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CIRCULAR ECONOMY AND ZERO WASTE TARGETS IN THE TERRITORIO & RISORSE BIOMETHANE AND COMPOSTING PLANT SANTHIÀ VC – ITALIA

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Abstract

Sustainability and circular economy are the dominant themes of the moment and are totally transversal to every sector, especially in the waste treatment sector where these issues intersect with the service offered to society. Good management of municipal waste is a service to society and an opportunity for the recovery of raw materials and energy. Modern engineering produces solutions and technologies which, when integrated, achieve the goal of almost zeroing waste to be disposed in landfills and total energy recovery of the same. Technologies, good engineering practices and the process procedures make plants safe for the environment and the operators, increase recovery efficiency, allow the operator a total control of the processes, and make the plant reliable and profitable. The purpose of this paper is to describe the full-scale waste plant of Territorio e Risorse Srl (T&R) of Santhià VC and explain the operational results in this revamped plant with modern design and technology. Start-up of the new anaerobic line showed: (i) plastic over screen production less than 15 wt. % of treated OFMSW; (ii) high specific biogas and biomethane production values (190 Nm^3 dry biogas/ton of fed ingestate). These values, better than in the literature, show an efficient OFMSW valorization process and a reduction in waste produced. It is possible to make our mind on a series of important and decisive issues for the success of an AD project as well as to get some important data about plant performance which set a new benchmark or biogas and RNG production from food waste.

Key words: anaerobic digestion, composting, SRF, circular economy, zero landfill

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1. Introduction

Food waste and green waste collection in Italy has advanced significantly, a number of plants have been built and some peculiarities of the Italian waste have led to implement new technologies and solutions (Mancini et al., 2019; Scalvedi and Rossi, 2021). Making a statement regarding the performance of one of the most recently constructed plants is the goal of this study. Waste source segregation and collection for bio waste totals 7.175.000 ton/y, or 121 kg/person/year. This includes 5.230.000 ton/year of food trash and 1945000 ton/year of green waste (Centemero and Confalonieri, 2022). This quantity of waste is processed in dedicated facilities using a variety of technologies, yielding 2.200,000,000 ton/y of compost and 400.000.000 Nm3 of biogas, which are then converted into 100.000.000 m^3 of renewable natural gas that is pumped into the gas grid, as well as 440.000 MWhe of electricity and 130.000 MWht of thermal energy.

The goal for 2025 is to segregate and collect 155 kg/ab/year of biowaste, which is equivalent to 9.000.000 ton/y. This implies the construction of 52 additional biogas plants, all of which are intended to provide RNG for an additional 300.000.000 Nm^3 per year (Fig. 1) (Centemero and Confalonieri, 2022). The target for 2030 is to meet at least 10% of Italy's natural gas needs using RNG, enabling Italy to complete the cycle of biowastes.

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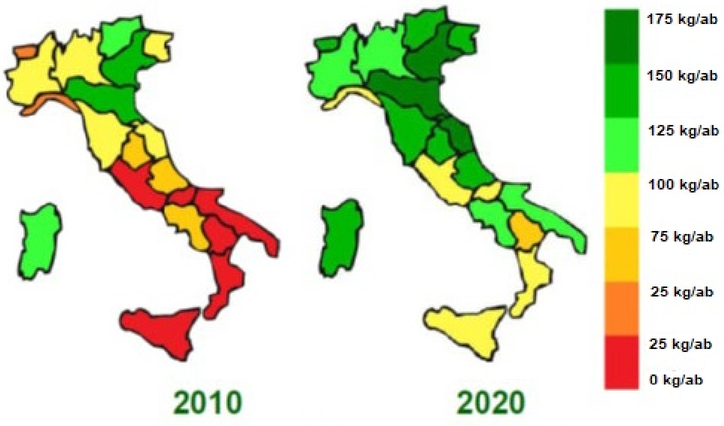


Fig. 1. Separate collection of waste in Italy

The technology created to remediate such waste streams has been fine tuned for such garbage and significantly advanced through time. This is because food waste is a heterogeneous material, and its physical and chemical characteristics depends on the definition of OFMSW is defined in different countries and other factors like weather, predominant economic activities, nutritional habits, seasonal changes and recollection system (Campuzano and González-Martínez, 2016).

