive 2003/30/EC of the European Parliament and of the Council of 8 May 2003 on the promotion of the use of biofuels or other renewable fuels for transport

[5] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC

[6] Directive 2009/33/EC of the European Parliament and the Council of 23 April 2009 on the promotion of clean and energy-efficient road transport vehicles

[7] Planed achievements in the whole paragraph are according to the National Action Plan on incentives for production and usage biofuels in transport sector in the period 2011-2020 (http://www.mingo.hr/default.aspx?id=3376), while data on actual consumption in 2011 are according to the report “Energy in Croatia 2011” prepared by the Ministry of Economy, (http://www.mingo.hr/default.aspx?id=3258)

Since biodegradable waste, disposed at landfills, has to be significantly decreased in the coming years, while fostering waste separation, all biodegradable components of municipal solid waste have not been taken into account as a potential source of biogas production. Only the leftover municipal solid waste, after the separation of plastics, paper and cardboard, has been considered as an input for biogas potential assessment.
Thus, for the assessment of municipal solid waste as a source for biogas production, two items were used: the production of MSW in Croatia as published by the Environment Agency and the assessment of leftover biodegradable components according to the MSW structure for the City of Zagreb.

The Law on waste imposes the responsibility for municipal solid waste management to all administrative units – cities and municipalities. In practical terms, this means that all citizens of Croatia must be covered by organized municipal solid waste management. This is almost achieved in practice – according to the Report on municipal waste by the Environment Agency for the year 2011, 96% of the population has been included in organized waste collection. The goal of including 90% of the population, set up for 2015 by the Strategy on waste management, was achieved in 2007; while the goal of 95% set up for 2020 was reached in 2009. Thus, keeping in mind the legislative obligations on municipal solid waste management for all administrative units and the population targets reached so far, the potential of biogas and biomethane will be calculated based on the entire population, i.e. as municipal solid waste collected from 100% of population.
While good results have been achieved in the scope of population included in organized waste collection, the same cannot be said for waste separation - the share of separated MSW is not at a high level – it varies from 2 to 25,9% among the 21 counties in Croatia. The majority (91%) of municipal biodegradable waste still ends up at landfills.

Table 1 shows mandatory maximum quantities of biodegradable waste at landfills by the end of 2013 and further on. However, according to the Environment Agency data, biodegradable waste disposed at landfills in 2011 amounted to 937.375 t, or, in other words, 370.604 t above the limit set for the end of 2013 in accordance with Directive 1999/31/EC. It is clear that paper and plastics still make up a significant part of biodegradable waste at landfills, and their separation in the first stages (collection in households and in municipalities) are the ultimate actions towards landfill deposit decrease as required by national and the EU legislations. Thus, those extra quantities at landfills (with a significant share of paper and plastics) have not been taken as the basis for biogas potential calculation.
Detail structure of municipal solid waste for all counties is not published, thus a share of biowaste in calculated MSW has been assessed. An actual data on MSW structure can be found for the City of Zagreb[8], which participates by the biggest share (20%) in the total MSW production in Croatia. Thus, if not fully accurate, it is a pretty much approximate to use a pattern of the biggest MSW producer to assess MSW structure of other municipalities.

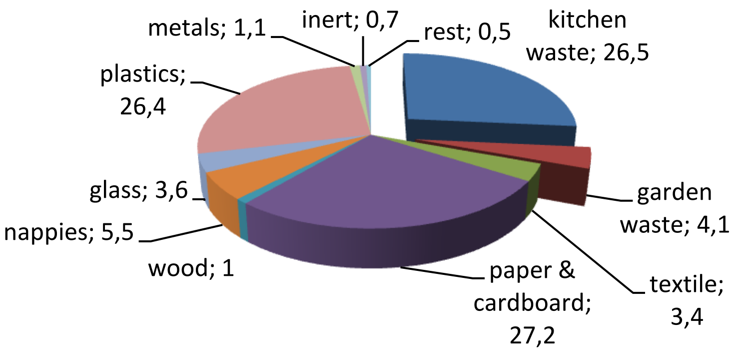

Figure 1 – Structure of municipal solid waste in the city of Zagreb (in %)
(Source:Bojan Ribic, Zagrebacki Holding – Cistoca, based on IPZ Report 2010)

As shown by the figure 1 above, kitchen and garden waste represent 30,6%, and nappies as of 5,5%, as biodegradable material can be add to it; which leads to 36,1% share of biowaste in municipal waste of the City of Zagreb. The same contribution has been used for biowaste calculation of other counties in Croatia.

