How to optimize a metropolitan solid waste management system by integrating open data via Geographic Information System

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Abstract

Purpose. A sustainable Metropolitan Solid Waste Management System (MSW-MS) was here developed by integrating demographic, territorial and economic Open Data, through a Geographic Information System (GIS) with the aim of providing a reference for a more sustainable waste management policy in the region.
Methods. A Work Breakdown Structure (WBS) was used to describe work packages required to design the proposed system: investigation on best practices, analysis of Open Data and project constraints, MSW-MS sizing, and MSW-MS assessment. Starting from the actual production and distribution of the waste in Sicily the proposed MSW-MS define a differentiated path to achieve the 50% recovery target established by the European Union while optimizing the production of biogas in an holistic approach where the organic fraction of the waste is co-digested with sludge resulting from the wastewater treatment plant. This scenario is finally compared to the current "landfill" scenario in terms of transportation cost and impacts through the use of the GIS-based model.
Results. All the fluxes of the MSW-MS have been evaluated in terms of fractions of waste produced/treated and energy produced/required. The current WM scenario and new as derived by the MSW-MS are critically compared in terms of transportation costs and related CO_2 emissions
Conclusions. The resulting differences are little significant when compared to all the other relevant components of a sustainable and holistic approach (i.e. landfill requirement reduction, energy saving, CO_2 reduction).
The proposed MSW-MS, to be applied in the three main metropolitan areas of the region, could produce, within an acceptable time frame, a dramatic but positive change in the way wastes are managed in this representative European southern region.

Keywords: holistic, WTE, GIS, transportation, Anaerobic co-digestion.

1 Introduction

Sicily is the largest island of Mediterranean has an area of 25,711 km^2 and a current population of approx. 5 million inhabitants being the most densely populated Mediterranean islands(inhabitants/Km^2). This is due to the presence of the three largest cities in Sicily, which significantly influence the population distribution in the island (Fig. 1). The concentration of population in these large centres have also significantly hindered the chance of applying a sustainable waste management in the island as the several separate collection initiatives applied, in the past, in these cities (i.e. Palermo, Catania Messina but also in Syracuse) have dramatically failed producing a counter-productive message to the population and a consequent vicious circle that in turn has discouraged stakeholders in subverting the historical 90% landfill-based scenario [1]. The great challenge for a proper management of municipal wastes in the region is still to increase the percentage of waste separate collection but also to develop pre-treatment and refining facilities for the collected materials (composting, anaerobic digestion and sorting plants) in order to effectively reduce the percentage of waste disposal into the current MBT-landfills. To win this battle also residual waste flows and non-recyclable materials must be carefully evaluated ensuring the needed capacity of WTE plants and maximizing all the potentials for the full exploitation of the thermal and electric energy produced from these plants. Actually, as the majority of landfills have now almost reached full capacity (June 2017), the Italian government has asked regional authorities to build two WTE plants. Indeed, although fully operational waste-to-energy technologies have been successfully applied worldwide [2], use of these applications remains scarce in the Southern Europe regions, and is subject to strong opposition from an incorrectly informed population**.**

Therefore, the building of new facilities with sufficiently capacity, the application of appropriate technologies, a proper location on the territory - based on an correct analysis of waste flows -and the choice of optimal transportation routes is of paramount importance. Decision makers may benefit by using analytical or simulation tools to address their choices and to share these last with population in order to reduce the strong and diffused resistance to new plants' construction. Specifically, the integration of transportation model with technologies - such as Global Positioning System (GPS), remote sensing, and Geographic Information System -able to link locations to the properties of those locations should provide help decision makers in shifting towards a completely different and holistic approach in the waste management of Europe's Southern regions [3-5].

In the past, the attentions of researchers to this problem was initially addressed to landfill site location. Leao et al. (2001) [6] presented a method to quantify the relationship between demand and supply of suitable land for waste disposal using a GIS. Based on forecasts of population growth, urban sprawl and waste generation, the method allows policy and decision-makers to measure the dimension of the problem of shortage of land into the future.

A GIS optimal routing model was proposed by Ghose et al. (2006) [7]to optimize collection paths for transporting the solid wastes to the landfill. The model uses information on population density, waste generation capacity, road network and types, storage bins and collection vehicles, etc. The model can be used as a decision support tool by Municipal Authorities for efficient management of the daily operations for transporting solid wastes, load balancing within vehicles, managing fuel consumption and generating work schedules for the workers and vehicles.

Also Chang et al. (2007) [8] proposed a Fuzzy Multi-Criteria Decision Analysis (FMCDA) combined with a geospatial analysis in order to select landfill sites. They employed a two-stage analysis synergistically to form a Spatial Decision Support System (SDSS) for MSW management in a fast-growing urban region. The first-stage analysis made use of the GIS thematic maps joined with environmental, biophysical, ecological, and socioeconomic variables and feed the data to the second-stage analysis using the Fuzzy Multi-Criteria Decision Analysis as a tool.

Sumathi et al. (2008) [9] addressed the siting of a new landfill using a MCDA and an overlay analysis using a GIS. Several factors are considered in the siting process including geology, water supply resources, land use, sensitive sites, air quality and groundwater quality. Weights were assigned to each criterion depending upon their relative importance and ratings in accordance with the relative magnitude of impact.