Italian waste is primarily comprised of putrescible waste (vegetables), with little green waste and a 7–10% contamination rate from shopping bags, the majority of which are made of biodegradable plastic (Table 1). Anaerobic digestion (AD) plants for food waste have evolved from wet AD, where the total solid (TS) content is between 10 and 12 percent, to dry digestion, where the TS is higher at 30 percent. This allows for the largest amount of biogas to be extracted from the waste stream while also significantly reducing the amount of wastewater that must be disposed of.

Table 1. Example of OFMSW composition analysis of food waste from Northern Italy region

***Fraction** (%)*	***Value***
Putrescible organic	87.40
Cellulosic material	1.04
Plastic materials	8.70
Glass	1.77
Metals	0.55
Others	0.54

The stream may now be disposed of more easily and more affordably thanks to improvements in the removal of pollutants (mainly plastics) from the substrate and a reduction in the amount of organic fraction that must be drawn along with the contaminants. To increase the circularity of the treatment, cleaned and odorless plastic can be used as solid recovered fuel.

The plant management has been heavily automated with a totally unmanned handling of the masses throughout the process, and the final step of processing the digestate with an appropriate composting has also been enhanced to produce a superior quality compost.

The Territorio & Risorse factory in Santhià, Italy, which is the focus of the current study, has been designed with all mentioned upgrades and now, after two years operation we are able to measure what are the real process statistic. As a result, a new benchmark for the industry has been established.

2. Case study

The Entsorga Group headquartered in Tortona Italy – over the years built more than a hundred composting, mechanical biological treatment and biogas plant in the EU, North Africa and the US by using their proprietary technologies and the 13 patents owned. The Company translates the concept of environmental sustainability with Eq. (1) showing how the human impact on the environment is the result of the product between the world population and the average individual consumption of resources, divided by the technology (www.entsorga.it).

$$Human\ Impact = \frac{Population * Consumption}{Technology} \quad (1)$$

A challenge that Entsorga took on 20 years ago**,** was focused on the research and development of solutions with high technological value and low environmental impact. This approach leads to designing waste treatment plants where the main requirement is their environmental performance which, we believe, is clearly achieved in the plant built for the Territorio & Risorse (T&R) plant in Santhià VC – Italy.

3. Plant system analysis

3.1. The plant

The T&R plant was built in 2010 as a just composting plant for a capacity of 40.000 t/y. The plant permitted capacity was, over the years, used to get source segregated food waste which was always got a much higher gate fee if compared to other streams such as green waste. Chopped wood was bought to be used as bulking agent in the compost mixture to be made with the food waste. All the process is carried out in enclosed buildings with a continuous air extraction, such air is the then cleaned by a biofilter.

In 2018 a new permit application was submitted to expand the plant with an anaerobic digestion unit to produce renewable natural gas (bio-methane) for a total plant capacity of 50.000 t/y. The permit was granted in September 2019 (https://www.ibabiogas.com/case-studycomposting-and-anaerobic-digestion-plant/)

3.2. Optimizing the pre-treatment

This first requirement addresses the need of minimizing the sorted-out streams which is extremely expensive to dispose (140-180 €/t). It is very well known in the industry that food waste has a contamination of 7-10% (Italy) essentially made up of plastic bags but also metals and other materials. The sorting operation is a very sensitive issue, the usual way to do such treatment is to use a bag opener and then some sort of screening and metal removal. In doing so you may obtain an amount of sorted out materials which may go from 20 to 40% of the throughput thus resulting in having a huge quantity of sorted out material made up of plastics which is dragging a lot of organic waste thus resulting in unaffordable disposal cost and in loosing precious methanogenic materials.

By using the proper pre-treatment line, the amount of sorted out materials is reduced to 14-15% only. On top of it by using squeezers rather than screener, the exposure of the biogenic particles to the process is increased and a faster start-up of the biogas generation process is obtained. Finally squeezers have a much lower maintenance requirement than screeners. A further advantage generated by such pre-treatment is the possibility to use piston pump and a pipeline to feed the digester preventing material leaks and clogging and reducing maintenance of the feeding line to a minimum.

