energies

MDPI

Article

Energy Contribution of OFMSW (Organic Fraction of Municipal Solid Waste) to Energy-Environmental Sustainability in Urban Areas at Small Scale

Umberto Di Matteo [1], Benedetto Nastasi [2,*], Angelo Albo [1] and Davide Astiaso Garcia [3]

1 Department of Sustainability Engineering—Università degli Studi Guglielmo Marconi, Via Plinio 44, 00193 Rome, Italy; u.dimatteo@unimarconi.it (U.D.M.); angelo.albo.80@gmail.com (A.A.)
2 Department of Architectural Engineering & Technology, Environmental & Computational Design Section, TU Delft University of Technology, Julianalaan 134, 2628 BL Delft, The Netherlands
3 Department of Astronautics Electrical Energy Engineering—Sapienza University of Rome, Via Eudossiana 18, 00184 Rome, Italy; davide.astiasogarcia@uniroma1.it
* Correspondence: benedetto.nastasi@outlook.com

Academic Editor: Xidong Wang
Received: 19 October 2016; Accepted: 9 February 2017; Published: 15 February 2017

Abstract: Urban waste management is one of the most challenging issues in energy planning of medium and large cities. In addition to the traditional landfill method, many studies are investigating energy harvesting from waste, not as a panacea but as a foreseeable solution. Thermo-chemical conversion to biogas, or even bio-methane under certain conditions, could be an option to address this challenge. This study focuses on municipal solid waste conversion to biogas as a local energy supply for the cities. Three urban models and their subdivision into urban areas were identified along with a typical Organic Fraction of Municipal Solid Waste (OFMSW) matrix for each urban area. Then, an energy analysis was carried out to provide an optimization map for an informed choice by urban policy-makers and stakeholders. The results highlighted how the urban context and its use could affect the opportunity to produce energy from waste or to convert it in fuel. So, in this case, sustainability means waste turning from a problem to a renewable resource.

Keywords: urban sustainability; municipal solid waste; biogas; bioenergy; sensitivity analysis; environmental management; distributed generation; energy planning

1. Introduction

Urban waste is a major current issue for cities moving towards sustainable urban environment. Since landfills are already considered an obsolete answer to this issue from both technical and legal points of view [1], energy harvesting from waste represents an attractive solution [2]. As a matter of fact, in other contexts landfills are still the suitable solution to face waste disposal and management. A first historical attempt in energy conversion of waste belongs to the post-industrial era when synthetic gas was produced by gasification processes to feed urban lighting infrastructures. Indeed, the so-called city-gas was stored in gazometers which can be found in most of the big cities around Europe and recognized as industrial heritage. Nowadays, minimization of waste production is essential for a more sustainable development of society, but energy harvesting from its flow is the most feasible option to handle the society transition [3] along with the implementation of promising renewable technologies [4,5]. Based on technical and legal regulations waste is classified for treatment or harnessing for energy purposes according to its physical and chemical composition. Recyclable matter such as glass, plastic and paper, if properly preserved, are excluded by specific processes within the separate collection approach. Waste is composed of an Organic Fraction (OF) which is the main responsible of the waste smell and humidity along with sanitary issues. Humidity is considered a key factor since it strongly affects the energy conversion to biogas. Nevertheless, OF has a high energy conversion potential since it is source of several hydrocarbons (HC) when treated by a process such as anaerobic digestion. The HC of highest energy content is methane (CH_4). Indeed, methanation is a common word used to name all of the aforementioned treatments. Furthermore, temperature plays a key role in energy conversion process in terms of output matrix, emissions and, last but not least, process energy demands. All those technical considerations should be driven by urban management language and practices to be easily applied and integrated by policy-makers and city stakeholders [6]. New concepts such as territorial energy vocation [7] are applicable to approach the sustainability of harnessing OF.

Local resources result beneficial in terms of energy sovereignty and economic cost required by new infrastructures, so distribution and transmission losses along with their impact on the environment could be avoided when consumption and production are matched [8]. Moreover, new players such as pro-sumers, excluded from the old centralized generation model, have been introduced by distributed RES deployment calling for a bi-univocal Grid. In this field, EU resolution [9] promoted this new actor, i.e., the PROducer-conSUMER, in the energy context, firstly, as off-grid solution to improve energy-access for those areas considered not economically profitable by big energy utilities to build energy networks, and secondly, to allows a free choice to citizens about their own energy supply [10]. Consequently, the link between the availability of local resources and sustainability considerations move towards the so-called Zero Kilometer Energy model [11].

Starting from those considerations, the authors investigated on energy contribution of Organic Fraction of Municipal Solid Waste (OFMSW) to urban sustainability so as to harness resources already available locally. Knowing that waste is not only an energy-related issue for municipal services, the authors intended them as a resource for growing energy community for an informed choice. Different urban morphology models were analyzed along with the composition of OFMSW matrix related to each zones within them. The biogas potential was associated to each area in terms of its use and the associated collection method, which are considered crucial elements by the authors.

2. Key Issues

Energy harvesting from waste is widely meant as valorization of exhausted materials so as to imply assessment on energy efficiency values mainly related to the end-use production devices such as boilers or CHP. The authors address the efficiency calculation moving towards a more comprehensive concept accounting for the initial energy content of OFMSW and its final use. Nevertheless recycling could be the foreseeable solution, and the anaerobic digestion fared well environmentally [12,13]. In Figure 1, the distribution of MW sources for anaerobic digestion is shown. Specifically, a very high growth potential is envisaged for the anaerobic digestion of OFMSW. Today a world average amount of 50% of MSW is landfilled, and with a content of 30% of OF composting, the current biotechnology for OFMSW recycling, is still problematic [14].

