BIOMASS EXPLOITATION FOR ENERGY SUPPLY AND QUALITY COMPOST PRODUCTION. AN EXEMPLARY CASE OF CIRCULAR ECONOMY IN THE NORTH

BIOMASS EXPLOITATION FOR ENERGY SUPPLY AND QUALITY COMPOST PRODUCTION. AN EXEMPLARY CASE OF CIRCULAR ECONOMY IN THE NORTH EAST OF ITALY

Veronica Novelli [1*], Paola Geatti, Luciano Ceccon, Sara Gratton

Department of Economics and Statistics, University of Udine, Via Tomadini, 30/A, 33100 Udine, Italy

Abstract

The goal 12 of the 2030 Agenda for Sustainable Development takes into consideration the responsible consumption and production in the perspective of circular economy. The agri-food sector is more actively involved in these initiatives, because it offers the possibility to exploit waste and by-products, by adopting suitable biotechnologies. Such processes can be carried out either under aerobic conditions, for the production of compost, or anaerobically, for the production of biogas. In this work the case of a plant managed by Desag Ecologia, located in the municipality of Sedegliano, in the North-East of Italy, is presented. The plant started up in June 2016. Its main activity consists in exploitation of organic fraction of municipal solid waste and urban forestry waste coming from separate waste collection. The basin of provenance of collected materials consists not only of the province of Udine, but also of other areas of the Friuli Venezia Giulia region and other northern Italian regions. The plant ensures the production of both biogas (used in a cogeneration installation for producing electricity and heat) and quality compost, which can be used in agriculture, after submission to physico-chemical analyses to verify the end-of-waste status. In this way, the reduction of waste disposal in landfill is ensured. Thermal energy is partially recovered for the production of hot water to heat the anaerobic digester, the leachate collection tank and the plant rooms. Approximately 10% of electricity is self-consumed for the needs of the anaerobic facility, the remaining amount is fed straight into the public electricity network.

Keywords: Biogas production, cogeneration, compost production, integrated anaerobic-aerobic plants, organic waste management.

[*] Author to whom all correspondence should be addressed: e-mail veronica.novelli@uniud.it; Phone +390432249335; Fax +390432249229

1. Introduction

The European Commission has adopted the revised Best Available Techniques (BAT) conclusions for waste treatment, published on August 17th, 2018, giving to the national authorities the guidelines for technical installation. The document contains BAT conclusions for the most common waste treatments, including mechanical, biological and physical-chemical treatments and treatment of water-based liquid waste (European Compost Network, 2018).

The Directive 2009/28/EC fixed the guidelines for waste management, recycling and recovery, in order to reach a separate waste collection (SWC) of 50% by 2020. According to the "Report on Municipal Solid Waste (MSW), 2017 Edition", (ISPRA 2017), Italy is not so far from this target, even if the situation is different among the regions: separate collection of MSW per capita increased on average from 199 kg/year in 2011 to 261 kg/year in 2016, corresponding respectively to 37.7% and 52.5%.

In 2016, in the Friuli Venezia Giulia (FVG) region, in the North-East of Italy, SWC was on average 67.1%, with a peak of 83.5% for the province of Pordenone. In FVG the percentage change between 2016 and 2015 was +6.7%.

The EC Communication 2015/614/EC promoted SWC in order to decrease landfill disposal, by introducing economic incentives for technological solutions (EC Communication, 2015). In Italy, the Ministerial Decree No 23 of June 2016 fixed exact dispositions for plants fed by biomasses, biogas and sustainable bio-liquids production (Ministerial Decree, 2016). According to the Legislative Decree No 387/2003, with the term biomass we mean the biodegradable part of the residues of forest sector, agricultural and food industry sectors, zoo-technical sector, organic waste (residues of green and scraps of food) (Legislative Decree, 2003).

Every year, the report on the State of Green Economy intervenes on national and European debate on the sustainability of economic recovery and job occupation. In particular, the General States of the Green Economy 2012 organized a national strategy for the revival of biomass supply chain: "Biomass potential in Italy is very high, but there are many obstacles for its exploitation. It will be necessary to develop the second and third generation of biofuels, the biogas/bio-methane supply chain and the energetic valorisation of biodegradable fraction of waste, taking into account the respect for the European hierarchy" (General States of the Green Economy, 2012).