The optimization of waste collection and transportation, through the use of GIS and a 3D route modeling software was studied by Tavares et al. (2008) [10] also in order to minimize fuel consumption. Their model considered the effects of road inclination and vehicle weight and was applied to two different cases: routing waste collection vehicles in the city of Praia, the capital of Cape Verde, and routing the transport of waste from different municipalities of Santiago Island to an incineration plant.

Batool & Ch (2009) [11] paid attention to the determination of total and per capita waste generation in the Metropolitan Lahore area studying its composition, storage, transportation, and disposal in open dumps, the cost of management of the existing system and the proposed improved system using the IWM-2 model and a GIS.

An Analytical Hierarchy Process (AHP) and a GIS were combined by Sener et al. (2010) [12], in order to determine the most suitable landfill site, by examining several criteria, such as geology and hydrogeology, land use, slope, height, aspect and distance from settlements, surface waters, roads, and protected areas (ecological, scientific or historical). Each criterion was evaluated with the aid of AHP and mapped by GIS.

Tavares et al. (2011) [13], in order to siting a municipal solid waste incineration plant, proposed a spatial multi-criteriaevaluation methodology to assess land suitability by combining the AHP to estimate the selected evaluation criteria weights with GIS for spatial data analysis; so they avoided the subjectivity of the judgments of decision makers.

Economopoulou et al. (2013) [14] described a software application capable of formulating alternative optimal MSW management plans, each of which meets a set of constraints reflecting selected objections and/or wishes of local communities. For each alternative plan, the system generates several reports that define the plan, analyze its cost elements and yield an indicative profile of selected types of installations, as well as data files that facilitate the geographic representation of the optimal solution in maps through the use of GIS.

Gbanie et al. (2013) [15] proposed a methodological framework outlining procedures for siting municipal landfill site in developing countries through scientific and engineering principles, social and economic factors. The proposed framework involves a multi-criteria GIS approach that blends two aggregation techniques: Weighted Linear Combination (WLC) and Ordered Weighted Averaging (OWA).

Hatzichristos et al. (2013) [16] used a GIS tools to redesign a waste management service of a certain municipality with the purpose of resource savings. The work concerns the methodology for the redesign of MSW infrastructure and of basic elements. The proposed model includes three stages: delineation of waste collection zones, allocation of trash and of recycling bins and redesign of garbage trucks routes.

Rada et al. (2013) [17] faced a few aspects related to the implementation of a Web-GIS based MSW management system. Their approach is critically analyzed referring to the experience of two Italian case studies and two additional extra-European case studies. Authors stated that the use of Web-GIS with RFID allows to create a parametric and modular system to supply modern solutions based on the operative standards of the Internet.
Zsigraiova et al. (2013) [18] proposed an innovative methodology for the reduction of the operation costs and pollutant emissions involved in the waste collection and transportation. The innovative feature lies in combining vehicle route optimization with that of waste collection scheduling. The optimization process of the routes to be travelled makes recourse to GIS and uses interchangeably two optimization criteria: total spent time and travelled distance.
The literature review highlights as, among the different factors, transportation is viewed as a critical component in an effective solid waste management system, the optimization of which purportedly contributes to social, economic and environmental sustainability. However, transportation issues (costs and related environmental impacts) are at times overestimated when comparing different scenarios, and final stakeholder decisions may be biased by this overestimation. It also appears clear the difficulty of applying a holistic design approach able to integrate the large amount of Open Data now available to designers to the site specific current and prospective conditions of the waste management in a territory. Starting from this evidence, this paper depicts a model to design an integrated Metropolitan Solid Waste Management System (MSW-MS) by combining demographic, territorial and economic Open Data, through a Geographic Information System which is applied in the evaluation of two antagonistic scenarios in Sicily region.

2 Methodology and compared scenarios

Two different scenario are here compared and evaluated also in terms of transportation cost and transportation emissions into the atmosphere: the current scenario in Sicily, mainly based on landfill disposal, and the proposed MSW-MS model developed according to the European Waste Hierarchy principles and to a holistic approach tailored to the specific conditions of the Sicilian territory. The Work Breakdown Structure (WBS), conceived to design the Metropolitan Solid Waste Management System (MSW-MS), is shown in Figure 1

