Waste-Water-Energy nexus: a feasible, sustainable approach in climate-change affected Mediterranean regions

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Suitability map for waste-to-energy plant location

Scarlat et al. 2019 Status and Opportunities for Energy Recovery from Municipal Solid Waste in Europe
Mediterranean Drought conditions areas
Issue: the diffusion of uncompromising approach

End of an error?
Was does not exist, you can recycle everything, if not it is a design mistake and you must correct it.
Refusal of any Waste treatment Plants (but WtE is first in line)
Issue: Non Recyclable waste
Issue: Non Recyclable waste
Issue: Non Recyclable waste
Issue: how many cycles – some scientific and public (?) concern
Issue: innovation in new composite materials versus potential recycling rate
Issue: ‘Social behaviour’
Door to door collection
(consierge+internal space)
Door to door
(consierge+internal space)
Issue: scraps from plastic waste selection

up to 50%
Scraps from composting up to 20%
Issues: we still have the unsorted waste (‘social behaviour’).
Circular economy is a fundamental part of the solution in waste management but…..

SUSTAINABLE Circular ECONOMY
Once we made the perfect door to door separate waste collection....
How far from the goal are we yet?

230 cm

90 cm
Two simple calculations: %
Separate collection VS Recycling

SC 75-80% (when???)

60-65% recycling

20-25% (unsorted)

32-38%

12-13% (Scraps)
Two simple calculations: %
Separate collection VS Recycling

SC 65-70% (soon???)

50-60% recycling

30-35% (unsorted)

40-48%

10-13% (Scraps)
How to manage Residual waste (unsorted + scraps)????
The first fork..

Unsorted waste 35%
Separate collection 65%
Scraps 13%
To selection 52% new materials
RESIDUAL 47.9%

????????
Residual waste to landfill (less than 10% at 2035)

- Waste 100%
- Unsorted waste 35%
- Separate collection 65%
- Scraps 13%
- To selection
  - 52% new materials
- Landfill 47.9%
- Leachate
Accepting it.... really the first step
Management Alternatives

Unsorted waste 35%
Separate collection 65%
Waste 100%

To selection
52% new materials

Landfill 47.9%
Leachate

WtE 47.9%
Recycling 14%
Energy

LANDFILL 3%

<10%

NO WtE
NO Landfill ....is there any other way?

Residual waste from 65% separate collection
48Kg over 100 kg
can go to.....
The third way… abroad

Economic losses… and RESILIENCE losses
The risks of the waste global market

How China's foreign waste ban has spurred the recycling industry
Fires at waste management plants in Italy

Rifiuti, in Lombardia un incendio al mese: «Inquinare è un business, ora la terra dei fuochi è qui»

Quattro roghi su 10 si verificano al Nord, nell'ultimo anno in Lombardia è divampato un incendio al mese. Milano, Brescia e Pavia le provincie più colpite

Incendi e spazzatura, tutta l'Italia è come la Terra dei fuochi

Negli ultimi tre anni si contano 290 incendi in impianti di rifiuti e recuperi dei rifiuti. La maggior parte delle regioni italiane. "Il rifiuto meno è il mese più caldo", si sente in una intersezione. Le preoccupazioni della relazione della Commissione parlamentare d'inchiesta sui rifiuti

Luca Rinaldi
Context and open issues: climate change and drought

Italy drought: 11 regions poised for state of emergency

The River Po at Linarolo in Lombardy has shrunk considerably

Eleven of Italy’s 20 regions are set to ask for a state of emergency to be declared in order to help tackle the ongoing drought.
Context and open issues: High impacts from discharges and zero wastewater reuse
Context and open issues: sludge management
HOW to change the waste/wastewater management paradigm in SouthEurope regions?

The term 'symbiosis' builds on the notion of mutualism in biological communities where at least two otherwise unrelated species exchange materials, energy, or information in a mutually beneficial manner.
The “Symbiosis Approach” is evaluated on the Metropolitan Area of Catania plus the provinces of Enna, Siracusa and Ragusa

It considers 2 million p.e. in terms of waste production and 545,000 p.e. in terms of the WWTP capacity
A water-waste-energy nexus approach to bridge the sustainability gap in landfill-based waste management regions