Organic waste recovery and recycling is a real example of Circular Economy. In Italy, this sector is living an expansion season: in fact, in the last 10 years it increased more than 10% on a yearly basis. The Italian operative plants treat about 9 million tons of bio-waste every year, with 1.9

million/year ton of compost production. The 33% of this compost has the Consorzio Italiano Compostatori (CIC) (Italian Consortium of Composters) quality mark. To obtain the mark, thus ensuring a high quality standard, compost is submitted to continuous checking (Italian Consortium of Composters, 2018).

More than 80% of Italian compost is used in the agricultural sector as fertilizer for cereals, foragers, grapevine, etc., while the other 20% as fertilizer for gardens and/or landscape scopes. The medium price of loose compost is about 10 euro per ton. The difference of price is also due to the transport. If compost is sold in bags, the price is higher, and can reach 120 euro per ton (Italian Consortium of Composters, 2018).

Exploiting the bio-waste means many associated activities: the collecting services, the technical effort for the plant project and realization, the activities for the valorisation and the use of compost. The collecting sector and selection and exploitation sector are getting closer. The affair volume of the supply chain for the collection-treatment of bio-waste is about 1.8 billion euro/year (Althesys Strategic Consultant, 2017).

The integrated plants, born to control the odorous emissions and to stabilize the biomasses, are constituted of sequential treatment lines to recover renewable energy under biogas/bio-methane form, and to transform the digestate, plus other organic waste, by aerobic treatment, in quality compost for use as fertilizer in the agricultural sector (ISPRA, 2017).

An integrated plant is a sustainable plant, from all the points of view, giving benefits to:

- the economy of the territory, by assuring work to the community and by producing profits (economic and social support for the society);
- the community that is sure that the collected organic fraction is re-cycled (to produce renewable forms of energy and compost);
- the environment from which less primary resources are taken, through the use of renewable materials (organic waste); biogas burns polluting less the environment, in comparison with fossil fuels (Arthur et al., 2011). Furthermore, the produced compost is suitable to fertilize fields, when the results of the chemical analyses assure its qualification to be used in the agronomic sector (Italian Consortium of Composters, 2018).

The composition of the substrate treated in the integrated plants is made up of 69% of wet fraction, 10% of green fraction, 15% of sludge and the remaining 6% of other waste: the organic fraction is 91% of the total waste managed by integrated plants (ISPRA, 2017).

Biogas composition mostly depends on the type of decomposed material and subsequent slight differences in chemical compositions could result from that as well: 50–85% CH_4 (methane); 20–35% CO_2; H_2, N_2 and H_2S form the rest (Pastorek et al., 2004; Salomon and Lora, 2009).

Biogas production can be considered an established sustainable process for simultaneous treatment of organic wastes and generation of renewable energy (Angelidaki et al., 2018; Mateescu et al., 2008), a clean fuel used for heat, electricity and transport (Scarlat et al., 2018). If biogas is used as fuel, it is necessary to remove carbon dioxide to increase the percentage of methane and subsequently its calorific power.

In Europe, biogas heat use presents many differences among the countries depending on their policy targets for 2020. Germany, Italy and Denmark are the European leaders, while progresses are expected in France, Poland, UK and The Netherlands (Scarlat et al., 2018).

In integrated plants, the digestate, which remains after anaerobic digestion, with addition of other organic waste, is submitted to aerobic digestion under particular time and temperature conditions, to produce quality compost.

In Italy, the Legislative Decree No 75/2010 fixed when organic waste, after composting, stop the waste status and become qualified amender: composted green amender, composted mixed amender and composted amender with sludge, depending on the typology of waste treated (Legislative Decree, 2010a).

According to the Legislative Decree No 205/2010, quality compost is defined "product obtained by organic waste composting under specific technic rules, to be adopted by the State, finalized to define contents and use compatible with environmental and health protection and, in particular, to define quality levels" (Legislative Decree, 2010b).

The aim of this study is to present a virtuous integrated plant, managed by Desag Ecologia, located in Sedegliano, in the province of Udine, in the North-East of Italy, that contributes to circular economy, by exploiting biomass (household organic and green waste) for the anaerobic production of biogas, and subsequently aerobic production of quality compost.