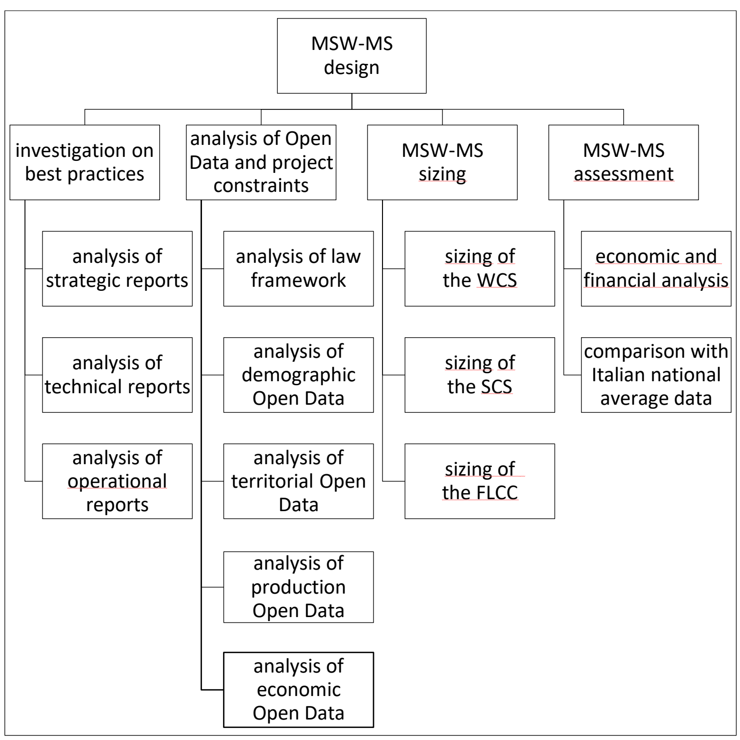
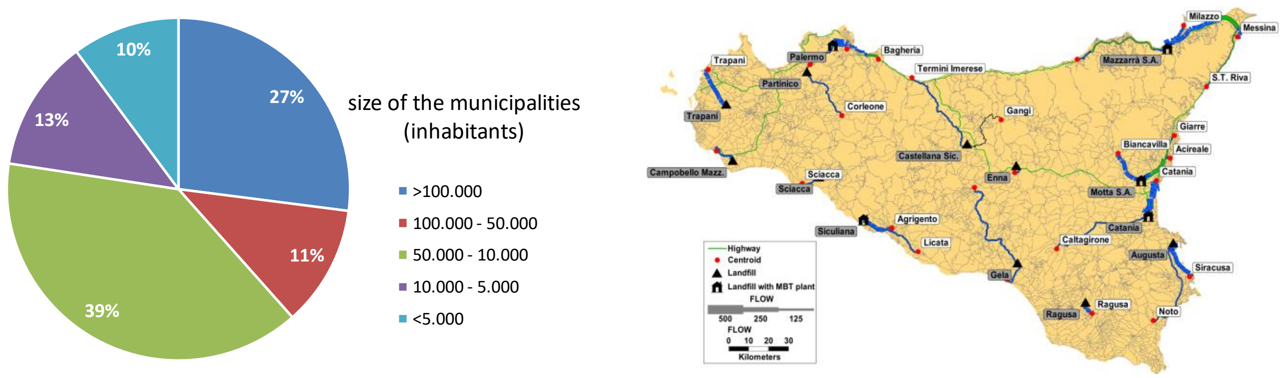


Fig.1: Work Breakdown Structure (WBS) conceived to design the Metropolitan Solid Waste Management System (MSW-MS)

2.1 Landfill scenario (current)

The first considered scenario represents the current waste management situation in Sicily. Separate collection is applied in an inconsistent and scarcely effective manner throughout the island, resulting in a poor recovery rate of about 10%. The residual waste (90%) is still disposed of in landfill. The majority of this residual waste is previously subjected to MBT (in landfills where this process has already been implemented).

In Sicily, the main landfills are concentrated in four geographic areas: Palermo, Catania, Messina and Agrigento (Fig. 1 A) with the main volumetric capacities concentrated in the Metropolitan area of Catania. Most of these landfills apply an MBT pre-treatment including a mechanical shredding, sieving and sorting process with recovery of metallic fractions (1% of total waste), which give rise to the separation by size of a "dry fraction" and a "wet fraction". However due to the insufficient design of the MBT plants, to the intrinsic physical and mechanical limitations of the process and to the often excessive imposed waste flux, the wet fraction containing most of the readily biodegradable components (but also lot of impurities) is frequently poorly bio-stabilized and always sent to landfill. Respirometric test requirements for landfilling this fraction are generally met but the result in terms of lowering its environmental burden is questionable as it is obtained more by drying the waste through forced aeration rather than by effectively stabilizing the organic component. This is confirmed by the undesired increase in biogas production as an effect of the shredding process that enhance biological activity. Likewise, following an additional low-efficiency sorting process aimed at recovering a small amount of plastics (1-2% of total waste), the dry fraction is also sent to the same landfill. As a consequence, the overall MBT pre-treatment that costs around 20 €/ton merely separates two fluxes and subsequently recombines the two in the landfill after a partial bio-stabilization and scarcely significant recovery outcome. To date, only a few composting plants have been operational over the entire regional territory; however, market demand for the resulting compost is poor and the product is often distributed to farmers free of charge. Sludge from all the wastewater treatment plan are also sent landfill after an (usually) aerobic stabilization, with the high related energy cost and CO_2 emissions to the atmosphere.