3.3. Minimizing water treatment requirement

By using a plug flow semi dry digester capable of having a total solid of 28-32 wt.% rather than the 10-12 wt. % of a wet digester helps a lot in this respect as you are reducing the water to 1/3 of the water you may have in a wet digester with 10-12% of TS (APAT, 2005). On top of it, a semi dry plug flow digester due to the agitator and the suspension capacity generated by the high solid in the ingestate allow us to avoid the know problems of sinking inert materials and floating materials creating a hard cap affecting wet digesters. Both issues are important as they require to be fixed to put the digester down and clean the tank, a very time demanding an expensive maintenance.

3.4. Maximizing the biogas production

In order to feed the digester 24/7 pre-treatment is made using maximum automation possible. Minimize the downtime of the plant which may happen for minimal malfunction or power supply instability which put the plant down and may keep the plant down for an entire night or weekend. The remote control of the plant enables the operators to intervene remotely.

3.5. Digester heating

The last requirement to meet is to improve the digester heating in order to save energy but also to have a tighter control over the project. Then the choice was to use a steam heating system which has the advantage to be extremely effective in distributing heat inside the processed material and in the position where such heating is more required, the inlet of the feedstock. On top of such benefit the system has no heat exchanger or pipe inside the digester thus avoiding corrosion of the pipes, leaks of the heating fluid or deposit of materials over such pipes and minimize the thermal stress in the digester concrete structure.

3.6. Biogas upgrading system

The upgrading system combines a number of filtering stages a water washing to clean the biogas from NH_3 and other soluble VOC, a chiller to reduce the gas temperature, a first activated carbon filter to specifically remove H_2S, a second activated carbon filter to remove VOC and, a membrane system to filter the CO_2.

3.6. Plant commissioning

The first filling of the digester was made by using digestate from several other plants with a mix shownin Table 2.

Table 2. Composition of the mix in digester

Inoculum matrices	***Volume, m^3***	***%***
Digestate o animal manure (cows) from wet AD	1740	87
Digestate from semi-dry process of food waste	240	12
Ingestate deriving from food waste pre-treatment prepared in the plant	20	1
Total volume of the digester	**2000**	**100**

Before starting the plant commissioning, the inoculum was tested by using the COW-LAB, a pilot digester in scale 1/12 which reproduces the much bigger digester and allowed to fine tune the inoculum composition and to schedule the increase of pre-treated food waste to be fed to the digester (Fig. 2).

3.7. Daily analysis

By running in parallel the Cow-Lab and the digester full scale, the full-scale digester performance and the biogas production can be predicted. .

This activity was supported by a strict daily analysis schedule, on both system:

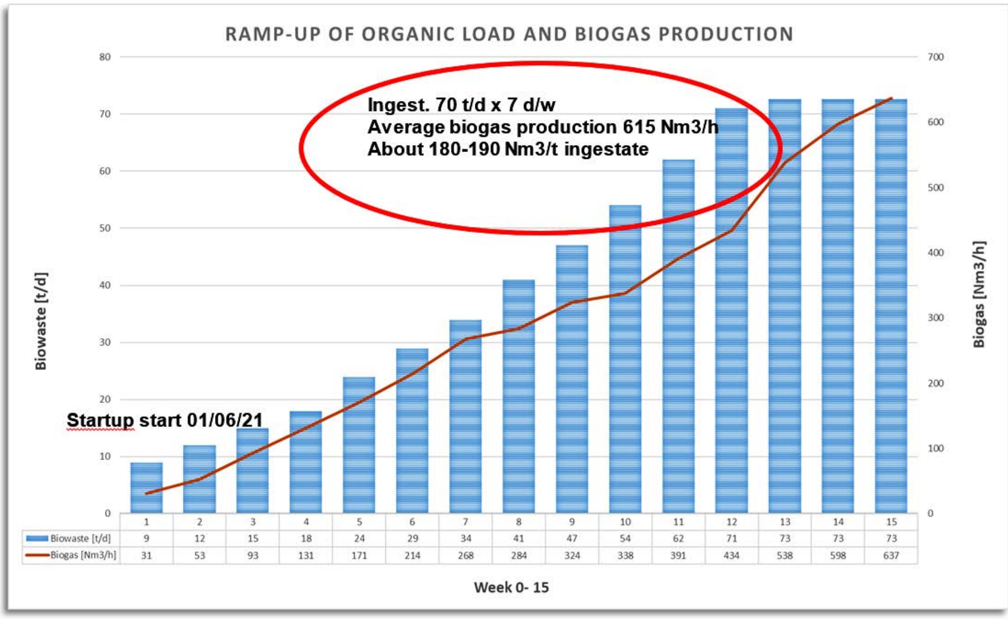
- biogas production
- biogas composition
- temperature
- pH
- FOS/TAC
- Total Solids TS
- Total Volatile Solids TVS