2. Materials and Methods

An in-depth analysis of virtuous cases of waste management in the FVG region allowed to find out a recent plant devoted to the treatment of the organic fraction of MSW and green waste on the basis of anaerobic/aerobic digestion: Desag plant, located in Sedegliano, in the province of Udine.

To deepen the case study, we visited the plant and interviewed the Chief Executive Officer (CEO) of the facility to collect data and information. Furthermore, some e-mails and calls were necessary to improve information on the characteristics and production aspects of the plant. Data and information collected are presented in Tables 3-7.

3. Case Study Presentation

Desag Ecologia S.c.a.r.l., born more than 10 years ago, is a special purpose entity set up with 100% private capital, of which leading private companies are part: De Vizia Trasfer S.p.A. and Sager S.r.l.; De Vizia Trasfer S.p.A. is specialized in heavy lifting and industrial installations assembly sectors, Sager S.r.l. is specialized in integrated waste management. In the case studied, Desag Ecologia signed a concession contract with a grantor society (A&T 2000) for the building of a plant for renewable energy and compost production, for a total period of 25 years in a project financing operation where the public authorities require private capitals for the realization of work for public use in accordance with current legislation (Italian Law, 1998). A&T 2000 is a public society born in 1998, as a natural evolution of an aggregation of municipalities of the province of Udine, with the aim of implementing economic and operational strategies in the field of municipal waste management. At present, it incorporates 50 municipalities and has a catchment area of 200,000 inhabitants. Within the project financing, A&T 2000 is the grantor subject, that is to say who shall provide the good, in this case waste. A&T 2000 deals only with ensuring the commodity (waste) at a specific tariff agreed with Desag Ecologia.

The construction and operation of an integrated plant of anaerobic digestion and composting were charged to concession holder, Desag Ecologia.

The Desag Ecologia plant is located in Pannellia, in the municipality of Sedegliano, in the province of Udine, in the North-East of Italy; its construction started in 2013 and the plant was put into service in June 2016. A schematic representation of the stages of the production process is given in the Results and Discussion section (Figure 1).

After a first phase of waste acceptance, aimed at selecting only compliant waste, a storage phase follows, in specific inner paved areas, coated with anti-wear anti-acid lining and provided with a liquid conveying system. During these phases, specific measures shall ensure the least pollutant or odorous emissions leakage. Accepted waste is classified into four categories: organic fraction of municipal solid waste and similar, mowing materials/small wood waste, large wood waste and sludge. Purity of incoming materials is verified by random sample analysis, visual check and bulky waste removal.

The production process provides for waste pre-treatments: initially waste pass through a machine devoted to the bags opening (the machine is also equipped with a system aimed at detecting foreign materials). Large wood waste shall be subjected to a possible volumetric reduction (chipping).

Anaerobic digestion. Anaerobic digestion is performed with dry batch modality, in a single stage of fermentation. The duration of such process, performed at 37 °C, is 28 days. The plant is constituted of 8 fermenters, that allow to treat indicatively 830 m^3 of mixture. The fermenters are equipped with a heating system of the fund and the walls, which is powered by the heat recovered by the group of biogas cogeneration. This system allows to maintain the process temperature in fermenters.

The fermenters are uploaded (and emptied after a fixed reaction time) in different days, properly scheduled, in order to ensure continuity to the process and to properly distribute downloading, mixture preparation and material uploading for the following cycle.

In order to ensure the conditions of constant moisture and controlled temperature, the leachate generated from biomass is collected and sprayed once again on medium in a controlled way.

Biogas Production. Anaerobic digestion process enables to obtain biogas, which in Degas Ecologia plant is conveyed into two co-generation groups (499 kWe each), for combined heat and electricity production. Before combustion, biogas shall be submitted to pre-treatments: filtration (on activated carbon), dehumidification (by means of a condenser) and compression at 80 mbar.

The Desag Ecologia plant is equipped with a safety torch, which shall be activated only in case of servicing of failure of cogenerator, or in the event of biogas overproduction and in the start-up phase. In order to ensure security, in the event that the torch is not sufficient, three emergency chimneys have been set up to ensure immediate leakage of excess biogas.

Combustion cogenerative engines are provided both with a system that allows the removal from biogas of sulphur compounds, before introduction in combustion chamber, and with a containment system of nitrogen oxides production in exhausted gases resulting from combustion.