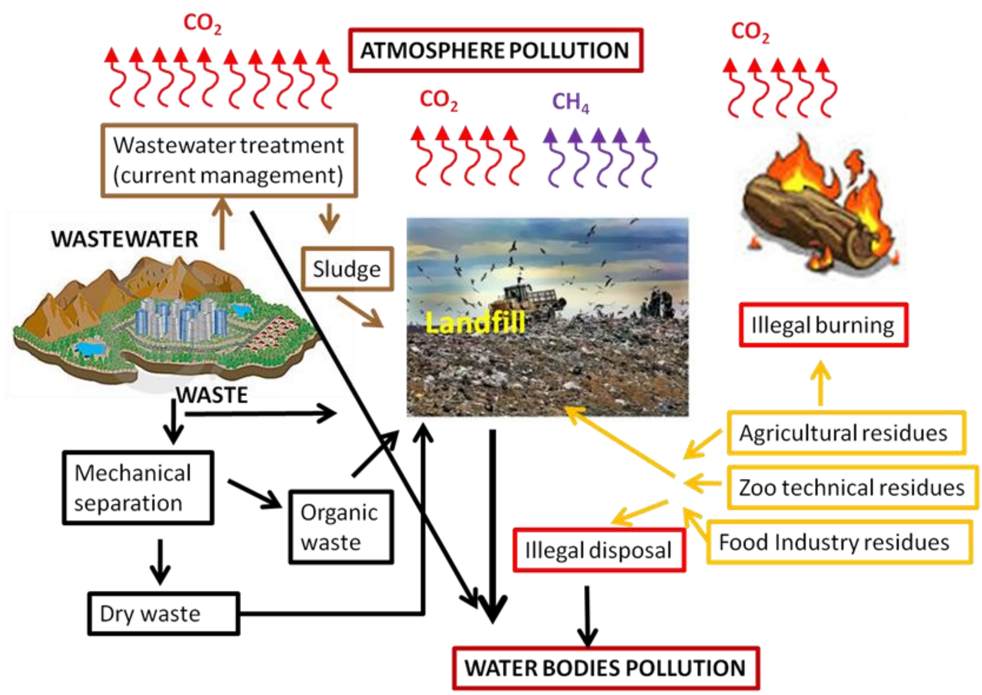
A) B)

Fig.2: A) Distribution of the population according to size of municipalities and B) current landfills distribution in Sicily

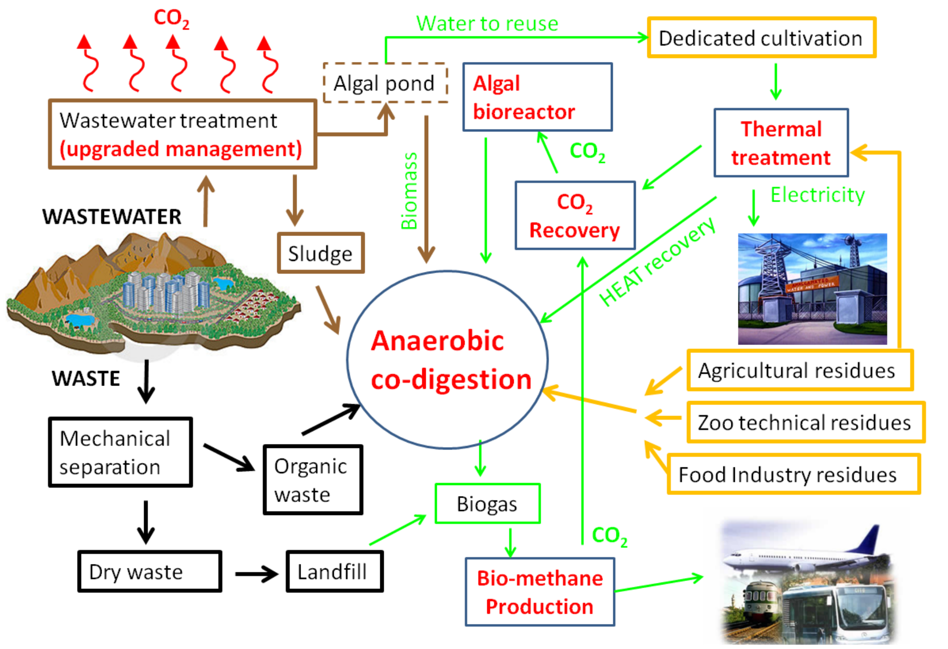
2.2 AD-optimized holistic scenario for enhanced energy exploitation of the organic fractions from urban wastes and WWTP sludge

In the alternative scenario, based on the proposed MSW-MS, the residual waste plus scraps would be treated in a new and large WTE plant located in the industrial area of Catania(with the purpose of minimizing transportation costs) and specifically close to Wastewater treatment plant in a view of enhancing a potential industrial symbiosis between the WTE plant and the WWTP. With these specific conditions the proposed scenario focus on the treatment of organic waste from separate collection by means of anaerobic co-digestion with the sludge from the WWTP. The proposed symbiosis allows to exploit the existing (upgraded) anaerobic digesters of the WWTP to co-digest the waste organic fraction and sludge from the water treatment, to use part of the thermal energy produced by the WTE plant to heat the digester, and to use the same WTE plant for the final disposal of dried sludge, thus exploiting its residual energy. The chance of recovering a small part of the heat from the WTE process would contribute towards enhancing biogas production through thermophilic AD so increasing recovery efficiencies of both the WTE and Anaerobic Digestion (AD) plants. Full heat recovery from WTE processes in regions such as Sicily is considered particularly challenging due