Total biowaste produced in Croatia in 2011 has been assessed at the level of almost 600.000 t, This quantity (as shown by Table 2) is taken further into calculation of biogas and biomethane potential production.
The potential biogas production for all Croatian counties has been calculated according to:

- Assessment of the potential biowaste production, as explained above
- the prevailing component of biowaste as shown by Figure 1, i.e. kitchen waste
- biogas yield for kitchen waste (as prevailing component of biowaste) is calculated according to Wellinger (2012):

$$\text{Biowaste (t/y)} \times 0{,}215 \times 123 = \textbf{Biogas (m}^3\textbf{/y)}$$

As explained earlier, the term "biogas" cannot be mutually exchanged with the term "natural gas". Thus, to put this quantity of biogas and the relevant energy into the context of the current natural gas consumption and energy consumption in the transport sector, a further step – biomethane potential production from MSW in Croatia has been calculated as the content of methane in biogas, adequate for the type of waste (which is 61%, according to (Welinger (2012)).

[8] Report by "Cistoca" within UrbanBiogas project

Table 2 – Assessment of Biomethane production in Croatia

County	MSW t/y	Biowaste t/y	Biogas m^3/y	Biomethane m^3/y
Zagrebačka	77.822	28.094	742.946	453.197
Krapinsko-zagorska	29.380	10.606	280.476	171.090
Sisačko-moslavačka	62.058	22.403	592.447	361.393
Karlovačka	57.777	20.857	551.563	336.453
Varaždinska	44.245	15.972	422.380	257.652
Koprivničko-križevačka	22.541	8.137	215.183	131.262
Bjelovarsko-bilogorska	39.333	14.199	375.493	229.051
Primorsko-goranska	136.481	49.270	1.302.945	794.796
Ličko-senjska	31.903	11.517	304.567	185.786
Virovitičko-podravska	32.194	11.622	307.344	187.480
Požeško-slavonska	17.433	6.293	166.418	101.515
Brodsko-posavska	51.980	18.765	496.240	302.706
Zadarska	91.395	32.994	872.526	532.241
Osječko-baranjska	94.719	34.194	904.260	551.599
Šibensko-kninska	48.486	17.503	462.867	282.349
Vukovarsko-srijemska	45.163	16.304	431.159	263.007
Splitsko-dalmatinska	223.145	80.556	2.130.303	1.299.485
Istarska	125.414	45.274	1.197.271	730.335
Dubrovačko-neretvanska	66.883	24.145	638.515	389.494
Međimurska	20.153	7.275	192.387	117.356
Grad Zagreb	326.789	117.971	3.119.743	1.903.043
Total	**1.645.295**	**593.952**	**15.707.061**	**9.581.307**

From the total amount of MSW produced in 2011 – 1.645.295 t; 36,1% or 593.952 t can be considered as biowaste, input material which can be then transferred into 15,7 Mmcm of biogas (see Table 2).
After the upgrade of biogas, i.e. the removal of CO_2 and other forbidden components, 9,6 Mmcm of biomethane is potentially available, on an annual basis, for injection into the gas network and/or usage by vehicles.
To illustrate, this is only 0,3% of the actual annual consumption of natural gas in the entire country (3,2 Bcm), but it is comparable to the yearly demand of cities with 8 to 13 thousands inhabitants, such as Djurdjevac, Daruvar and Krapina. This is also the total consumption of Karlovacka County in 2011, one of the counties in the initial stages of gasification[9].
Furthermore, those 9,6 Mmcm are 10 times more than the current consumption of CNG in the transport sector.
According to the General Conditions on Gas Supply (OG 43/09), the lower heating value of natural gas in the grid has to be between 33,100 and 40,200 MJ/m^3. Taking into account composition of gas in the network (domestic production + import from Russian sources), the standard value is 33,33835 MJ/m^3.
Thus, this potential biomethane quantity of 9,6 Mmcm represents 0,319 PJ of energy, i.e. 0,639 PJ when double counting biofuels produced from waste. This is equal to the quantity of biomethane in the transport sector predicted to be used annually from 2017 to 2020, as defined by the “National Action Plan on incentives for production and usage biofuels in the transport sector for the period 2011-2020”. It has to be noted that the Plan does not include the biomethane produced from municipal waste, instead, it focuses on potential production from agricultural, industrial and sewage waste.