Composting. Composting of the mixture is carried out inside 8 independent bio-tunnels, isolated from the external environment. The static heap technique is adopted. The bio-tunnels are supplied with a floor aeration equipment, a system of suction of the exhausted air (conveyed to the treatment section in order to eliminate odorous emissions), a device of collection of the process liquids (stored in a devoted tank) and an automatized system of monitoring and control of the process parameters (temperature, moisture, oxygen and carbon dioxide concentrations).

The composting process provides for the previous preparation of the mixture in a covered area in front of the bio-tunnels and the subsequent loading of the mixture. The bio-tunnels are loaded in sequence, at pre-defined time intervals, to assure the process continuity and the correct management of the time for the steps of downloading, mixture preparation and material loading for the subsequent cycle.

When the process ends, compost is sent to the step of primary ageing to degrade the most complex compounds. Then the material is transferred to the area of secondary ageing, located under a roofing.

The final step of refining has the aim of separating possible extraneous fractions which can be present in compost, that is, plastics, iron components and materials with an unsuitable size (greater than 10-15 mm).

At the end of the secondary ageing step, the material is transferred to the sieving step. On the obtained compost, sampling and chemical-physical analyses are carried out to verify the end-of-waste status. In particular, the employed criterion is the respect of the limits provided for by the enclosure No 2 to the Legislative Decree No 75/2010 relative to the mixed composted amender (Legislative Decree, 2010a). In case of not compliance with the aforesaid criterion, compost can either be managed as waste and sent to authorized plants, or recycled in the production process for the preparation of the mixture to be subjected to composting, or used as filtering bed during the bio-filtration process.

Systems for shooting down of emissions into the environment and control systems. The Desag Ecologia plant uses systems under continuous improvement for reduction of diffuse and fugitive emissions. All operations that can generate dust or odor are located inside buildings, in enclosed spaces. The plant is endowed with a suction system, which conveys air to bio-filters which are filled with a mixture of aged compost, bark and sawdust.

The facility is equipped with separate networks of collecting, treatment and discharge of wastewater. The plant is fitted with an automation system, which allows monitoring of process parameters and their dynamic setting, notification of operating faults, activation of correction or emergency procedures, actuation of equipment, plant programming and control.

4. Results and Discussion

In 2016, Italian production of municipal solid waste (MSW) was 30.1 million t, with a 2% increase, in respect of 2015, corresponding to 590,000 t. The percentage of separate waste collection (SWC), calculated as the ratio between the amount of materials collected by separate waste collection and the amount of materials collected as unseparated MSW x 100, was 52.5%, with an increase of 5 points if compared with 2015.

SWC per capita was 261 kg at the national level, 328 kg in the North of Italy (+38 kg more than in 2015), 266 in the Centre (+28 kg more than in 2015) and 169 in the South (+20 kg more than in 2015). From 2011 to 2016, SWC variation was 62 kg per capita (Table 1).

In 2016, SWC of organic fraction (kitchen scraps = wet fraction, and waste coming from the management of gardens and parks and ornamental green = green) in Italy was 6.5 million t, considering also the quantity destined to domestic composting, more than 220,000 t; an increase of almost 450,000 t (+7.3 %) was observed compared with 2015.

Table 1. Separate waste collection (SWC) in t, in % and in kg/year per capita from 2011 to 2016 in Italy (ISPRA, 2017)

	Amount of SWC collected (x1000 t)				**SWC %**				**SWC per capita (kg/year)**			
	North	Centre	South	Italy	North	Centre	South	Italy	North	Centre	South	Italy
2011	7,327.0	2,122.5	2,398.5	11,848.0	51.1	30.2	23.9	37.7	269	183	116	199
2012	7,234.4	2,229.6	2,528.3	11,992.3	52.7	33.1	25.5	40.0	266	192	123	202
2013	7,400.4	2,414.8	2,693.2	12,508.5	54.4	36.4	28.8	42.3	266	200	129	206
2014	7,803.1	2,700.2	2,898.1	13,401.4	56.7	40.8	31.3	45.2	281	223	139	220
2015	8,043.4	2,868.2	3,109.3	14,020.9	58.6	43.8	33.6	47.5	290	238	149	231
2016	9,091.4	3,214.3	3,516.4	15,821.9	64.2	48.6	37.6	52.5	328	266	169	261

In 2016, in the FVG region MSW production was 582,052.2 t, SWC was 67.1%, with a variation of +6.75% if compared with 2015. The more virtuous province was Pordenone, with 82.3% (Table 2).