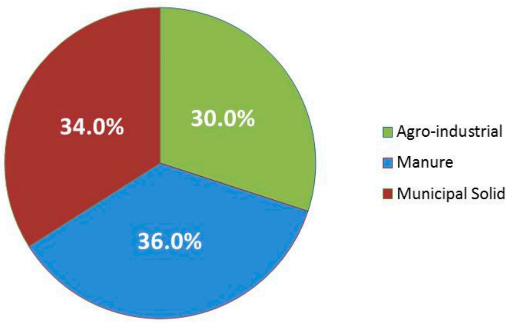

Figure 1. Distribution of waste sources for anaerobic digestion [15].

A preliminary review of literature indicated that about 20%–30% of the energy produced by anaerobically digesting waste is consumed by the process itself for big power plants and higher percentage values are forecasted for the small-scale ones [16].

Missing information was found for this latter scale in terms of studies. Indeed, laboratory plant sizes comparable to the waste production of a range from one to ten dwellings are available in literature [17].

The authors' intention is to investigate the preliminary energy gains achievable from small scale biogas treatment and use plants to increase sustainability level of existing urban energy systems where to integrate local energy from a not harnessed resource, i.e., waste.

In order to carry out an energy analysis, theoretical production and substrate composition should be delved deeper. The theoretical yield of biogas production can be calculated by the so-called Buswell equation taking into account the chemical composition of feed-stocks [18,19], as shown in Equation (1):

$$B_{o,th} = \frac{\left(\frac{a}{2} + \frac{b}{8} - \frac{c}{4}\right)22.4}{12a + b + 16c} \left[\frac{\mathrm{Nm^3CH_4}}{\mathrm{kgVS}}\right] \tag{1}$$

To do so, the general chemical equation of the reaction is reported below as Equation (2):

$$\begin{aligned} C_aH_bO_cN_dS_e + \tfrac{1}{4} \quad & (4a - b - 2c + 3d + 2e)\mathrm{H_2O} \\ & \rightarrow \tfrac{1}{8}(4a - b + 2c + 3d + 2e)\mathrm{CO_2} + \tfrac{1}{8}(4a + b - 2c - 3d - 2e)\mathrm{CH_4} \\ & + d\mathrm{NH_3} + e\mathrm{H_2S} \end{aligned} \tag{2}$$

Starting from that, the ratio between CH_4 and CO_2 is affected by the oxidation state of the carbon fraction in the material. To sum up, a higher reduction grade of the carbon content corresponds to a higher methane production, as shown in Table 1.

Table 1. Biogas composition calculated by the oxidation state method.

Substrate from Waste	Oxidation State	% Methane	% Carbon Dioxide
Paper	−0.049	51.0	49.0
Yard	−0.089	51.5	48.5
Wood	−0.138	52.1	47.9
Food	−0.548	57.1	42.9

Furthermore, in those materials, the proportion of carbohydrates, proteins and lipids affects the biogas yield. The lipid contribution entails higher volumes of biogas per feed-stock unit of mass than both carbohydrate and protein ones. The microorganisms used in anaerobic digestion process are sensitive to the substrate chemical composition and, specifically, to its carbon to nitrogen (C/N) ratio [20]. Typical C/N ratio values are reported in Table 2.

Table 2. C/N ratio of familiar biodegradable materials.

Household Waste	C/N Ratio
Kitchen waste	25–29
Fruits and vegetable waste	7–35
Food waste	3–17

Notwithstanding, the actual biogas production from anaerobic digestion is considerably lower than the theoretical maximum value. Data related to pure substrate is present in a previous publication [21] but, it is expressed per mol, as reported in Table 3.

Table 3. Volumetric and mass fractions of biogas from the mesophilic anaerobic digestion of OFMSW.

Substrate from Waste	% vol. CH_4 (m^3/kmol)	% vol. CO_2 (m^3/kmol)	% Mass CH_4 (kg/kmol)	% Mass CO_2 (kg/kmol)
Paper	34.78	59.22	22.02	103.10
Yard	30.45	56.55	19.28	98.45
Wood	34.79	64.61	22.02	112.48
Food	46.2	37.8	29.25	65.81

As a matter of fact, only mixed waste substrates have been tested in accordance with the actual compositions of collected waste. Moreover, co-digestion with other kind of substrates is demonstrated to be more efficient and, consequently, more studied as gathered from the literature in [22] but, this further mixing process requires a deep chemical compatibility analysis to obtain any important enhancement in biogas yield.

3. Materials and Methodology

As explained in the previous section, several factors affect the feasibility of energy harvesting from waste. To assess it properly, the authors have built a methodological approach by a parametric analysis along with the support of data from literature and from surveys to the stakeholders such as biogas plant manufacturers, environmental specialists and lawyers. The key elements chosen for the analysis are the following ones:

- Mass flow rate of the substrate, expressed as m (t/y);
- Biogas production of the substrate as function of its chemical composition and its collection typology, expressed as q (Nm^3/t);
- Auxiliaries consumption in terms of electricity and heating demand, expressed in s (kWh/t).

Referring to the power plant size, the identified correlation with specific urban environments entailed the choice of small scale. In order to handle the scale effects on the energy effectiveness of those energy scenarios, a sensitivity analysis was carried out accounting for the aforementioned parameters. In details, the span of sizes, in terms of input substrate mass flow rate, ranges from 3000 t/y to 25,000 t/y. The first value corresponds to a typical urban area with a population equal to 20,000 citizens, having assumed a yearly OFMSW production of 150 kg per inhabitant, while the second value is the typical power plant available on the market where the size is defined by financial considerations rather than sustainability principles.