9 http://www.hsup.hr/dokumenti/hr/PGH%202012.pdf

4. TECHNOLOGIES & INVESTMENTS

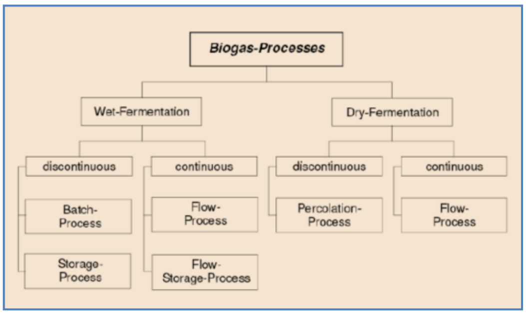

Figure 2 - Biogas processes – wet and dry systems,
(Source: Wellinger, (2012))

The selection of technology depends on the share of dry substance which is related to the type of biowaste collected. As it has been described in the previous chapter, the municipal waste collected in Croatia is still mixed, but as shown by Figure 1, i.e. waste composition of mainly kitchen waste will be taken into account as feedstock for a biogas plant. Kitchen waste has 25% total solids in its content. Thus, the chosen AD system can be both wet and dry digestion, while feeding can be two-fold also: continuous feeding or batch system. All systems are present on the market, with proven operation records for more than 20 years.
The focus of this work is the potential and cost assessments, with a general costs overview, not concrete biogas plants with detailed input and technological parameters.

In order to make such a general investment cost assessment, the results of „Comparative economical analysis of biogas production costs between standard wet anaerobic digestion and dry fermentation of biodegradable fraction of municipal solid waste" by V-M. Kovacevic have been used.

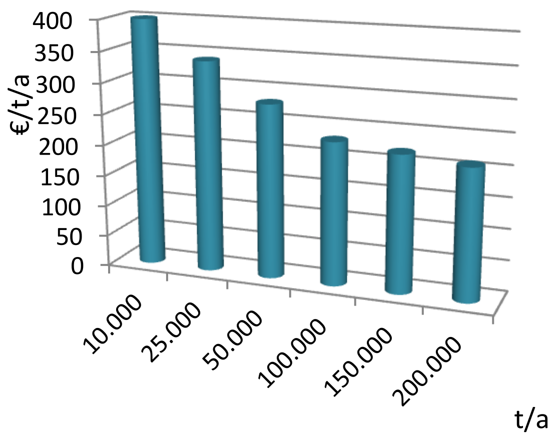

Figure 3 – Investment costs of biogas plant per unit of input waste capacity
(*Data source: Kovacevic, (2010); own creation of figure)*

By using approximate costs per t of input waste, as shown in Figure 3 and the quantities of biowaste, as assessed within the previous chapter, investment costs can be calculated on county by county basis.

Investment costs are at the level of 230 EUR/t/a only for the City of Zagreb and Splitsko-dalmatinska County, the two counties with the biggest annual biowaste quantities, followed by 280 EUR/t/a for Istarska and Primorsko-goranska County, whereas the investment costs are 340 EUR/t/a and 400 EUR/t/a for all other counties, respectively.