Table 2. Population, municipal solid waste (MSW) in t and in kg/year per capita, separate waste collection (SWC) in t and in % in 2016 in the Friuli Venezia Giulia region and Δ% 2016-2015 (ISPRA, 2017)

Territorial area	**Population**	**MSW (t)**	**MSW per capita (kg/year)**	**SWC (t)**	**SWC %**	**Δ% 2016-2015**
Province of Udine	531,466	258,643.1	486.7	180,495.3	69.8	+ 5.1
Province of Gorizia	139,673	69,476.5	497.4	47,392.4	68.2	+ 10.2
Province of Trieste	234,682	110,801.2	472.1	44,961.8	40.6	+ 16.3
Province of Pordenone	312,051	143,131.3	458.7	117,825.6	82.3	+ 5.0
Friuli Venezia Giulia region	1,217,872	582,052.2	477.9	390,675.0	67.1	+ 6.7

In 2016, the plants of mechanical-biological treatment worked, in Italy, more than 10.8 million t of waste, with a 4.4% increase in respect of previous year. About 5.7 million t were recovered in these plants at the end of the process (+ 10% in respect of 2015). Almost 3.4 out of 5.7 million t were addressed to composting plants, about 2 million t to integrated aerobic/anaerobic treatment plants and little more than 249,000 t were worked in anaerobic digestion plants.

In 2016, 326 plants (309 in 2015) were working in Italy. More in particular, 274 plants (263 in 2015) were devoted only to aerobic treatment (composting), 31 plants (26 in 2015) to integrated aerobic/anaerobic treatment (ISPRA, 2017) and 21 plants (20 in 2015) to anaerobic digestion (Bacenetti et al., 2013; Bozano et al., 2012). 26 plants were located in the North, in particular 2 in the FVG region, 2 in the Centre and 3 in the South. In these plants, biogas is produced by anaerobic digestion and compost by aerobic degradation of digestate and other organic waste. The composition of the treated substrate is made up of 69% of wet fraction, 10% of green fraction, 15% of sludge and 6% of other waste: the organic fraction is 91% of the total waste managed by integrated plants (ISPRA, 2017).

In this paper, the case of the plant located in the municipality of Sedegliano, in the province of Udine, in the North-East of Italy, is taken into account. The plant is devoted to recovery by anaerobic digestion both of the waste coming from separate collection of the organic fraction of MSW and of sludge, and to subsequent composting to produce quality compost. In the plant, anaerobic digestion of the raw materials is carried out to produce biogas, which is then transformed into both electric power by two cogeneration engines of the whole potential of 998 kW, and thermal power, which is used to heat the fermenters in order to keep the process temperature of about 37°C.

The potentials of the plant are 31,000 t/year of incoming waste, 3 million Nm^3/year of biogas production and 10,300 t/year of compost production (Table 3).

Table 3. Plant potentials

Incoming waste	99 t/day
	31,000 t/year
Generative groups electric power	2 groups (499 kW each)
Biogas production	3,000,000 Nm^3/year
Compost production	30 t/day
	10,300 t/year

Anaerobic digestion. Anaerobic digestion provides for previous preparation of the mixture, which is made up by:

- 50% of waste represented by the organic fraction of MSW and by green waste (mowing and trimming materials, small wood pieces);
- 50% of digestate produced by the anaerobic fermenters and recycled into the process, to allow the development of a suitable bacterial population.

Percent composition of the mixture for anaerobic digestion is shown in Table 4.

Table 4. Mixture composition for anaerobic digestion

Material type	Percentage
Recycled digestate	50.0
Organic fraction of MSW	42.9
Mowing and trimming materials/small wood pieces	7.1
Total	100.0

In Table 5 the biogas production characteristics are presented.