Organic Fraction of Municipal Solid Waste requires high energy expenditures to be converted into biogas but, they could be easily and fruitfully supplied by the CHP system integrated in the production cycle [23]. Recent development of biogas technology for feeding CHP after EU Nitrate Directive acceptance in Germany, Italy and France, supported by dedicated incentive schemes moved the authors to consider it as a viable option for emerging energy community to be self-sufficient. The AD was identified as driver for waste not belonging to re-use and re-cycle so as to provide a further element in the forthcoming Circular Economy concept for small communities. So, in this study, the end-use by means of designed cogeneration size is taken into account in terms of electrical and thermal efficiency values and their correlation with the rated power. So, a fourth parameter is involved in the sensitivity analysis, resulting crucial for the power cycle balance. To do so, the consumption of auxiliaries was direct linked to the yearly mass flow rate of the substrate. The electricity and heating demand to treat the substrate are plotted as profile in Figure 2.

Having accounted for data available in [24–26] related to the electricity demand and in [26–28] related to heating one, two regression curves were built to carry out the subsequent energy analysis. Then, the energy efficiency of all the conversion process was defined as:

$$\eta_{plant} = \frac{E_{net}}{E_{gross}} \tag{3}$$

where:

- E_{net} is the useful energy output from the cycle on annual base;
- E_{gross} is the gross energy content of the produced biogas volume.

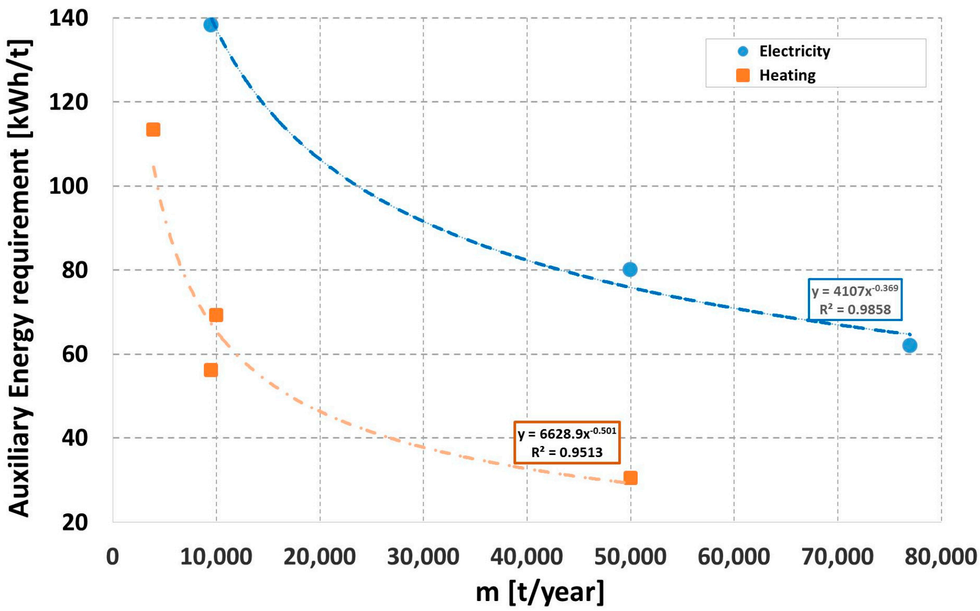

Figure 2. Incidence of auxiliaries' consumption per biogas production plant size.

Moreover, in Equations (4) and (5) E_{aux} is the auxiliaries' electrical and thermal energy demand. While, the specific thermal energy production Φ and the cycle inefficiency ζ were defined:

$$\Phi = \frac{E_{net}}{m} \left[\frac{\text{kWh}}{t}\right] \tag{4}$$

$$\zeta = \frac{E_{aux}}{E_{gross}} \tag{5}$$

Energy balance is affected by the biogas production plant layout, especially by the choice of the digester technology. In addition, substrate chemical composition represents the key point. The authors estimated from survey in industry stakeholders the values of digester performance within the well-established technologies. Moreover, they considered ten different substrates taking into account for each one, its origin in terms of urban area morphology, and its proven biogas production, as shown in Table 4.

Table 4. Substrates chosen from the authors along with their biogas production per unit of mass.

Substrate	Collection Mode	q (m^3/t)	References
M1	Mechanically Sorted	119.0	[29]
M2	Mechanically Sorted	123.0	[25]
M3	Mechanically Sorted	126.7	[30]
M4	Mechanically Sorted	128.0	[24]
M5	Mechanically Sorted	140.0	[26]
M6	Hand Sorted	239.2	[31]
M7	Mechanically Sorted	242.6	[32]
M8	Separated Sorted	396.8	[30]
M9	Source Sorted	474.8	[30]
M10	Source Sorted	556.4	[33]

It is remarkable that direct collection of waste in the place of its production preserves the highest biogas potential and its accidental emissions [34,35], while the mechanical collection entails longer periods of waste storage and a subsequent reduction of available energy. Curbside residential rubbish pick-up in residential area shows also this time dependence issue. The lowest values are representative of waste collection without a separation procedure so that further effort is required at the treatment plant in the landfill and the substrate is of low quality. Policy instruments are available to promote the most effective collection and their use close to the production sites [36] as well as the LCOE when associated to new renewable solutions [37] or hybridized with conventional cycles [38].