Periodic analysis has also been scheduled supported by a certified laboratory:

- organic substance
- TKN total Kjeldhal nitrogen
- Weender analysis
- micro-nutrients
- food waste composition

The result of 15 weeks ramp-up schedule summarized in Fig. 3, which correlates the increasing amount of ingestate (food waste) fed to the plant during the plant ramp up and the amount of biogas produced. The first point to consider is the production of biogas vs. throughput now stable at 190 Nm^3 dry biogas/$t_{ingestate}$ (considering a biogas moisture content equal to 10 v,v %) which is exceeding the expectations originally set at 150 $Nm^3/t_{ingestate}$ found in a similar plant in Netherlands (de Laclos et al., 1997).

Fig. 1. Image of the Cow-Lab (www.entsorga.it)



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Biowaste [t/d]	9	12	15	18	24	29	34	41	47	54	62	71	73	73	73
Biogas [Nm3/h]	31	53	93	131	171	214	268	284	324	338	391	434	538	598	637

Fig. 2. Ramp up: feeding ratio vs. biogas production

In Tilburg plant the pre-treatment line is composed of a rotating screen, a magnetic separator and a shredder that crush the waste and reduce the particle size below 80 mm (de Laclos et al., 1997). The specific biogas production found in Santhià is close to Biomethane potential (BMP) found in literature by Campuzano et al. for the Italian OFSMW from 7 different cities, equal to 213.06 Nm^3 /$t_{ingestate}$ (Campuzano and González-Martínez, 2016). While some increase of biogas production may be explained by the efficiency of the pre-treatment and with the quality of the process discussed in previous chapters.

Another interesting issue is shown in Table 4: a decrease in feeding the digester of 50% during weekend leads to a considerable decrease in biogas production. During Saturday, Sunday and Monday, approximately 30, 30 and 12 tonnes respectively were loaded to the digester. Biogas production remained approximately constant between Friday and Saturday, but dropped on Sunday, from around 11000 Nm^3/d to 8353 Nm^3/d. Production rose again, restoring the load to 70 ton/d with a production around 13000 Nm^3/d of wet biogas per ton of ingestate. This testifies to a fast degradation kinetics of anaerobic microorganisms. Campuzano et al. in their research discuss the physical, chemical and bromatological characteristics of food waste from different countries and cities. They searched a correlation between these properties and the biomethane potential (BMP).

Table 5 shows an elaboration of the data presented in the paper. As shown in Table 5 the average BMP of OFMSW in Italy from 7 cities is 213,06 Nm^3 biogas per ton of ingestate. The variability of BMP depends on the variability of OFMSW which depends on weather, predominant economic activities, nutritional habits, seasonal changes and recollection system. (Campuzano and González-Martínez, 2016). Compared to BMP, which is the maximum amount of biomethane and biogas that can be produced from one tonne of feedstock, some full-scale plants show lower values depending on the efficiency of converting biomass into biogas.

Table 3. Biogas production sensitivity related to feeding

Date	*Ingestate [ton/d]*	*Biogas [Nm^3/d]*
04/10/2021	59.86	5.434.0
05/10/2021	60.00	10.353.0
06/10/2021	59.57	11.150.0
07/10/2021	44.97	10.613.0
08/10/2021	60.00	11.250.0
(Saturday) 09/10/2021	30.01	11.051.0
(Sunday) 10/10/2021	30.00	8.353.0
(Monday) 11/10/2021	12.02	6.264.0
12/10/2021	70.00	8.938.0
13/10/2021	70.00	12.727.0
14/10/2021	70.00	11.615.0
15/10/2021	70.00	14.345.0
16/10/2021	50.00	13.052.0
17/10/2021	50.00	11.487.0
18/10/2021	69.22	11.356.0
Total	**805.65**	**157988.0**

Table 5. The average BMP of OFMSW in Italy from 7 cities (adapted upon Campuzano and González-Martínez, 2016). For each country, it is reported the mean value found for different cities divided by country. For the average of Spain, the values reported for the city of Cadiz were excluded; It is considered unrepresentative. BMP (Nm^3 biogas /ton) was calculated considering a methane percentage in biogas of 58 %.