Table 5. Characteristics of biogas production

Biogas produced per year	3,000,000	Nm^3/year
Production hours	8,760	hours/year
Biogas flow per hour	342	Nm^3/hour

The cogeneration engines allow the production of electric and thermal power. About 10% of the electric power obtained is employed for the needs of the plant itself, whereas the remaining amount is distributed by the Enel network. The thermal power obtained is partly recovered by the use of heat exchangers to produce hot water at the temperature of about 85°C. Hot water is employed to heat the digesters, the tank of percolate collection and the technical rooms. The amounts of energy involved in the management of the plant in 2017 are shown in Table 6.

Table 6. Plant energy amounts in 2017

	Thermal power (MWh/year)	**Electric power** (MWh/year)
Production	5792	5500

Own consumption	870	550
Amount sold to a third party	-	4950
External supply	-	3965

*Composting. C*omposting provides for preliminary preparation of the mixture, which is made up by:

- material digested following anaerobic fermentation (about 50% by weight),
- wood waste after chipping and sludge,
- material already subjected to composting and recycled,
- material subjected to primary ageing which is not yet aged,
- intermediate fraction obtained by compost refining, with size between 10-15 and 100 mm,
- possible compost which proved to be not compliant with the criteria established to define the end-of-waste status, and for which the suitability to be recycled in the process has been positively evaluated.

The percent composition of the composting mixture is shown in Table 7.

Table 7. Mixture composition for composting

Material type	Percentage
Digestate from the plant	58.5
Not aged compost	30.3
Big wood pieces/waste	6.7
In-between fraction from refining	4.5
Total	100.0

The composting step has the aim of metabolizing the most easily biodegradable materials; it lasts 14 days and is carried out at the temperature of 55°C by employing the static heap technique. At the end of the process, compost is transferred to the primary ageing step, during which the most complex materials are degraded. The primary ageing step lasts 28 days. Then the secondary ageing step follows, during which the material is periodically turned over. This step lasts 20 days. At the end, compost is forwarded to the sieving section, that allows the separation of the following fractions:

- fraction with a size smaller than 10-15 mm, representing compost, on which plastic suction and separation of iron materials are carried out. On this fraction, sampling and chemical-physical analyses are carried out to check the end-of-waste status;
- fraction with a size between 10-15 and 100 mm, mainly made up by woodchips, which can be recycled for the preparation of the mixture to be subjected to composting;
- fraction with a size larger than 100 mm, made up by rejected materials which are managed as waste in authorized plants.

The quality compost obtained is certified by Italian Consortium of Composters for use in the agricultural sector.

The matter balance foreseen is shown in Figure 1.