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Landfill
Leachate

ABSTRACT

The present paper, evaluating the feasibility of the water cycle are not fully utilized in the current landfill-based waste management systems. The huge amount of wastewater and biogas currently produced by landfills cannot be reused or recycled. Therefore, a possible solution could be the integration of the water-waste-energy nexus into landfills. This integration would allow a better use of the resources and a reduction of the environmental impact of landfills. The main benefits of this approach are an increased energy production, reduced greenhouse gas emissions, and improved water quality. The drawbacks are the increased costs of the equipment and the complexity of the operation. A comparative analysis of the three scenarios (A, B, and C) is presented in the paper. Scenario A is the current landfill system, Scenario B is the recycling and composting system, and Scenario C is the industrial symbiosis system. The results show that Scenario C is the most sustainable option, as it reduces the costs and environmental impacts of the current system. Consequently, the implementation of the water-waste-energy nexus into landfills could be a valuable tool to bridge the sustainability gap in the waste management sector.
**Energy**

A reduction in global impacts through a waste-wastewater-energy nexus: a life cycle assessment

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Comparison of three scenarios

- **SCENARIO A (current)**
  - WASTE (Unsorted, Separate Collection 30%)
  - WASTEWATER
  - WWTP
  - Recycling and recovery
  - Landfill

- **SCENARIO B (2030)**
  - WASTE (Separate Collection 68%)
  - WASTEWATER
  - WWTP
  - Recycling and recovery
  - Landfill

- **SCENARIO C (2030)**
  - WASTE (Separate Collection 68%)
  - WASTEWATER
  - WWTP
  - Recycling and recovery
  - Landfill

**Key Environmental Aspects**
- Recycled energy
- CO₂ emissions
- Air emissions
- CH₄ emissions
- VOC emissions
- Water bodies discharge
- Sludge
- Organics
- Bottom ashes
- Residuals
- Inertized APC residues
- Bio-methane upgrade

Emissions and recycling pathways are highlighted in the diagram, showing the environmental impact and sustainability measures for each scenario.
Symbiotic exchanges

1. Part of the heat generated by waste-to-energy, suitably commensurate through a well-dimensioned management of steam spills, can be used, also in semi arid climate regions to carry out the AD in the thermophilic phase reducing digestion times and volumes, increasing the biogas production yield with an advantage that also affects the greater efficiency of sludge digestion compared to more traditional mesophilic processes.
Symbiotic exchanges

2. Also the recovery of the energy content of OFMSW is maximized as it is no longer necessary to burn, in the boiler, part of the biogas produced by the same process. The heat is now supplied by the treatment of the residual fraction of MSW in the WtE plant. The biogas produced can be totally converted into biomethane thus maximizing any economic incentives.
Symbiotic exchanges

3. Energy demand for the treatment of OF waste is severely reduced, leaving only the minimum residual maturation phase to the much more expensive energy-consuming composting with an advantage in terms of direct and indirect CO₂ emissions (for energy production) while still producing quality compost.
Symbiotic exchanges

4. Part of the heat from waste-to-energy could also be used in the process of converting biogas into biomethane, reducing the costs for its use in public transportation and waste collection trucks, increasing the benefits of circularity for the territory and further reducing GHG emissions;
Symbiotic exchanges

5. Part of the heat from waste-to-energy can be used to pre-drying the dewatered digestates (sludge of even both) with a view to their energy recovery, in a dedicated line of the waste-to-energy plant, which also collects contributions from other smaller nearby plants, to ensure recovery of phosphorus from the ashes and eliminate the problem of final disposal (ZERO DISCHARGE).
Symbiotic exchanges

6. The electricity produced by the WtE plant can be partially used (a few percentage units) to support the tertiary treatment phase and pumping of the treated wastewater to the agricultural areas in order to make the cost of the treated wastewater competitive, guaranteeing its full reuse avoiding that the concentrated load is discharged into water bodies with the related impacts, especially in islands and coastal areas (ZERO DISCHARGE GOAL). The huge amount of remaining electricity can go to the market.
Symbiotic exchanges

7. A further part of the electricity produced by the WtE plant could be used to support the entire wastewater treatment process in full view of industrial symbiosis (Almost ZERO CO₂ Emissions Goal).

- The oxidation phase in the water line should in any case be conducted as a classic scheme with a high load to minimize energy consumption, taking into account subsequent reuse also through a limitation of denitrification.
Symbiotic exchanges

8. Part of the purified effluent can be used as cooling water for the waste-to-energy plant, saving a precious resource for other uses and increasing the overall circularity of the proposed system.
Symbiotic exchanges

9. The residual fraction and non-recyclable waste are reduced in volume (about 10%) by reducing the landfill requirement and the consequent impacts.
Industrial Symbiosis scenario

**Symbiotic exchanges**

10. Thanks to the **recovery of bottom ashes** in construction materials, the **reduction of waste to be disposed of in landfills** could be further limited to only inertized fly ash (approximately 2-4% of the total waste, in full **compliance** with the **European directives** (which set the limit of 10% by **2035**)). This allows to **increase the overall recycling of materials** (+5-10%) of the total waste depending on the residual portion) - significantly increasing the circularity of the entire system **helping to respect Recycling EU Directives**.
11. Part of the heat from WtE can be used to support surrounding industries (existing or wishing to enter the industrial district) by exploiting the residual heat at advantageous conditions for their processes (e.g. agri-food process industry), in addition to any heating and cooling needs, in full view of industrial symbiosis with a consequent reduction of their CO₂ emissions.