4. Urban Fabric and Biogas Potential

Searching for local solutions can address urban sustainability, especially by avoiding the construction of new infrastructures and transportation as well as the associated environmental and economic costs. Furthermore, solutions suitable for existing urban environments lead to the identification of the proper scale of intervention. Indeed, in the field of waste-to-energy, big size entails strict environmental and logistic assessment for making the plant and its chain fit in the eco-systems and even in an existing city. On the other hand, the small-scale does not appear profitable even if supported by feed-in-tariff since the energy paradigm goes for centralized generation. Therefore, to investigate on the energy effectiveness of small scale solutions and their fit in urban environments, the authors focused on the link between urban context and the production of locally available waste. To do so, the first step is finding adequate data of well-proven technologies and verified biogas yield from different OFMSW substrates, as shown in the previous section. The original work consists in connecting the substrate to its "producer", highlighting its function and its location within the urban environment. A key parameter chosen by the authors is the density of the urban tissue. As depicted in Figure 3, it corresponds to a specific urban morphology along with precise intended use of the built environment and spatial distribution.

Figure 3. Urban fabric and historic intended use for waste quality assessment.

Urban density is a feature connected to the urbanization phenomenon which involved the considered area. The time and the building typology associated to the development of a specific area provide crucial details about its current use and its relation with the energy sector. For instance, it is already well-established in Urban Heat Island mitigation [39,40], and it could be suitable for estimating the potential of its waste production. For instance, in current historic and dense city centres, the gentrification process and ICT evolution have provoked the substitution of function from dwellings to prestigious offices, so to determine a variation on quality and quantity of the produced waste substrate. At the same time, mobility space designed for pedestrians rather than vehicles entails a difficult handling process to collect the waste. In this way, only high density areas make the daily waste collection meaningful since it is expensive in terms of time as well as economics.

An opposite situation is related to the high-rise buildings built after the Second World War to meet the increasing demand for housing. The high concentration of users provides the opportunity to design a few collection points and to go through the new-built mobility connections economically. The other side of the coin consists in the quality of residential waste and its way of collection and separation. Indeed, mono-functional areas such as big office district already cope with the waste issues in order to optimize the process at least in terms of expenses. While, for residential ones, the inhabitant does not take care of waste as an economic issue but as a sanitary problem to solve practically along with the avoidance of smells and used space [41].

Hence, from the analysis of verified substrates and associated biogas yield the authors identified values representative of certain urban areas to understand a holistic feasibility of the small scale waste-to-biogas facilities and its real contribution to local urban sustainability [42].

Four Samples of Urban Substrates

As previously reported from Table 4 in Section 3, ten substrates were selected from the literature to represent typical urban environment values. The code M and the number identify a specific condition along with the intended use of the waste producer and its location in urban fabricalong the typology of this latter. Here, four samples are described to familiarize readers with the mentioned values. To be more clear, the minimum and the maximum biogas yield values are considered along with two medium values, which are M1, M10, M5 and M6, respectively.

The code M1 corresponds to a typical waste coming from low-rise dwellings, collected twice per weeks in dedicated boxes and mechanically sorted in the treatment plant after its collection. The energy potential value is low due to the reduced HC content caused by long exposure to air and consequent degradation. Furthermore, the mechanically separation starts from a low degree of purity of the substrates since the collection boxes are not typically protected against the introduction of non-recyclable materials as well as the incorrect sealing with respect to the weather agents.

As regards M10, it comes from the canteens of office districts which collect the waste daily and is obliged to follow strict regulations in handling sanitary dangerous goods such as waste. Moreover, the precise definition of the quality is possible from the scheduled menu as well as the supply chain documents available from the environmental quality management systems. The size of a canteen, profitable after a certain amount of users, allows it to feed daily a small-scale biogas plant by providing controlled and pure food wastes.

In the range between those extreme values, it is possible to find many different values and associated urban tissues. For instance M5 and M6 are quite similar values but they are related to different contexts as well as collection methods. This latter element is strongly affected by the urban fabric. For instance, the size of the streets and the accessibility to the buildings, the shape of the urban model as a grid or a linear structure determine the typology of collection, its time per week and, subsequently, the final biogas yield of the corresponding substrate.

Referring to M5, it is related to dense housing areas such as the ones built during the 1960s and 1970s across Europe. The high concentration of the production provides favourable conditions for the collection but the social conflicts and issues around citizenship information reduce the quality of the collection. In many case, the waste must be further separated by a machine at the treatment plant. This process leads to further energy and economic costs so as to reduce the chance for small-scale power plant.

Finally, M6 shows a similar value to M5. It comes from a wise hand-sorted collection in new medium-rise urban areas already built under the advertisement of sustainable buildings and dedicated mostly to high-income people. That means new facilities to handle all the waste collection chain such as pumped air transport or automatic bin accessible by ICT supports by citizens ready for future Smart City. Then, healthier lifestyle associated to those people entails high degree of purity of the substrates along with higher methanation potential.

To sum up, the urban environment and its detailed analysis could provide high-level data to estimate correctly the potential of waste-to-energy, especially for those scales currently not competitive on the market. Interesting outcomes derive from the relation between mobility infrastructures and their design with the location of the waste producers in the area. This is the reason why new urban settlements are going to be designed with the road as infrastructure facility for energy, water and waste management.

The concept of peer grid which is the key concept of the decentralized generation could be found in the urban fabric to make the existing built environment suitable for the transition towards future sustainable and smart cities.

5. Results and Discussion

At the end of the analysis of relation between urban environment and quality of waste, it is remarkable that the chemical composition and subsequent biogas potential are variable depending on collection mode of waste and urban area of origin. Anyway, from literature data it results that q ranges from about 120 to 560 m^3/t. To account for this wide range of potential, the influence of m and q on the energy balance of the biogas production plant was analyzed. The conversion efficiency η_{plant} trends with changes in substrate yearly flow rate are depicted in Figure 4 for each waste typology.

The graph can be divided by two values, i.e., 6000 and 15,000 t/y, in three coloured areas. The first area, highlighted in red, denotes the size where the initial energy expenses are huge. The trend of substrates lines has a high slope and the conversion efficiency values are low. Then, the second area in blue shows a lower slope, especially for the substrates of lowest biogas potential such as q values up to 242.6 m^3/t. Finally, in the green area, the changes in flow rates affect little η_{plant}.