Table 3 – Estimation of investment costs for biogas production plant / County by county

County	Biowaste	Investments	Biogas	Specific investment
	t/y	€	m^3/y	$€/m^3$
Zagrebačka	28.094	9.551.884	742.946	12,86
Krapinsko-zagorska	10.606	4.242.462	280.476	15,13
Sisačko-moslavačka	22.403	7.617.019	592.447	12,86
Karlovačka	20.857	7.091.496	551.563	12,86
Varaždinska	15.972	6.388.917	422.380	15,13
Koprivničko-križevačka	8.137	3.254.991	215.183	15,13
Bjelovarsko-bilogorska	14.199	5.679.675	375.493	15,13
Primorsko-goranska	49.270	13.795.505	1.302.945	10,59
Ličko-senjska	11.517	4.606.856	304.567	15,13
Virovitičko-podravska	11.622	4.648.852	307.344	15,13
Požeško-slavonska	6.293	2.517.350	166.418	15,13
Brodsko-posavska	18.765	7.505.942	496.240	15,13
Zadarska	32.994	11.217.853	872.526	12,86
Osječko-baranjska	34.194	11.625.798	904.260	12,86
Šibensko-kninska	17.503	7.001.355	462.867	15,13
Vukovarsko-srijemska	16.304	6.521.577	431.159	15,13
Splitsko-dalmatinska	80.556	18.527.766	2.130.303	8,70

Istarska	45.274	12.676.803	1.197.271	10,59
Dubrovačko-neretvanska	24.145	8.209.197	638.515	12,86
Međimurska	7.275	2.910.072	192.387	15,13
Grad Zagreb	117.971	27.133.323	3.119.743	8,70
Total	**593.952**	**182.724.693**	**15.707.061**	**11,63**

Most of the counties have the annual input of biowaste bellow 50.000 t. Only the City of Zagreb has an input that is higher than 100.000 t. Since specific costs are lower for bigger plants, i.e. for larger waste input, it would make sense to use the economics of scale. In other words, it would be better to build several regional plants rather than a MSW biogas plant in each of the counties.
The author has decided to group counties based on their geographical position, traffic connections and their quantity contribution.
With these different groupings, the annual biowaste input for individual plants increases, decreasing investments costs. The resultant approach of organizing biogas production in one plant for several counties, allows us to decrease investment costs. For Grouping A, annual investments costs would be decreased from 340 EUR/t down to 220 EUR/t, for Grouping B they from 280 to 220 EUR/t, for Grouping C and D investments costs would be 220-230 EUR/t/a, while Grouping E (i.e. having 3 biogas plants to service the entire country) reduces investments costs to 200-220 EUR/t/a. An overview of the estimated investment costs for different grouping of counties has been shown in Table 4.

Table 4 – Estimation of investment costs for biogas production plant/ Different grouping of counties

Grouping	Biowaste	Investments	Biogas	Specific investment
	t/y	€	m^3/y	€/m^3
21 plants	593.952	182.724.693	15.707.061	11,63
8 plants (grouping A)	593.952	149.355.799	15.707.061	9,51
6 plants (grouping B)	593.952	136.092.252	15.707.061	8,66
5 plants (grouping C)	593.952	133.375.009	15.707.061	8,49
5 plants (grouping D)	593.952	132.486.564	15.707.061	8,43
3 plants (grouping E)	593.952	123.644.995	15.707.061	7,87

It is clearly shown that lower investments costs can be achieved by constructing fewer plants with bigger input capacity. However, the exact combination and final design would depend on the development strategies of waste management, administrative settlements and, at the end of the day, further usage of biogas/biomethane – all issues out of the scope of this work.