Country	*TS*	*TVS / TS*	*BMP (Nm^3 CH_4/tonTVS)*	*BMP (Nm^3 biogas /ton ingestate)*
Belgium	25.50	94.12	319.00	132.00
China	27.45	85.66	319.00	128.43
Colombia	16.00	94.38	297.00	77.32
Denmark	29.10	84.44	509.13	215.69
Germany	25.50	88.24	528.00	204.83
Ireland	29.40	95.24	529.00	255.38
Italy	27.28	87.79	522.04	213.06
Lebanon	18.60.	92.47	350.00	103.79
Mexico	29.70	75.08	545.00	209.54
South korea	21.10	82.46	502.00	150.60
Spain	25.13	72.41	221.50	69.51
United Kindom	26.67	91.25	402.00	168.66
United States	32.10	79.23.	306.00	134.18

An example is the full-scale plant in Tilburg (Netherlands), operating with Organic Fraction of Municipal Solid Waste (OFMSW) in a semi-continuous, high solid, one step, plug-flow type process with biogas yields from 90 m^3/ton fresh garden waste to 150 m^3/ton fresh food waste (de Laclos et al., 1997). Biogas production depends on several factors:

- Size resulting from the pre-treatment;
- Residence time of the biomass inside the reactor;
- Biological stability.

In the Santhià plant after an adaptation time, a specific biogas production of 200 Nm^3 wet biogas per ton of ingestate was reached with an average methane content of 58 %, and a sulphide hydrogen concentration of 500 ppm. This first results id deviating from the data in bibliography and set a new benchmark for the sector also by considering the profitability impact of this kind of infrastructure.

The reason for such performance resides in the pre-treatment exposing the material to a quick degradation, the solid digestion and the heating system and in the working HRT of 28 days. The specific electricity consumption recorded in the pre-treatment section and the digester are respectively 6.6 kWh/t food waste and digester 1.5 kWh/$t_{ingestate}$.

3.8. The Zero Waste and circularity targets

As said, the plant has the ambition to go close as zero waste as possible thus meaning the possibility to divert the total inlet waste from landfill and turn as much waste is possible into energy (Renewable Natural Gas) and reuse all other remaining fraction. To do so as already explained the plant aims to maximize the biogas production, but there are other two targets to consider:

- Minimize the wastewater to be sent to cleaning plant.
- Reuse the plastics rejects to produce a solid recovered fuel (SRF).

The plant is made up by 3 lines (Fig. 4): food waste is delivered to the anaerobic digestion plant which produces biogas and has as reject the sorted-out plastics and the digestate.

The digestate with a TS of 20-22% is suitable to be composted by mixing it with the bulking agent (chopped wood) without undergoing previous water solid split (such separation may be necessary during plant start-up when TS is lower). The composting process harnesses the High Efficiency Biological Treatment technology (HEBioT is a patented Entsorga process) and has a very high evaporation capacity thus allowing the plant to get rid of most of the water. Eventually additional leachates in the plant may be sprayed over the masses in aerobic fermentation an the evaporated as well, only 4 wt.% of the waste throughput is disposed as leachate to cleaning plant. The compost process lasts 30 days and produces a quality compost sold to farmers and mainly use in rice crops. Plastic rejects are extremely expensive if disposed to Energy from Waste plants then it was mandatory to minimize their disposal. The solution is to further aerobically bio-dry such plastic and then mechanically refine the product to get to a high quality SRF in form of a fluff suitable to replace coal in cement kilns.