Different behaviour can be noticed for the energy net production profiles shown in Figure 5. Specific net energy is reported as a function of substrate yearly flow rate for each waste. It is noteworthy that in the same ranges of the previous graph, there are changes in line geometry but, the main outcome is the energy net independence of biogas production plant size from the value equal to 10,000 t/y. As aforementioned, the changes are remarkable for low potential substrates while the influence of m is negligible on high potential ones, so the link between urban fabric and foreseeable local waste-to-energy would allow to identify the areas suitable for this energy process and to account for it as a further element for improving its sustainability. Scale becomes the crucial challenge to associate the feasible solution to the proper environment.

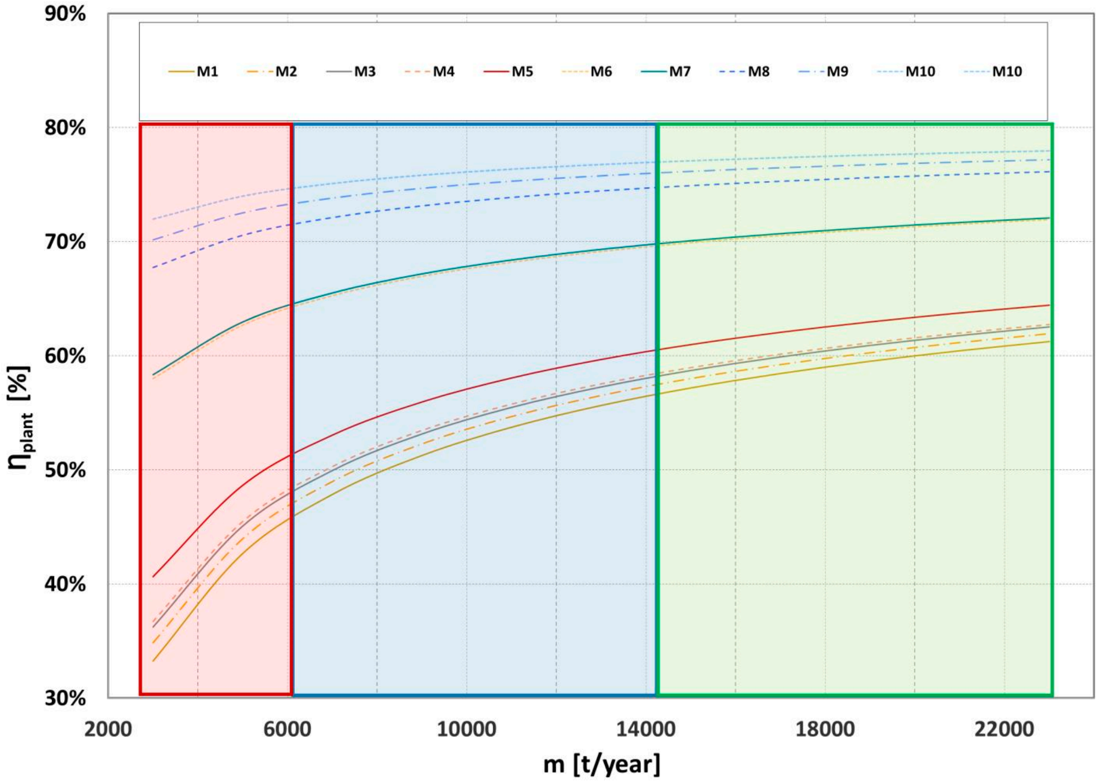

Figure 4. Conversion efficiency of biogas production plant with changes in yearly flow rate and substrate typology.