to the warm climate and the relative lower demand for heat compared to northern regions, although district heating and/or cooling networks could be carefully evaluated to fulfill the overall need of the industrial area surrounding the WTE plants.Within the proposed holistic scenario a shift in the paradigm of wastewater and sludge management for the other WWTPs serving the small tows surrounding the main centre is also proposed. A modification in the their water treatment line management should involve the adoption of higher loading factors, the reduction of the sludge return flows and, consequently, of sludge age and oxidation level so to significantly lower energy consumption and CO_2 emissions (both in the treatment phase and in the production of the required energy). A further modification in the sludge treatment line management by locally dehydrating (by centrifugation) the “fresher” sludge (without any further treatment) from each small plant and directly transporting it to the centralized anaerobic co-digestion plant. A sludge less oxidized, will allow a higher energy recovery (i.e. biogas production) in the co-digestion process.
This management model could also be included in a broader perspective, especially in Mediterranean areas where renewable energy contribution is still too focused on wind and solar energy and few woody biomass cogeneration plants by involving farmers, local companies and authorities in setting new paths for selected organic residues from farms and food-industry towards a correct and controlled energy recovery (through anaerobic co-digestion) so diverting these wastes from the current, widespread uncontrolled and illegal disposal or unauthorized combustion.
Finally, the proposed scenario could promote the first substantial integration of bio-methane from anaerobic digestion and build the conditions for a potential increase of biomethane-fuelled vehicles (in public transport) with the consequent reduction of traditional pollutant emissions as produced by the current circulating vehicles.
Of course many barriers still exists to the prospected establishment of biogas potentials exploitation, such as public reluctance to waste treatment plants, little diffusion and knowledge of anaerobic plants, consequent slowness of the authorization process, difficulties in the access to a local heat market and financing (venture capital), instability in the incentive framework (taxes and local or national subsidies) and also the lack of data on the potential mass and energy balance.



A)



B)

Fig. 3: Pictorial representation of the two evaluated scenarios A) current and B) proposed scenario for waste management in the metropolitan area of Catania

The mass balance of the proposed MSW-MS is based on a separate collection target of 65%. Actual recovery rate is obtained by evaluating the scrap from the waste sorting treatment for each category of waste. Scraps are then added to residual waste (35%), which should be forwarded to the WTE plant. It is however supposed that a small part of this waste can be still treated in the MBT plants(25%of the residual fraction - i.e. 12% of total produced waste)for the production of Solid Recovered Fuel (SRF) to be used in specific plants (e.g. cement plants), although the chance of further recovery is low having already obtained most of the valuable part of the waste from the separate collection route.

2.3 GIS-based model application for transportation cost evaluation

The GIS-based model application focused on the analysis of transportation of solid wastes in the metropolitan area of Catania including the main Centre and all the surrounding small towns and fractions. Definition of unit transportation cost is not easy due to the number of variables involved that are not always easily quantifiable in monetary terms. In the study, the cost of transportation was calculated as the sum of different cost components related to the distance traveled, personnel, and the vehicle utilized to collect waste, including fuel costs, tire costs, road tax and truck maintenance costs. Using the above specific costs and assuming an average speed of 30 km/ton the urban road network and 55 km/ton the extra-urban road network, a unit transportation cost of 0.11 €/ton-km was considered (0.14 €/ton-km in the case of separate collection). Finally a 140 g amount of CO_2 emitted per ton of waste and per km of transportation was considered to provide only a partial indicator of the impact of transportation on the environment [19].

3 Results

3.1 MSW-MS design and sizing

On the basis of the positive results obtained in small Sicilian towns and according to the experiences in other areas of the country [20], different separate collection targets were hypothesized for the main centre of the metropolitan area and the surrounding towns, for each of the waste fractions [21]. From this analysis it comes out as a 50-60% recovery target can be easily achieved in the small towns and about a 10-15 % target in centre of the metropolitan area, leading to the overall target of 65% recovery for the entire metropolitan area (about 10^6 inhabitants with a mean daily waste production of 1,5 kg per capita per day). Results from the analysis are represented in Table 1 where the scrap produced by the selection treatment of each single fraction is consequently evaluated as a percentage of the total scrap produced as well as of the entire amount of the waste.

Table 1 - Separate collection fractions and scraps resulting from their treatment for each categories of wastes

Fractions	**Percentage of each fractions with respect to the overall waste (%)**	**Scrap produced by the single fraction selection treatment (%)**	**Percentage of the single scrap production with respect to the overall scrap (%)**	**Percentage of the single scrap production with respect to the overall waste**
Green	13.94	15.00	3.22	2.09
Organics	14.07	35.00	7.57	4.92
Glass	0.30	0.00	0.00	0.00
Paper	13.94	15.00	3.22	2.09
Plastic	4.60	50.00	3.54	2.30
Ferrous Materials	1.21	0.00	0.00	0.00
Aluminum	0,00	0.00	0.00	0.00
Wood	3.46	15.00	0.80	0.52
Multimaterial Glass	9.88	0.00	0.00	0.00
Multimaterial Metals	0.63	0.00	0.00	0.00
Waste Equipment	1.00	0.00	0.00	0.00
Other SC	0.78	50.00	0.60	0.39
Bulky Recovery	1.21	50.00	0.93	0.61
Total Differentiated	**65.00**	**-**	**19.9**	**12.9**
Residual Waste				
Urban Refusal	26.90	-		26.90
Bulky Residues	5.09	-		5.09
Road Sweeping	2.99	-		2.99
Total Unsorted Collection	**35.00**	-		**35**
TOTAL Separate + Unsorted	**100.00**	-	-	**47.9**

Considering all the scraps originated from the sorting activity, a final overall recovery rate corresponding to 52,1% of total waste produced in area is considered for the following analysis and sizing of the system.