12. Part of the heat from WtE can also be used to pre-drying biomasses from the agricultural sector before their energy recovery in the same waste-to-energy plant, reducing disposal problems;
Symbiotic exchanges

13. A part of the CO$_2$ produced by the conversion process into biomethane and/or contained in the fumes of the waste-to-energy plant could be recovered (e.g. converted into algal biomass to be used for high added value products).
14. The liquid fraction of the digestate can be recirculated to the WWTP as effluent, greatly reducing management costs (with direct/indirect recovery of nutrients).

15. The composted digestate and the wastewater contribute to increasing the agricultural yield by favoring a closure of the organic cycle.
A rough energy balance

- Energy required for the WWTP (year) 9,9 GWh
- Energy required for tertiary treatment + pumping (year) 20,2 GWh
- WtE Electricity production (year) 452,6 GWh
- WtE Heat production (year) 726,1 GWh
- Heat requirement for sludge digestion (year) 14,2 GWh
- Heat requirement for sludge drying (year) 29 GWh
- Heat requirement for OF digestion (year) 19,4 GWh
- Heat requirement for digestate drying (year) 112 GWh
- Other Companies (district heating and cooling)
Life Cycle Assessment

**Step 1:** Goal and scope definition

**Step 2:** Inventory analysis (LCI)

**Step 3:** Impact analysis (LCA)

**Step 4:** Interpretation

Life-cycle thinking

**Sustainable Circular Economy**

- Impact assessment method: Product Environmental Footprint (PEF) → **climate change**
- Software: SimaPro 9.1.0.7
- Database: Ecoinvent 3
GOAL:
Comparison of three scenarios:

- current scenario (A)
- future scenario (B)
- Improved future scenario by symbiosis (C): holistic approach fully exploiting the water-waste-energy nexus

FUNCTIONAL UNIT:
- Annual production of MSW in the reference metropolitan area
- Annual production of urban wastewater in the reference metropolitan area
System boundaries of the future scenario A

**System boundaries - Scenario A**

- **Wastewater**
  - WWTP
  - Pre-thikening
  - Anaerobic digestion
  - Dyehydration
  - MBT
  - Landfill
  - CHP
  - Electric Energy
  - Polyelectrolyte

- **Organic**
  - Sludge
  - Treated water
  - Composting
  - Scrap
  - Biogas (60% CH₄)
  - Electric Energy
  - Diesel
  - Thermal Energy

- **Unsorted**
  - MBT
  - Leachate
  - Metals to recovery
  - Electric Energy
  - Scraps
  - Biogas (50% CH₄)

- **Municipal solid waste**
  - Paper, plastic, glass, metals, wood, textiles, RAEE, swiper, other..
  - Selection
  - Recycling
  - Recycled Materials
  - Landfill
  - Electric Energy
  - Leachate

- **Separate collection 30%**
  - Electric Energy
  - Emissions
  - Environmental emissions
System boundaries of the future scenario B

Valutazione di sostenibilità ambientale di sistemi integrati per la gestione di acque reflue e rifiuti

Separate collection 68%

Wastewater

WWTP

Electric Energy

Polyelectrolyte

Electric Energy

Heat

Anaerobic digestion

Dehydration

Electric Energy

Polyelectrolyte

Supernatant

CHP

Electric Energy

Emissions

Environmental emissions

Organic

Municipal solid waste

paper, plastic, glass, metals, wood, textiles, RAEE, swiper, other...

Electric Energy

Selection

Recycling

Recycled Materials

Landfill

Plasmix a WtE

Leachate

Biogas (50% CH₄)

Electric Energy

Thermal Energy

Emissions

Biogas (60% CH₄)

Emissions

Recycled Materials

Other ...
The dotted processes are alternative sub-scenarios; C1: Digestate-to-Compost (DtC); C2: Digestate-to-WtE (DtWtE).
Contributions of the macro-processes to the total value of each indicator. (A, current scenario; B, future scenario; C, future symbiosis scenario in the DtWtE option).
Contribution analysis: a) Climate Change
Contribution analysis: a) Climate Change; b) Ecotoxicity freshwater; c) Resource Use, mineral and metals; d) Resource Use, fossil.
Take Home (Chania) Message
Recycling and WtE are complementary to divert waste from landfill