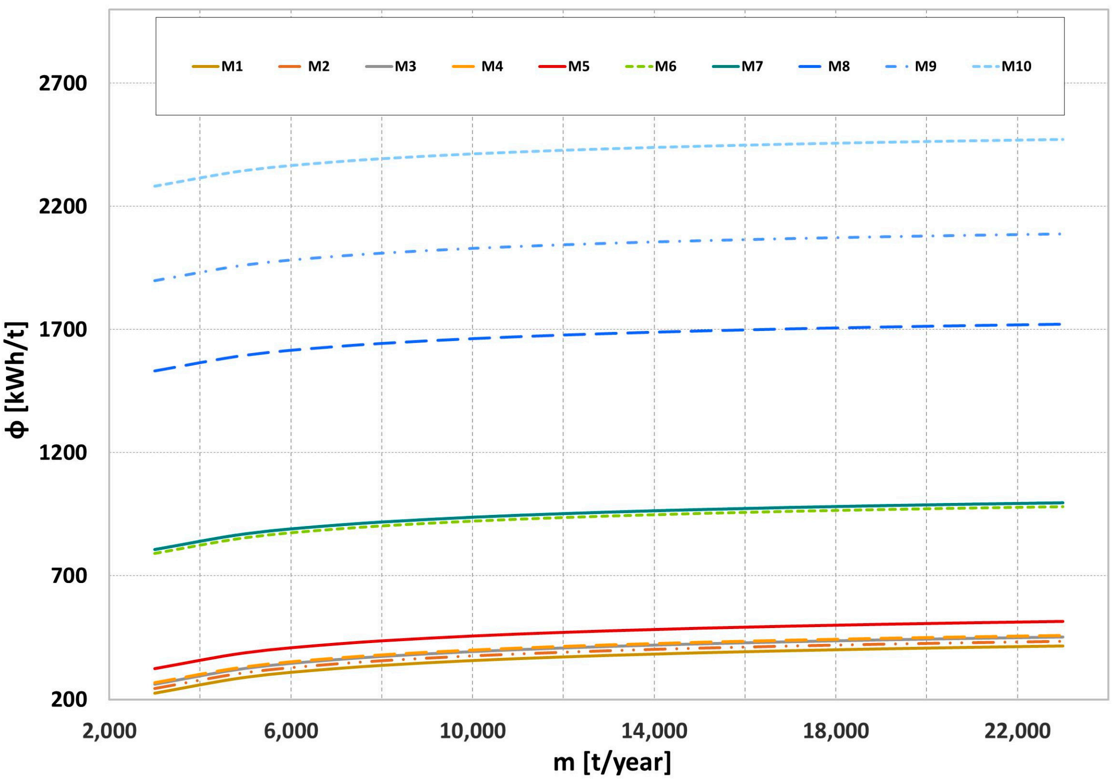

Figure 5. Net energy production of biogas production plant with changes in yearly flow rate and substrate typology.

Referring to the inefficiency of the different substrate + treatment + energy production layouts, it is useful to show the relationship between them and the system conversion efficiency so as to have a comprehensive view. Four substrates were chosen to represent all the variety shown in Table 4. The lowest and the highest biogas production values, i.e., M1 and M10, were considered together with two intermediate values, i.e., M5 and M6.

The threshold between the curves of system inefficiency and conversion efficiency represents the starting point of energy profitability of the chosen substrate, i.e., the minimum required yearly mass flow rate. The associated CHP plant size can be identified by calculation.

As depicted in Figure 6, the curves η and ζ of the substrates M1 and M6 have a common point while the other ones do not. It implies that for low-quality substrates the small scale is not a feasible solution in terms of energy analysis. All the curves have an asymptotic trend moving towards the highest yearly mass flow rate.

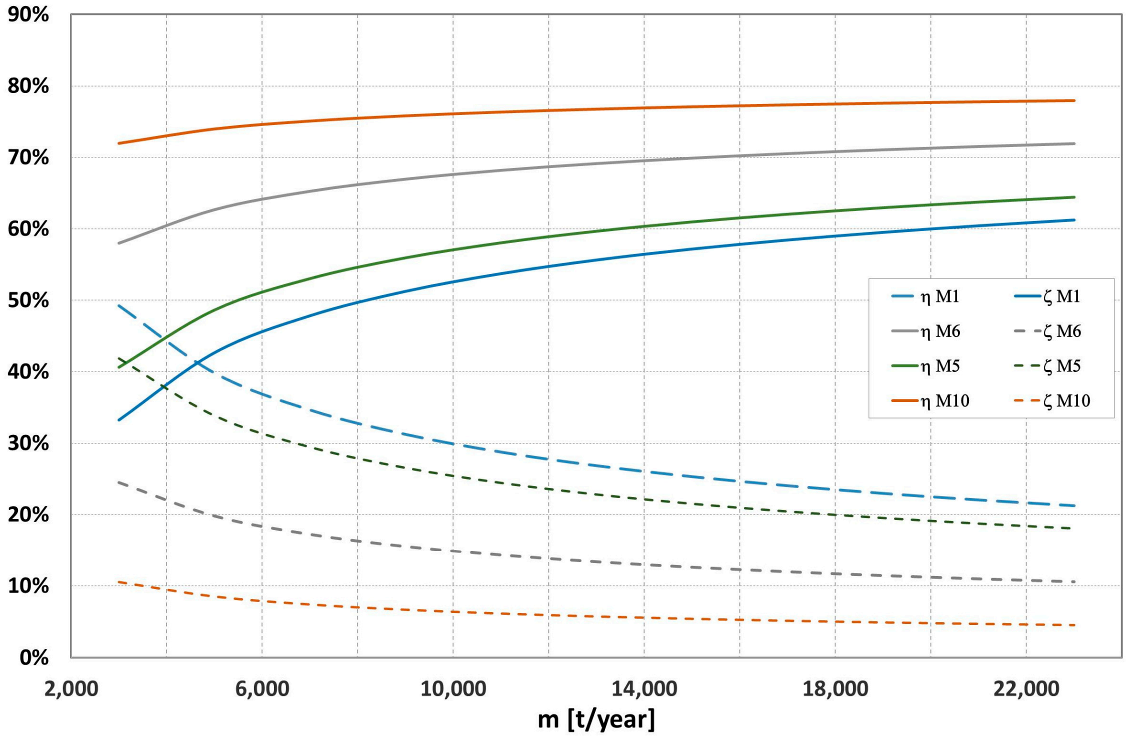

Figure 6. Efficiency and Inefficiency with changes in yearly flow rate and substrate typology.

This demonstrates the current interest of market stakeholders to invest in big size power plant. The best quality substrate shows high inefficiency values until m equal to 10,000 t/y. Other pathway such as further treatment to produce bio-methane as suggested in [43], could involve only high m values and high productive substrates to maintain an energy convenience. Then, other research shows foreseeable scenarios where renewable hydrogen storage systems interact with renewable electricity excess and biomass gasification plants to build future sustainable networks [44].

6. Conclusions

Energy harvesting from waste is a feasible option to handle the societal challenge to move towards more sustainable energy pathways. The study presented an energy analysis as a function of substrates available on the urban areas, their potential, their yearly mass flow rate and the associated power plant size. The methodology elaborated by the authors allows to manage this issue at small scale, usually forgotten by the market but useful to achieve energy sovereignty of local communities. The link between urban areas and their potential of building biogas facility and supply can help policy-makers and energy planner for preliminary evaluation of the feasibility of that technology in a certain area.