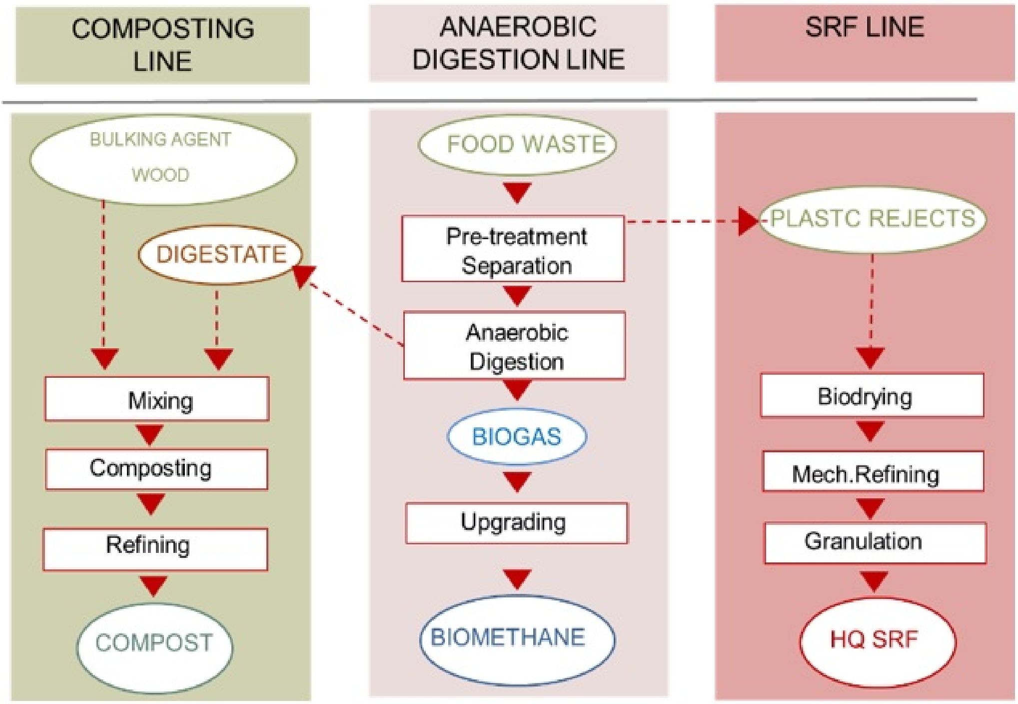


Fig. 3. Block flow diagram

Such SRF 3 wt.% of the throughput, which because of its quality 16-19 MJ/kg and a moisture content of 15-19% can be considered a commodity (according to EN 15359), it has a market value, and its use is very well consolidated in Europe and meets the European environmental policies by triggering a number of environmental benefits. The main benefit is that due to the biogenic content of SRF such fuel can be considered a renewable fuel and every ton of fuel used in replacement of coal triggers about 50% in weigh of CO_2 equivalent diversion, according to IPPC calculation methods (Entsorga Report, 2017).

4. Mass balance

4.1. Quantitative block diagram

In the end, the resulting plant mass balance is the one reported below and shows a minimal amount of rejects to be disposed in landfill or requiring further treatment thus positioning the plant among the ones with highest landfill diversion and maximum gas production.

4.2. Operational data – pretreatment

Plastics output from pre-treatment is around 15 wt. % of treated OFMSW, therefore after leachate realise, with an organic matter dragging of 7 wt. % and a moisture content of 65 wt. %.

The pre-treatment doesn't need water for working but it was possible to feed leachate from the receiving pits into the digester. After an adaptation time, a specific biogas production of 200 Nm^3 wet biogas per ton of ingestate was reached with an average methane content of 58 %, and a sulphide hydrogen concentration of 500 ppm.

4.3. Operational data anaerobic digestion

After an adaptation time, a specific biogas production of 200 Nm^3 wet biogas per ton of ingestate was reached with an average methane content of 58 %, and a sulphide hydrogen concentration of 500 ppm. The working HRT is 28 days. The specific electricity consumption recorded in the pre-treatment section and the digester are respectively 6.6 kWh/t food waste and digester 1.5 kWh/$t_{ingestate}$.

4.4. Environmental Key Performance Index

The reduced amount of leachate sent for external disposal and solids to be sent to landfill by 1 % and 3 % respectively; the latter result achieved through the recovery of the plastic fraction as SRF representing 10 wt. % of the starting waste.