The resulting fluxes have been estimated for the main waste fractions(recycled, organic, residual) and are shown in Fig.4. Based on the previous analysis, approximately 315 tons/d of organic waste can be addressed to AD for biogas production, approx. 465 tons/d can be recycled as Secondary Raw Materials (SRM) and approx.720 tons/d of residual waste and scraps can be sent to the WTE treatment plant. It should be noted that the resulting size of WTE plants in this scenario (263.000 t/y) should satisfies the R1 criterion included in the Waste Framework Directive 2008/98/EC [22], without the need for heat recovery, thus determining, for the hypothesized WTE processes, the role of "recovery operation" (R1, Annex II) rather than "disposal operation" (D10, Annex I). A Lower Heating Value of 10,736 MJ/t is used consistent with the values from other equivalent plants operating in Italy is adopted to calculate the produced energy that is 7,7 GJ[21].By considering a thermal yield of 58% and an electricity yield of 26%,the thermal energy produced is 4,476 GJ, while the amount of electricity produced is equal to 2,006 GJ. It is also estimated a combustion residues production of 15% of the residual waste (108 tons) but it is assumed that all bottom ash from the process could be recovered, thus reducing the need for the landfilling to only 1-2% of total waste produced [21]. The per-capita sludge production on dry basis (gr/pe d) was estimated as 80 gr /ab d (on dry basis), consequently the total production of dry sludge for the case in study is 43.5 ton/d. The waste activated sludge produced during the treatment process is supposed to be thickened at a concentration of solids in the range7 – 8% and co-treated with organic fraction of municipal solid wastes (OF-MSW) into the anaerobic digester. The OF-MSW can be firstly shredded and screened using a trommel screen after metals removal. Low magnetic permeability materials can be removed and the substrate can be shredded using a blade hammer(15 mm cut size). The biomass is then sent to a wet mixer/separator where the total solid content is diluted using the waste activated sludge coming from the waste water treatment plant. The floating residual materials and bottom residues are withdrawn and sent to the WTE process. The mixture is then sent to the digester by a shredding pump, together with the rest of the excess sludge. The digester is supposed to operate at a total solids concentration of the mixture (sludge + OF-MSW) of 13% TS so to achieve the semi-dry operating conditions. With respect to the temperature, thermophilic (55 °C) operating condition are easily achieved thanks to the heat provided by the WTE plant. The digester volume is calculated multiplying the mass flow rate in input (Sludge + OF-MSW) times the Hydraulic Retention Time, which is assumed to be 20 days. Given a SGP of 0.25 for sludge and 0.8 for a good quality OF-MSW, basing on the sludge and biowaste inlet streams in our model, a mean SGP value of 0.65m^3 biogas/kg TVS for thermophilic condition is assumed [24]. The heat requirement of sludge digesters generally depends on the temperature difference between incoming sludge flow and digester; heat losses through reactor walls, floor and roof and heat losses that might occur through piping and biogas production. By appropriate construction, the heat losses in the piping can be minimized to the point where such losses can be neglected [25]. Considering a prudential feeding average temperature of 12 °C and the thermophilic operating conditions the heating requirements have been estimated. Complete results from the described estimates are reported in Table 2.