The urban density, taking into account the features of the analyzed urban area, plays a key role in determining the waste-to-energy opportunity. The study demonstrates the convenience in terms of system efficiency of specific combinations of the aforementioned parameters and it was a first attempt to order biogas data available in literature and to make it ready for use for local energy planners. The results promote the deployment of medium-size biogas power plant close to the urban waste production, pinpointing the nature of those areas where it is energy effective.

Acknowledgments: The authors appreciated with gratitude all the involved industrial stakeholders.

Author Contributions: Umberto Di Matteo supervised the paper preparation; Benedetto Nastasi conceived and designed the study and wrote the paper; Angelo Albo made the calculations; Davide Astiaso Garcia contributed in reporting from the industrial stakeholders.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. European Parliament. Decision No. 1386/2013/EU of the European Parliament and of the Council on a General Union Environment Action Programme to 2020 'Living well, within the limits of our planet'. *Off. J. Eur. Union* **2013**, *L354*, 171–200.
2. Chaliki, P.; Psomopoulos, C.S.; Themelis, N.J. WTE plants installed in European cities: A review of success stories. *Manag. Environ. Qual. Inte. J.* **2015**, *27*, 606–620. [CrossRef]
3. Wang, N.-Y.; Shih, C.-H.; Chiueh, P.-T.; Huang, Y.F. Environmental Effects of Sewage Sludge Carbonization and Other Treatment Alternatives. *Energies* **2013**, *6*, 871–883. [CrossRef]
4. Salata, F.; Golasi, I.; Domestico, U.; Banditelli, M.; Lo Basso, G.; Nastasi, B.; de Lieto Vollaro, A. Heading towards the nZEB through CHP + HP systems. A comparison between retrofit solutions able to increase the energy performance for the heating and domestic hot water production in residential buildings. *Energy Convers. Manag.* **2017**, in press. [CrossRef]
5. Rovense, F.; Amelio, M.; Ferraro, V.; Scornaienchi, V. Analysis of a Concentrating Solar Power Tower Operating with a Closed Joule Brayton Cycle and Thermal Storage. *Int. J. Heat Technol.* **2016**, *34*, 485–490. [CrossRef]
6. Rossi, F.; Castellani, B.; Presciutti, A.; Morini, E.; Anderini, E.; Filipponi, M.; Nicolini, A. Experimental evaluation of urban heat island mitigation potential of retro-reflective pavement in urban canyons. *Energy Build.* **2016**, *12*, 340–352. [CrossRef]
7. Nastasi, B.; Di Matteo, U. Solar energy technologies in Sustainable Energy Action Plans of Italian big cities. *Energy Procedia* **2016**, *101*, 1064–1071. [CrossRef]
8. Cicatiello, C.; Franco, S.; Pancino, B.; Blasi, E. The value of food waste: An exploratory study on retailing. *J. Retail. Consum. Serv.* **2016**, *30*, 96–104. [CrossRef]
9. European Parliament Resolution of 21 May 2013 Current Challenges and Opportunities for Renewable Energy in the European Internal Energy Market (2012/2259(INI)). Available online: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//NONSGML+TA+P7-TA-2013-0201+0+DOC+PDF+V0//EN (accessed on 22 September 2016).
10. Antizar-Ladislao, B.; Turrion-Gomez, J.L. Decentralized Energy from Waste Systems. *Energies* **2010**, *3*, 194–205. [CrossRef]
11. De Santoli, L.; Mancini, F.; Nastasi, B.; Piergrossi, V. Building integrated bioenergy production (BIBP): Economic sustainability analysis of Bari airport CHP (combined heat and power) upgrade fueled with bioenergy from short chain. *Renew. Energy* **2015**, *81*, 499–508. [CrossRef]
12. Arafat, H.A.; Jijakli, K.; Ahsan, A. Environmental performance and energy recovery potential of five processes for municipal solid waste treatment. *J. Clean. Prod.* **2015**, *105*, 233–240. [CrossRef]
13. Passeri, N.; Blasi, E.; Franco, S.; Martella, A.; Pancino, B.; Cicatiello, C. The environmental sustainability of national cropping systems: From assessment to policy impact evaluation. *Land Use Policy* **2016**, *57*, 305–312. [CrossRef]