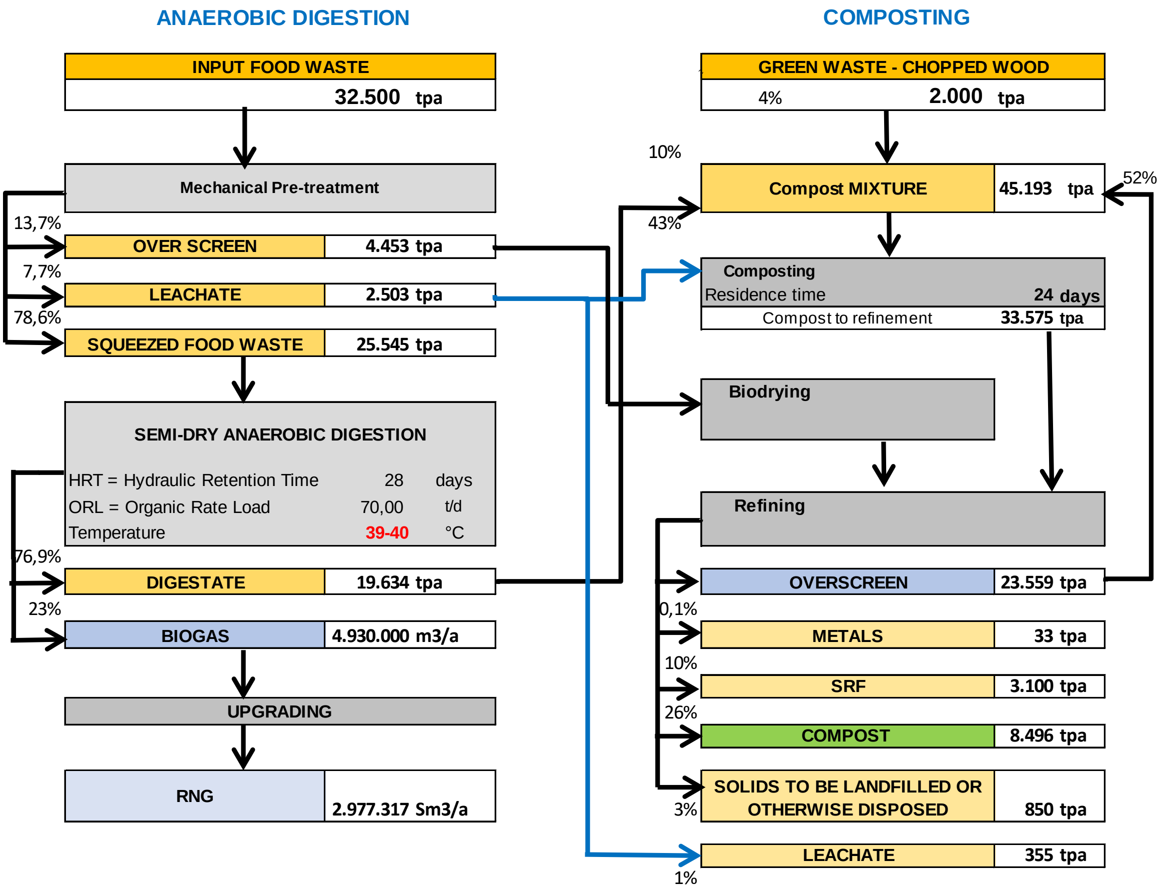


Fig. 4. Block diagram of plant mass balance

5. Conclusions

Every waste treatment plant has its own context and waste. Waste is non-homogeneous, and it is influenced by many variables such as the season, consumption habits, collection methods and policies etc.

Although there are some technical principles and practices which, if correctly applied, can lead to a high-performing plant maximizing energy production, circularity and landfill diversion. Far from having the ambition of being a scientific paper the present document re-set some key performance index with data measured in the field which likely will make the investment in AD plants more appealing from both the environmental and economic point of view. Several of the findings in this research seem to be establishing new standards for anaerobic digestion.

In particular, biogas production of 200 $Nm^3/t_{ingestate}$ may seem particularly significant because, while on the one hand, the designer must take into account different sizing for the gas units in the plant (upgrading, compressors, meters), on the other hand, it produces greater profitability and faster payback.

The achievement of a waste diversion rate of 91% shows how advantageous a plant like this is for the environment and shows how this kind of plant is a key option for the transition from fossil fuels to renewable energy.

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