Biogas upgrade – Biomethane production

Biogas is a mixture of methane and carbon dioxide. Biogas produced from the AD process is composed of methane (50-70%) and carbon dioxide (30-50%), with smaller amounts of hydrogen sulphide and ammonia, while traces of hydrogen, nitrogen, carbon monoxide and oxygen can be present occasionally.
In order to be injected into the gas network or used by vehicles, gas has to fulfill technical standards. In other words, biogas cannot be directly used, it has to be cleaned of organic and inorganic impurities and upgraded to the characteristics which meet the requirements for natural gas grid injection and for use by vehicles.
In practical terms, biogas has to be enriched in methane (from 53-70% to a minimum of 85% in Croatia), while the share of carbon dioxide has to be decreased (from 47-30% down to 7% max). The removal of CO_2 at the same time means enrichment in CH_4, and increasing energy value. There are various methods of carbon dioxide removal, based on the absorption (water, polyethylene glycol, mono- and di-ethanolamine) or adsorption processes (carbon molecular sieves or pressure swing adsorption) and on membrane separation (low pressure and high pressure). Along with the upgrade, i.e. the removal of carbon dioxide, biogas also has to be cleaned of hydrogen sulphide. Hydrogen sulphide is a hazardous and very corrosive gas, thus it has to be removed before any further application of gas, including any upgrading processes.
Available technologies include sulphide precipitation, biological scrubbing, chemical-oxidative scrubbing, and adsorption of metal oxides or activated carbon. All of those technologies add a bit to the overall investment costs of biomethane production. For the assessed production, upgrade costs have been estimated using the Biomethane Calculator and the groupings of counties.

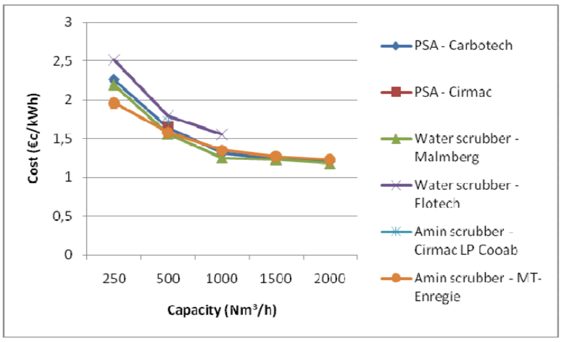

Figure 4- Estimated cost of biogas upgrading plants using different technologies
(Source: Wellinger, (2012) / Urban et al, (2008))

As a summary, the estimation of investment costs for biomethane production from MSW (biogas production + upgrade to biomethane) – is shown in Table 5.

Table 5: Estimation of investment costs

Grouping	Biowaste	Biogas	Biomethane	Specific investment costs /to transmission network	Specific investment costs / to distribution network	Total Investments /injection in transmission network	Total Investments /injection in distribution network
	t/y	m^3/y	m^3/y	€/m^3 biogas	€/m^3 biogas	€	€
21 plants	593.952	15.707.061	9.581.307	11,81	11,77	185.550.392	184.859.281
8 plants (grouping A)	593.952	15.707.061	9.581.307	9,64	9,60	151.450.138	150.853.270
6 plants (grouping B)	593.952	15.707.061	9.581.307	8,78	8,75	137.944.637	137.380.754
5 plants (grouping C)	593.952	15.707.061	9.581.307	8,60	8,57	135.141.110	134.590.421
5 plants (grouping D)	593.952	15.707.061	9.581.307	8,55	8,51	134.236.958	133.688.154
3 plants (grouping E)	593.952	15.707.061	9.581.307	7,97	7,94	125.194.234	124.677.996

(Source: own calculation + Biomethane Calculator)

5. NATURAL GAS NETWORK OF CROATIA

To be able to assess the potential biomethane for grid injection, a configuration of the existing natural gas network – both, transmission and distribution – has to be known, and this is an aim of this chapter.