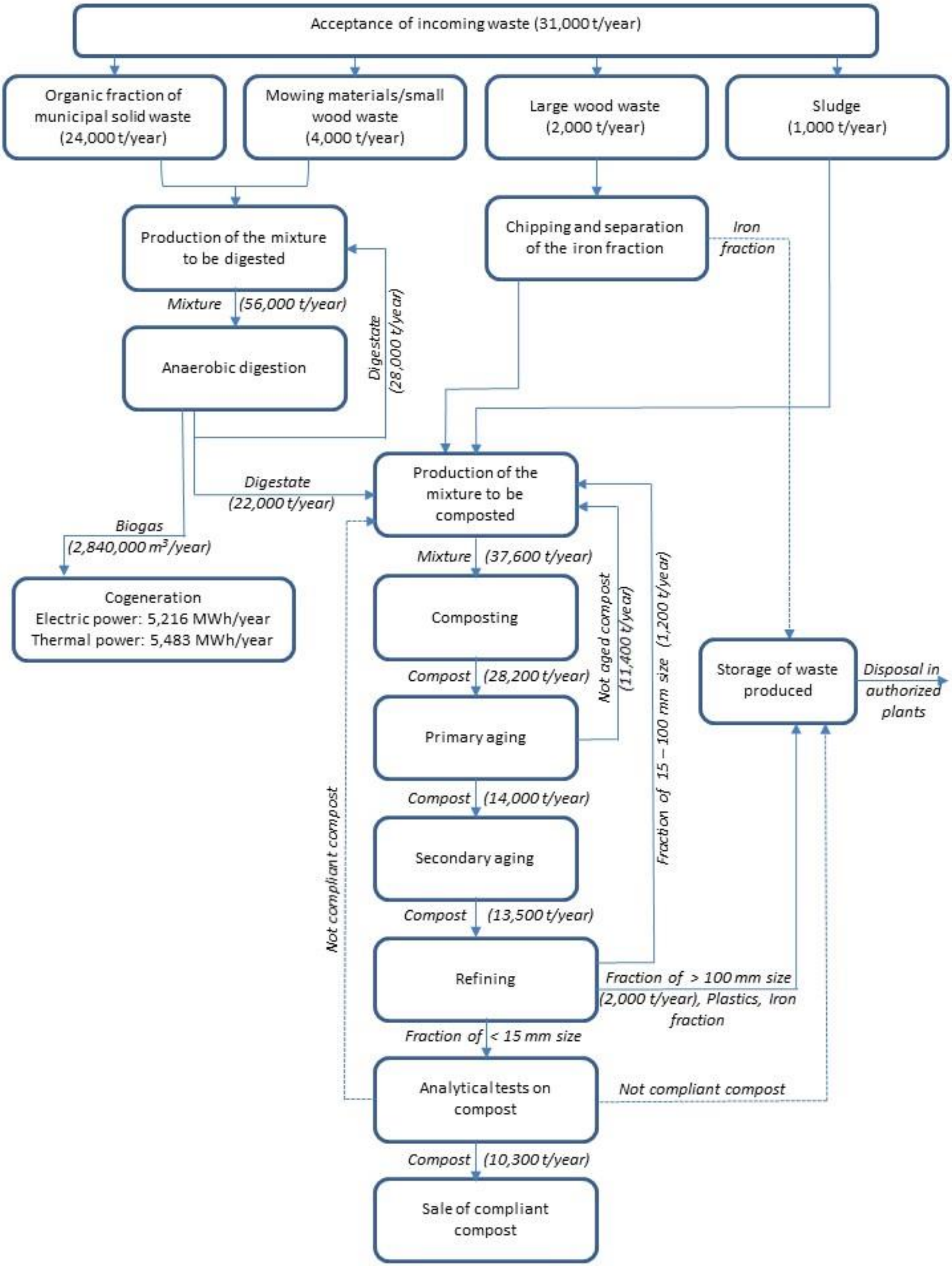

Fig. 1. Matter balance foreseen for Degas Ecologia plant

The output of materials obtained in 2017 was 3,408 m^3 of biogas, 10,293 t of refined compost, 2,030 t of waste and 2,630 m^3 of percolate.

At present, 75% of the raw materials treated by the plant comes from the FVG region, while the rest from other basins, but in the future the plant manager will extend SWC to the whole region. In fact, even if the plant started its activity in 2016, the management foresees to enlarge the plant potential, by a new area of waste reception, already authorized by the Environmental Integrated Authorization (EIA), and for which other building licences are required, starting works in 2019. EIA, regulated by the II part of the Legislative Decree No 152/2006, authorizes the running of plants that carry out activities cited in annex VIII, forcing measures to avoid or reduce air, water and soil emissions (Legislative Decree, 2006).

5. Conclusions

The waste management EU policies act in order to reduce the environmental and health impact. Waste production is increasing because population and consumes are growing, so their production in unavoidable, but it is important to improve the technologies for recycling the materials that can be transformed in renewable forms of energy and/or products to be used in different sectors.

To increase the SWC percentage at the national level, by reducing the differences among the Italian regions, is a duty of national policies, by the reduction of the gap between the collected and the recycled waste.

Desag Ecologia is able to operate in the perspective of Circular Economy through:

- the exploitation of the organic fraction of MSW and green waste;
- the production of a renewable form of energy, biogas, that can be used to produce heat and electric energy;
- the production of quality compost for agricultural use.

The concept of sustainability, founded on the three main pilasters, economy, environment and society, fits well with the activities of the plant taken into account.

The renewable sources sector, in particular the biogas sector, is living an important increase, involving investments, new work places and several positive effects on the national economy.

Acknowledgements

The authors contributed equally in idea conception, acquisition of information, data analysis and comment, drafting of the manuscript.

References

Althesys Strategic Consultant, (2017), Waste, a National Strategy towards 2030, (in Italian), On line at http://www.althesys.com/wp-content/uploads/2017/12/rass-WAS-21-nov-17-ASSEMBLATA.pdf

Angelidaki I., Treu L., Tsapekos P., Luo G., Campanaro S., Wenzel H., Kouglas P.G., (2018), Biogas upgrading and utilization: Current status and perspectives, *Biotechnology Advances*, **36**, 452-466.