14. Mata-Alvarez, J.; Macé, S.; Llabrés, P. Anaerobic digestion of organic solid wastes. An overview of research achievements and perspectives. *Bioresour. Technol.* **2000**, *74*, 3–16. [CrossRef]
15. Divya, D.; Gopinath, P.; Christy, M. A review on current aspects and diverse prospects for enhancing biogas production in sustainable means. *Renew. Sustain. Energy Rev.* **2015**, *42*, 690–699. [CrossRef]
16. RIS International Feasibility of Generating Green Power through Anaerobic Digestion of Garden Refuse from the Sacramento Area. Feasibility Study Sacramento Municipal Utility District, Sacramento, CA, USA. 2005. Available online: https://nerc.org/documents/sacramento_feasibility_study.pdf (accessed on 22 September 2016).
17. Andreottola, G.; Ragazzi, M.; Foladori, P.; Villa, R.; Langone, M.; Rada, E.C. The unit intregrated approch for OFMSW treatment. *UPB Sci. Bull.* **2012**, *74*, 19–26.
18. Symons, G.E.; Buswell, A.M. The methane fermentation of carbohydrates. *J. Am. Chem. Soc.* **1933**, *55*, 2028–2036. [CrossRef]
19. Buswell, A.M.; Mueller, H.F. Mechanism of methane fermentation. *Ind. Eng. Chem.* **1955**, *44*, 550–552. [CrossRef]
20. Chen, Y.; Cheng, J.J.; Creamer, K.S. Inhibition of anaerobic digestion process: A review. *Bioresour. Technol.* **2008**, *99*, 4044–4064. [CrossRef] [PubMed]
21. Nallathambi Gunaseelan, V. Anaerobic digestion of biomass for methane production: A review. *Biomass Bioenergy* **1997**, *13*, 83–114. [CrossRef]
22. Mao, C.; Feng, Y.; Wang, X.; Ren, G. Review on research achievements of biogas from anaerobic digestion. *Renew. Sustain. Energy Rev.* **2015**, *45*, 540–555. [CrossRef]
23. Ryu, C.; Shin, D. Combined Heat and Power from Municipal Solid Waste: Current Status and Issues in South Korea. *Energies* **2013**, *6*, 45–57. [CrossRef]
24. Murphy, J.D.; McCarthy, K. The optimal production of biogas for use as a transport fuel in Ireland. *Renew. Energy* **2005**, *30*, 2111–2127. [CrossRef]
25. Watkins, P.; McKendry, P. Assessment of waste derived gases as a renewable energy source—Part 1. *Sustain. Energy Technol. Assess.* **2015**, *10*, 102–113. [CrossRef]
26. Reichhalter, H.; Bozzo, A.; Dal Savio, S.; Guerra, T. Analisi Energetica, Ambientale ed Economica di Impianti a Biogas in Provincia di Bolzano. 2011. Available online: http://www.provincia.bz.it/agricoltura/download/Bilancio_ecologico_di_impianti_a_biogas.pdf (accessed on 22 September 2016).
27. Berglund, M.; Börjesson, P. Assessment of energy performance in the life-cycle of biogas production. *Biomass Bioenergy* **2006**, *30*, 254–266. [CrossRef]
28. Banks, C.J.; Chesshire, M.; Heaven, S.; Arnold, R. Anaerobic digestion of source-segregated domestic food waste: Performance assessment by mass and energy balance. *Bioresour. Technol.* **2011**, *102*, 612–620. [CrossRef] [PubMed]
29. De Baere, L.; Verstraete, W. High-rate anaerobic composting with biogas recovery. *BioCycle* **1984**, *25*, 30–31.
30. Mata-Alvarez, J.; Cecchi, F.; Pavan, P.; Llabres, P. The performances of digesters treating the organic fraction of municipal solid wastes differently sorted. *Biol. Wastes* **1990**, *33*, 181–199. [CrossRef]
31. Owens, J.M.; Chynoweth, D.P. Biochemical methane potential of Municipality Solid Waste (MSW) components. *Water Sci. Technol.* **1993**, *27*, 1–14.
32. Valorga. Waste recovery as a source of methane and fertilizer. The Valorga process. In Proceedings of the 2nd Annual International Symposium on Industrial Resource Management, Philadelphia, PA, USA, 17–20 February 1985.
33. Viturtia, A.M.; Mata-Alvarez, J.; Cecchi, F.; Fazzini, G. Two-phase anaerobic digestion of a mixture of fruit and vegetable wastes. *Biol. Wastes* **1989**, *29*, 189–199. [CrossRef]
34. Castellani, B.; Morini, E.; Filipponi, M.; Nicolini, A.; Palombo, M.; Cotana, F.; Rossi, F. Comparative analysis of monitoring devices for particulate content in exhaust gases. *Sustainability* **2014**, *6*, 4287–4307. [CrossRef]
35. Lo Basso, G.; Nastasi, B.; Astiaso Garcia, D.; Cumo, F. How to handle the Hydrogen enriched Natural Gas blends in combustion efficiency measurement procedure of conventional and condensing boilers. *Energy* **2017**, in press. [CrossRef]
36. Finnveden, G.; Ekvall, T.; Arushanyan, Y.; Bisaillon, M.; Henriksson, G.; Gunnarsson Östling, U.; Söderman, M.L.; Sahlin, J.; Stenmarck, Å.; Sundberg, J.; et al. Policy Instruments towards a Sustainable Waste Management. *Sustainability* **2013**, *5*, 841–881. [CrossRef]

37. Lo Zupone, G.; Amelio, M.; Barbarelli, S.; Florio, G.; Scornaienchi, N.M.; Cutrupi, A. Lcoe evaluation for a tidal kinetic self balancing turbine: Case study and comparison. *Appl. Energy* **2017**, *185*, 1292–1302. [CrossRef]
38. Rovense, F. A Case of Study of a Concentrating Solar Power Plant with Unfired Joule-Brayton Cycle. *Energy Proc.* **2015**, *82*, 978–985. [CrossRef]
39. De Santoli, L.; Mancini, F.; Rossetti, S.; Nastasi, B. Energy and system renovation plan for Galleria Borghese, Rome. *Energy Build.* **2016**, *129*, 549–562. [CrossRef]
40. Rossi, F.; Anderini, E.; Castellani, B.; Nicolini, A.; Morini, E. Integrated improvement of occupants' comfort in urban areas during outdoor events. *Build. Environ.* **2015**, *93*, 285–292. [CrossRef]
41. Nastasi, B. Planning of rural-urban continuum towards a sustainable relationship between agricultural and energy production. In *Agricultural Development within the Rural-Urban Continuum*; Print & Mail (PRIMA): Hamburg, Germany, 2013.
42. Nastasi, B.; Di Matteo, U. Innovative use of Hydrogen in energy retrofitting of listed buildings. *Energy Procedia* **2016**, in press.
43. Pöschl, M.; Ward, S.; Owende, P. Evaluation of energy efficiency of various biogas production and utilization pathways. *Appl. Energy* **2010**, *87*, 3305–3321. [CrossRef]
44. Astiaso Garcia, D.; Barbanera, F.; Cumo, F.; Di Matteo, U.; Nastasi, B. Expert Opinion Analysis on Renewable Hydrogen Storage Systems Potential in Europe. *Energies* **2016**, *9*, 963. [CrossRef]