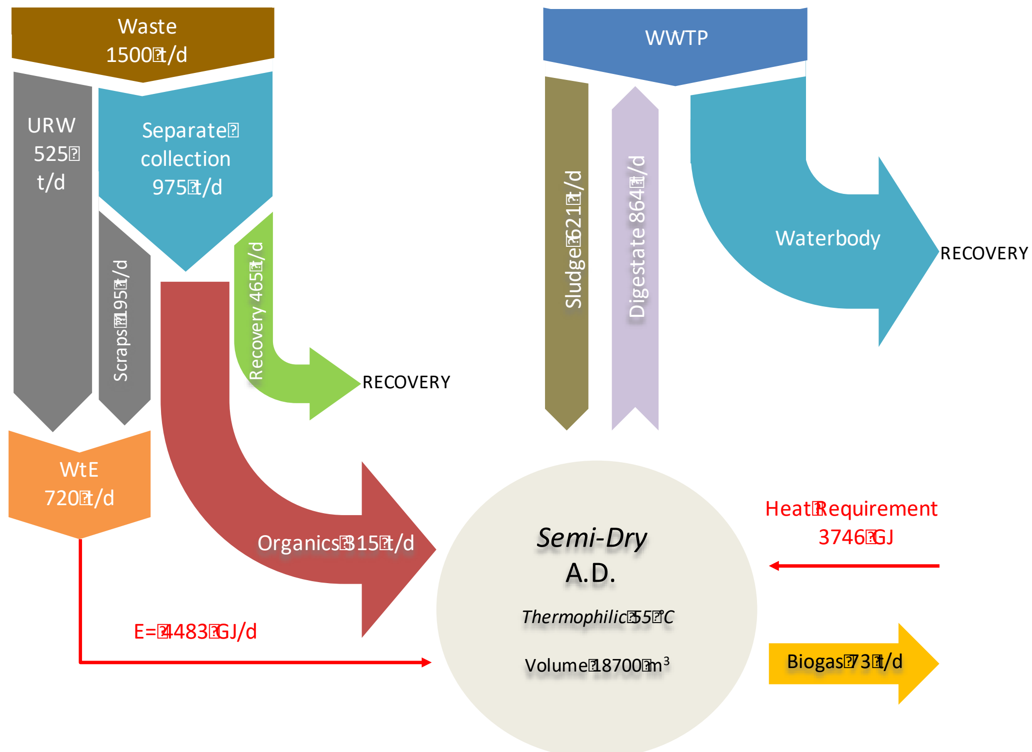


Fig. 4 Main fluxes in the proposed "AD"-optimized waste management scenarios for the metropolitan area of Catania

Tab. 2 Maindesign parameters for the proposed anaerobic digestion system

Parameter	Value	U.M.
OF-MSW	315	t/d
OF-MSW $_{TS}$	25	%
OF-MSW $_{TVS}$	80	%
Sludge	621	t/d
Sludge $_{TS}$	7	%
Sludge $_{TVS}$	70	%
Mixture	937	t/d
Mixture $_{TS}$	13	%
Digester Volume	18,728	m^3
OL *OF-MSW*	63	t_{TSV}/d
OL sludge	30	t_{TSV}/d
OL Mixture	93	t_{TSV}/d
OLR	4.9	kg_{TSV}/m^3 d
SGP	0.65	m^3biogas/kg $_{TVS}$
T_{feed}Thermophilic	12	°C
T_{out}Thermophilic	35	°C
v° BIOGAS	60,752	m^3biogas/d
BIOGAS	73	t/d
DIGESTATE	864	t/d
Heat Requirement	3746	GJ

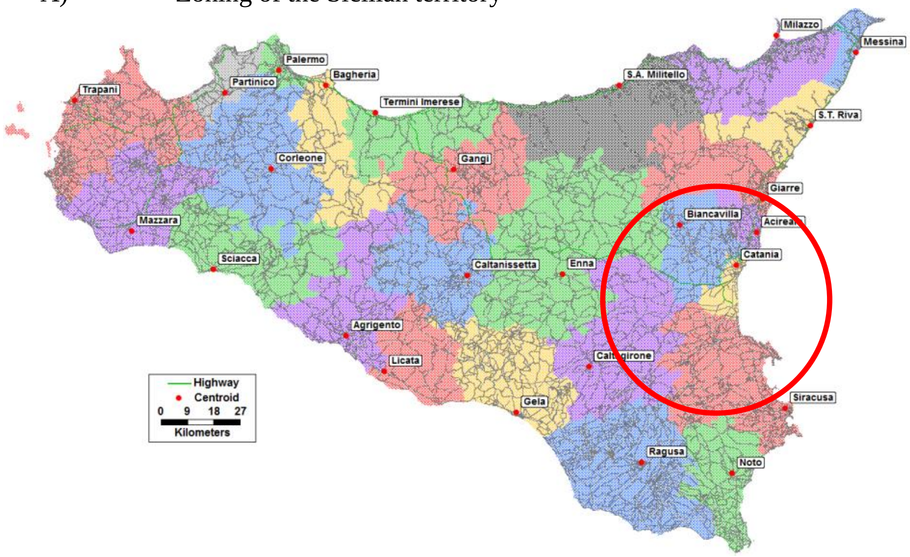
3.2 GIS-based model application and transportation cost comparison between the scenarios

The optimization model was implemented to yield the graphic processing (Fig.5) of optimized daily waste flows (tons/day) and respective costs from waste generation nodes to the treatment and disposal plants (Tab.3). The cost (5580 €/day) of transportation for the disposal of waste in landfills (the current scenario) is lower than the alternative scenario. This is due to the straightforward transportation to landfill of about the 90% of the total waste produced

However, this scenario is no longer sustainable. Land is becoming an important and scarce resource on the island and the use of space close to more urbanized areas by landfills is a huge problem. It should be pointed out that the majority of existing landfill sites will exceed their life expectancy within the next few years, and it will become even more difficult to identify new sites due to increasing public opposition. A reduction of required landfill volumes is thus strongly desirable with the aim of lessening environmental impact and implementing a truly integrated waste management system in line with European waste management policies.