Among the 21 counties, only Dubrovacko-neretvanska County is not covered by the natural gas transmission network. In practical terms, this means that 97% of the population has access to the transmission network, i.e. from the network accessibility point of view; biomethane produced from municipal waste of 97% of the population can be injected into the transmission network. If we would like to be more precise, and to exclude those municipalities in Splitsko-dalmatinska County which have not yet been passed by the transmission pipeline, the scope of the population is 93%.
However, the injection of biomethane in the transmission network has to fulfill technical standards, in the first place, an adequate pressure. The transmission network in Croatia is projected to operate at 50 bar and 75 bar and according to the Transmission Network Code (OG 50/09 and 88/12), the minimum input pressure is 70 bar and 45 bar respectively. This means that, in order to be injected in the transmission grid, biomethane must first be compressed to 45 or 70 bar. Such a compression would increase by 30 to 50% specific investment costs per m^3 (from the range of 6,58-13,59 EUR cents to the range of 9,86 to 17,99 EUR cents). It would make sense if all biomethane were produced in a few regional waste treatment centers, collecting available biowaste from several counties. But then storage in municipalities and the transport of biowaste to centers have to be organized – which can be very impractical, environmentally unfriendly and challenging.
From technical and economical points of view, injection of biomethane into natural gas distribution network is easier and more frequently applied by those Member States who have some experience with biomethane injection into the gas grid. In Croatia that has not been the practice so far. All produced biogas has so far been used directly for heat and electricity production. The distribution networks have been well developed in Northern and Eastern Croatia, while in Istria, Lika and Dalmatia only some cities have gas distribution. Nevertheless, approximately 52% of the population is covered by the gas distribution network, i.e. biomethane produced from municipal waste of 52% of the population could be easily injected into distribution network from the network accessibility point of view.
An additional and very important question is the question of price, i.e. if biomethane produced from MSW can compete with natural gas prices. From estimations done for biogas and biomethane production, specific investment costs for 1 m^3 of biomethane which can be injected into the grid range from 7,94 to 11,77 EUR, while the prices of natural gas, at the distribution level, were from 0,4 to 0,8 EUR for 1 m^3.

6. USAGE OF NATURAL GAS IN TRANSPORT IN CROATIA

Despite the relatively developed natural gas network and the long existence of the gas market in Croatia, the usage of natural gas in the transport sector is very low. The total quantity of CNG used in 2011 was only 906.206 m^3, which represents 0,03 PJ of the 85 PJ consumed in the transport sector[10]. Compressed natural gas is mainly used in the city of Zagreb and this mainly by CNG buses in public transport. The total CNG fleet counts 143 vehicles or 0,01% of total number of vehicles in the country.[11]. Nevertheless, the price of CNG in transport is at the level of 1,16 EUR per m^3. The situation is a bit different with cars run on liquefied petroleum gas (LPG). LPG contributes 2,02 PJ of the total energy consumption in the transport sector – 67 times more than CNG. A network of more than 100 LPG filling stations is spread around the country (unlikely only two CNG stations in the entire Croatia) and a growing number of personal vehicles is retrofitted with a gas tank and gas supply system in addition to the original liquid fuel system. This might be a sound basis for further development of CNG as a vehicle fuel.

[10] According to the report "Energy in Croatia in 2011", published by the Ministry of Economy
[11] According to NVGA statistics for 2011

7. DESCRIPTION OF RESULTS

The first step in the assessment of biomethane potential form urban waste in Croatia was the estimation of municipal waste produced in Croatia. This was done at a very accurate level, since good data were available – population data from the 2011 Census and the 2011 MSW production figures reported by the responsible companies and summarized by the Environment Agency.

Total **MSW** produced in Croatia was **1.645.295 t** in 2011.

The next step was to estimate how much of the produced MSW could be used for biogas production. This was not so straight forward – taking into account all the obligations set by the legislation on waste separation, re-cycling and re-using on the one hand, and on the reduction of landfilled biodegradable waste on the other. The decrease of landfill deposit and separation and re-cycling go hand in hand, thus only the left-over biodegradable waste has been counted, i.e. only what can remain after the pre-separation of paper and cardboard. More or less, this remainder corresponds with kitchen and garden waste. The MSW structure has been assessed according to the available structure for the City of Zagreb.

Total **Biowaste**, produced in 2011 in Croatia, was estimated at the level of **593.952 t** and this quantity was basis for further estimations of biogas potential.

A further step was the estimation of how much biogas, and biomethane, respectively, can be produced. This was done using the relationship between biogas yields and methane content for concrete types of waste.

Biogas production was estimated at **15.707.061 m^3**, and expecting a methane content of 61%, **biomethane** production was estimated at **9.581.307 m^3**.

In order to ensure such biomethane production, **investment costs** in the range from **8 to 12 EUR/m^3 of biogas** are needed. In absolute terms, that would be between 124 and 186 millions EUR. **The costs depend on the number of biogas plants** – one in each of the counties, or 8, 6, 5 or 3 bigger regional centres, and on injection into the distribution or transmission natural gas network.

For a comparison, the Strategy of waste management in the Republic of Croatia (2005) foresees 460 millions EUR for establishment of regional centres for waste management.