Arthur R., Baidoo M.F., Antwi E., (2011), Biogas as a potential renewable energy source: A Ghanaian case study, *Renewable Energy*, **36**, 1510-1516.

Bacenetti J., Negri M., Cantore A., Cantarella P., Fiala M., (2013), A detailed monitoring of an anaerobic digestion plant in Northern Italy, *Environmental Engineering and Management Journal*, 12, 109-113.

Bozano P., Nosiglia V., Vitali G. (2012), Co-digestion of biowaste and commercial waste with agricultural residues –Experiences from Castelleone (Italy), Fourth International Symposium on Energy from Biomass and Waste, Venice (Italy), 12-15 November 2012, On line at: https://www.biotecsistemi.it/media/cms/PBozanoPaperVenice2012_rev1.pdf

EC Communication, (2015) Communication 2015/614/EC, Closing the loop - An EU action plan for the Circular Economy, On line at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52015DC0614

EC Directive, (2009), 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, *Official Journal of the European Union*, L 140/16, 05.04.2009, Brussels.

Eurostat, (2018), Municipal Waste Statistics, On line at: https://ec.europa.eu/eurostat/statistics-explained/pdfscache/10360.pdf

European Compost Network, (2018), BAT Conclusions for Waste Treatment published, On line at: https://www.compostnetwork.info/bat-conclusions-for-waste-treatment-published/

General States of the Green Economy, (2012), Renewable energies: a handbook to develop them in Italy (in Italian), On line at: http://www.statigenerali.org/2012/09/rinnovabili-un-decalogo-per-svilupparle-in-italia/

ISPRA, (2017), Report on Municipal Solid Waste (MSW), 2017 Edition, (in Italian), On line at: http://www.isprambiente.gov.it/files2017/pubblicazioni/rapporto/RapportoRifiutiUrbani_Ed.2017_n.272_Vers.Integrale_rev08_02_2018.pdf

Italian Consortium of Composters, (2018), Recovery and Recycling of Organic Waste: a Real Example of Circular Economy (in Italian), On line at: http://www.compost.it/attachments/article/1341/Dati%20del%20settore%202018.pdf

Italian Law, (1998), Law of 18 November 1998, No 415, Modifications to the Law 11 February 1994, No 109 and further dispositions as regards public works (in Italian), *Official Journal of the Republic of Italy*, No 284, 04.12.1998, Ordinary Supplement No. 199, Rome.

Legislative Decree, (2003), Legislative Decree of 29 December 2003, No 387, Implementation of Directive No 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market, (in Italian), *Official Journal of the Republic of Italy*, No 25, 31.1.2014, Rome.

Legislative Decree, (2006), Legislative Decree of 3 April 2006, No 152, Code on the Environment (in Italian), *Official Journal of the Republic of Italy*, No 88, 14.04.2006, Ordinary Supplement No 96, Rome.

Legislative Decree, (2010a), Legislative Decree of April 29, 2010, No 75, Reform and Revision of Discipline on Fertilizers, in accordance with Article 13 of Law July 7th 2009, No 88. *Official Journal of the Republic of Italy*, No 126, 26.5.2010, Rome.

Legislative Decree, (2010b), Legislative Decree of 3 December 2010, No 205, Dispositions of implementation of the Directive 2008/98/CE of the European Parliament and of the Council of 19 November 2008 relative to waste and abrogating some directives (in Italian), *Official Journal of the Republic of Italy*, No 288, 10.12.2010, Ordinary Supplement No 269, Rome.

Mateescu C., Băran G., Băbuţanu C.A., (2008), Opportunities and barriers for Development of biogas Technologies in Romania, *Environmental Engineering and Management Journal*, **7**(5), 603-607.

Pastorek K., Kara J., Jevic P., (2004), Biomass as renewable source of energy: economics and energy aspects (in Czech), Prague, FCC Public, 286.

Salomon K.R., Lora E.E.S., (2009), Estimate of the electric energy generating potential for different sources of biogas in Brazil, *Biomass and Bioenergy*, **33**(9), 1101-1107.

Scarlat N., Dallemand J-F., Fahl F., (2018), Biogas: Developments and perspectives in Europe, *Renewable Energy*, **129**, 457-472.