The alternative Scenario has a higher cost of transportation (7350 €/day) compared to the current one, as it comprises the increased transportation due to separate collection routes. However, this scenario includes main environmental benefit and avoid infraction procedure from the European Commission to have not reduced landfills in the region. Finally, considering overall unit disposal costs per day (ranging from 80 to 120 €/ton depending on the landfill and the presence of MBT) and comparing these with unit transportation costs for the same tonnage of waste over 100 km (from 11 up to 15 €), it is clearly evident that transportation impinges on the overall management costs to a small extent. and should not weigh so heavily on the choices of the regional waste management plant. Experiences from more environmentally sustainable countries [26,27] confirm how a holistic approach should be adopted in order to avoid inappropriate solutions, increase energy recovery and minimize environmental issued associated with landfilling.

A) Zoning of the Sicilian territory



B) Analysis of transportation fluxes in the proposed Scenario for a future sustainable waste management in Sicily

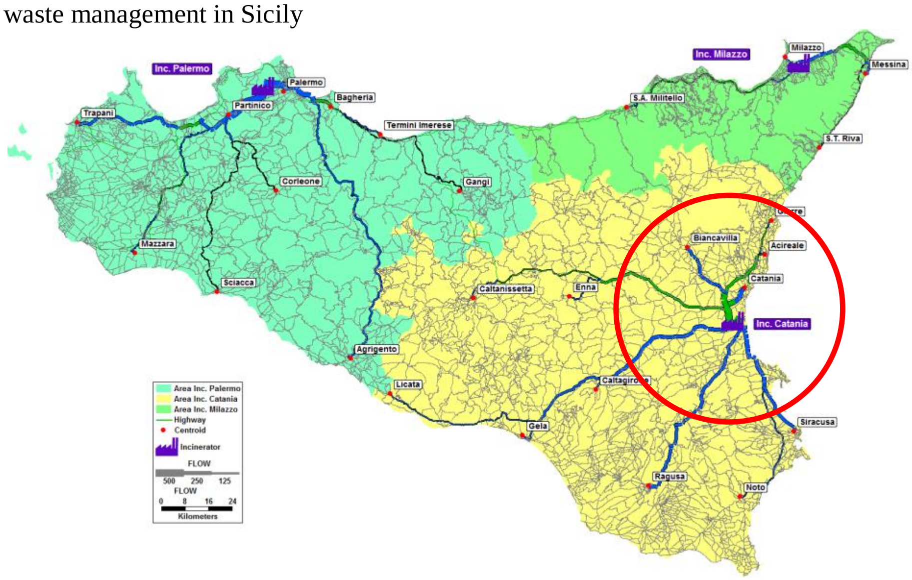


Fig.5 A) Zoning of the Sicilian territory with regard to distribution of waste generation; B) "AD"- optimized scenario for waste management in Sicily with three large WTE plants located near the WWTP;

Tab. 3 Comparison between the current and proposed waste management scenarios for the metropolitan area of Catania

Scenario	Separate collection (%)	Recovery (%)	Composting plants[1] (%)	AD (%)	MBT (%)	WTE (%)	Landfill (%)	Total Transportation cost (€/day)	CO_2 emissions (Kg/day)
Current	15	12	5	0	90[2]	0	88	5580	6510
Expected	65	52	0	20[1]	0	48	2[3]	7350	8400

[1]included in recovery value. [2] MBT, receiving all residual waste is considered here only as pretreatment before landfilling (recovery = 2% is included in the overall recovery value); [3]output of WTE treatment considering the full recovery of bottom ash.

4 Conclusions

Although European Commission Waste Directives have established a mandatory increase in waste recovery rate and the need for residual waste disposal with energy recovery to produce a significant reduction of landfill disposal municipal solid waste management is still a major concern for regional authorities and planners in Sicily. Several financial, political and environmental issues complicate the decision-making process in the region.

This study has confirmed the importance of GIS-based tools in expediting the analysis of a huge amount of spatial and aspatial data and allowing the correct evaluation of transportation-related costs and environmental burden when evaluating the location of facilities for a correct waste management planning. The specific application of this tool to the Sicilian context, demonstrated the ease of comparing completely different scenarios to assess transportation costs and related impacts in terms of CO_2 emissions. The results obtained have highlighted how transportation costs for the scenarios investigated were considerably less important compared to the costs of waste treatment and disposal and should not be over-emphasized or accentuated in order to influence public acceptance on the location, size and typology of facilities, which should rather be defined in line with a more holistic approach.

Although the present analysis has not evidenced significant differences in waste transportation costs between the two compared scenarios the application of the proposed "AD" scenario to large metropolitan areas including different and site-specific approaches to populations in the main centre and the surrounding small fractions and towns,could significantly help waste management companies and stakeholders shifting, from the current, totally unsustainable, low rate-recycling scenario to a more sustainable ones based on a proper management of both the organic and the residual waste fractions. Co-digestion of organic waste fraction with other organic residues from the territory could be further promoted as an alternative path able to mitigate the present high environmental impacts (CO_2 and CH_4 emissions from aerobic treatment and landfill) while recovering a significant amount of renewable energy that is currently “wasted”. The introduction of anaerobic digestions as an effective stabilization process and the consequent unpleasant odorous emissions mitigation could also represent a key factor in public perception and acceptance of upgraded or new plants for waste treatment.

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