Injection into the natural gas grid, from pure point of availability of the network, would not be a problem.

Since the **natural gas transmission network** covers a significant area of the country, most or even all the biomethane can be injected into the grid if we consider a regional biogas plant for the entire Dalmatia. An injection into the transmission grid would require an increase of pressure at 45 or 70 bar, which would cause an increase of the total investments costs by 3-4%.

More than half of the Croatian population is covered by a **natural gas distribution network** – which means the possibility to inject a half of biomethane into the distribution network without any problems, regardless of the number of biogas plants. The numbers of plants, i.e. possible load hours and biogas flow, have a more significant impact on investment costs.

However, it has to be noted that the price of natural gas in Croatia at the distribution level is between 0,4 and 0,8 EUR/m^3, i.e. 10-20 times lower that specific investment costs needed for 1 m^3 of biomethane produced from MSW.

The usage of **biomethane by vehicles** is strongly interlinked with the usage of methane by vehicles (Biomethane is methane; the difference is only in source of production). CNG consumption in the transport sector in Croatia is at a very low level and in limited areas.

Additionally, the price of CNG as vehicle fuel is at level of 1,16 EUR/m^3, i.e. 7 to 10 times lower than specific investment costs needed for 1 m^3 of biomethane produced from MSW.

8. CONCLUSIONS

The potential of biogas from biowaste is significant. It can be used for producing energy by re-using waste and as a solution for the required redesign of waste management.

The preamble of Directive 2008/98/EC says "The first objective of any waste policy should be to minimise the negative effects of the generation and management of waste on human health and the environment. Waste policy should also aim at reducing the use of resources, and favour the practical application of the waste hierarchy."

In conclusion, biodegradable waste, disposed at landfills, has to be significantly reduced in the coming years. Tapping into its potential can be one of the steps towards the required landfill decrease and re-use.

Despite Croatia's widespread natural gas network, the potential for injection into the gas grid is rather low. Biomethane is methane, and it has to be competitive the same market. This is by far not the case – for the time being, gas prices in the retail market are 0,4-0,8 EUR/m^3 or 10-20 times lower that specific investment costs needed for 1 m^3 of biomethane produced from MSW. Unlike the electricity produced from renewable sources, biogas (biomethane) injection to the gas grid is not supported by feed in tariffs, which compensate the differences in production costs.

Biomethane application in the transport sector would make more sense, from the aspects of RES targets and conditions set up for the transport sector. In the first place, energy of biofuels produced from waste count double towards the target, and in a way biomethane for MSW is feasible. Furthermore, all available renewable sources for transport fuels will play a more significant role after the proposal of the European Commission on limits for 1st generation biofuels at 6% has been accepted by the European Parliament. In practical terms, this means that the RES-T target by 2020 remains 10%, but only 6% can be achieved by 1st generation biodiesel and bioethanol which meet sustainability criteria. For Croatia, this does not seem as a significant problem – only 0,91% in the transport sector in 2011 was met by bio-liquids and it still has a long way to go to reach 6%. But, nevertheless, the remaining 4% also have to be achieved from other sources. And again, biomethane from MSW is feasible, much closer than 2nd and 3rd generation biofuels.

Biomethane from MSW makes the most sense for municipalities as such. They have to deal with their own waste and organise their own public transport. Biomethane can be a good answer to both issues. The example of the city of Zagreb shows a good direction, so far only half a picture – CNG buses in the public transport. The examples of the city of Cakovec and the island of Krk show another part of the picture: a well organised MSW separation and collection system. Biomethane potential – the topic of this work – makes a bridge between both required actions: waste management and the introduction of a greener public transport.
In the end, the sum of many small contributions in waste management and the decrease of GHG emissions become apparent on the bigger, state-level scale.
For the comprehensive biogas and biomethane potential to be reached in Croatia, all other potential sources have to be considered: sewage water, food industry, agriculture, food markets and hotel food waste etc. Also, costs and benefits of usage of biogas in electricity and heat production and in the transport sector have to be elaborated further, in order to have a comprehensive waste to energy potential analysis for Croatia.

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