AUTH

LHTEE

# Managing and recycling bio-waste in Greece through the implementation of a developed circular economy system


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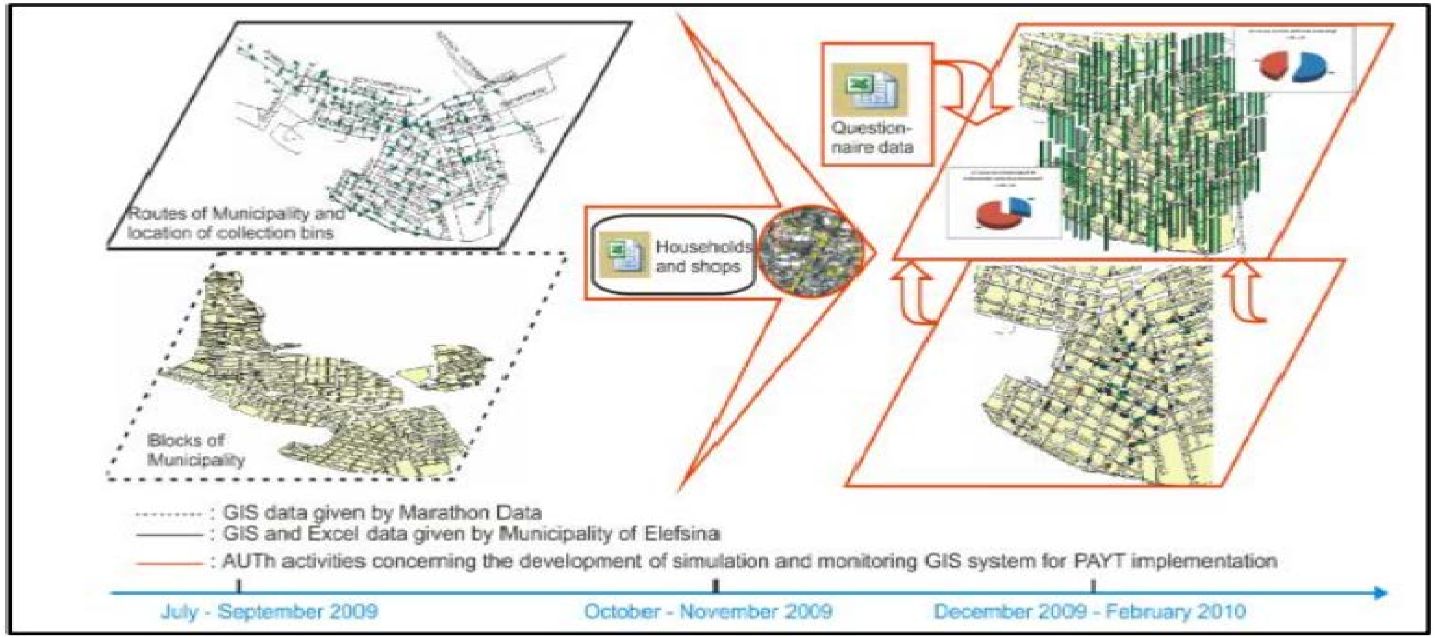
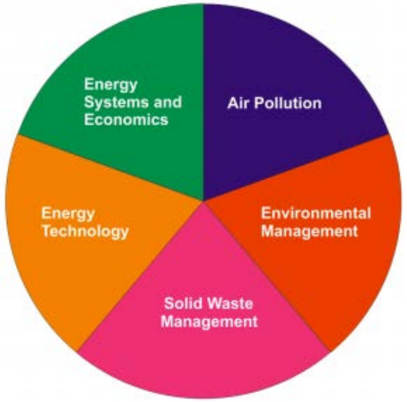
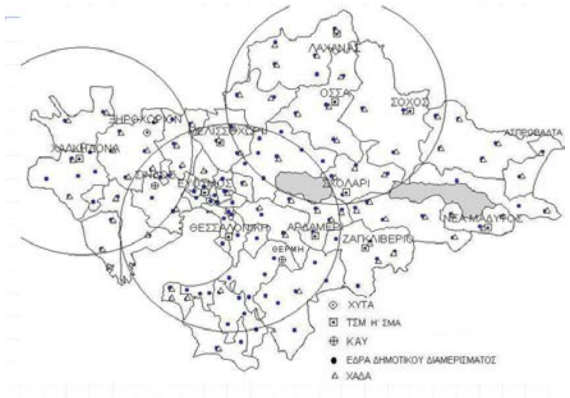
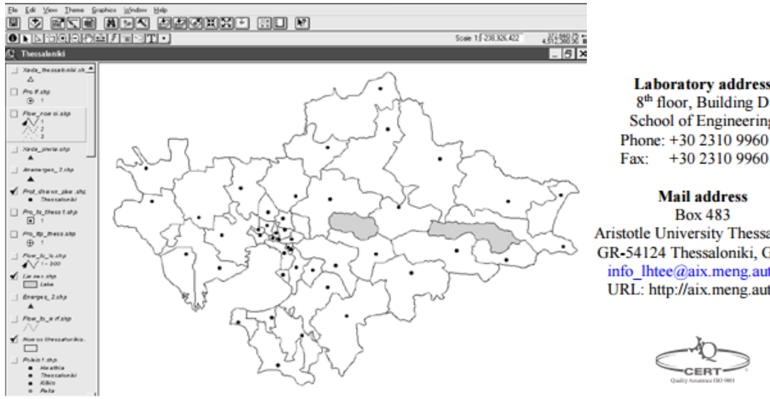
# Laboratory of Heat Transfer and Environmental Engineering (LHTEE)




**Main Research Topics**





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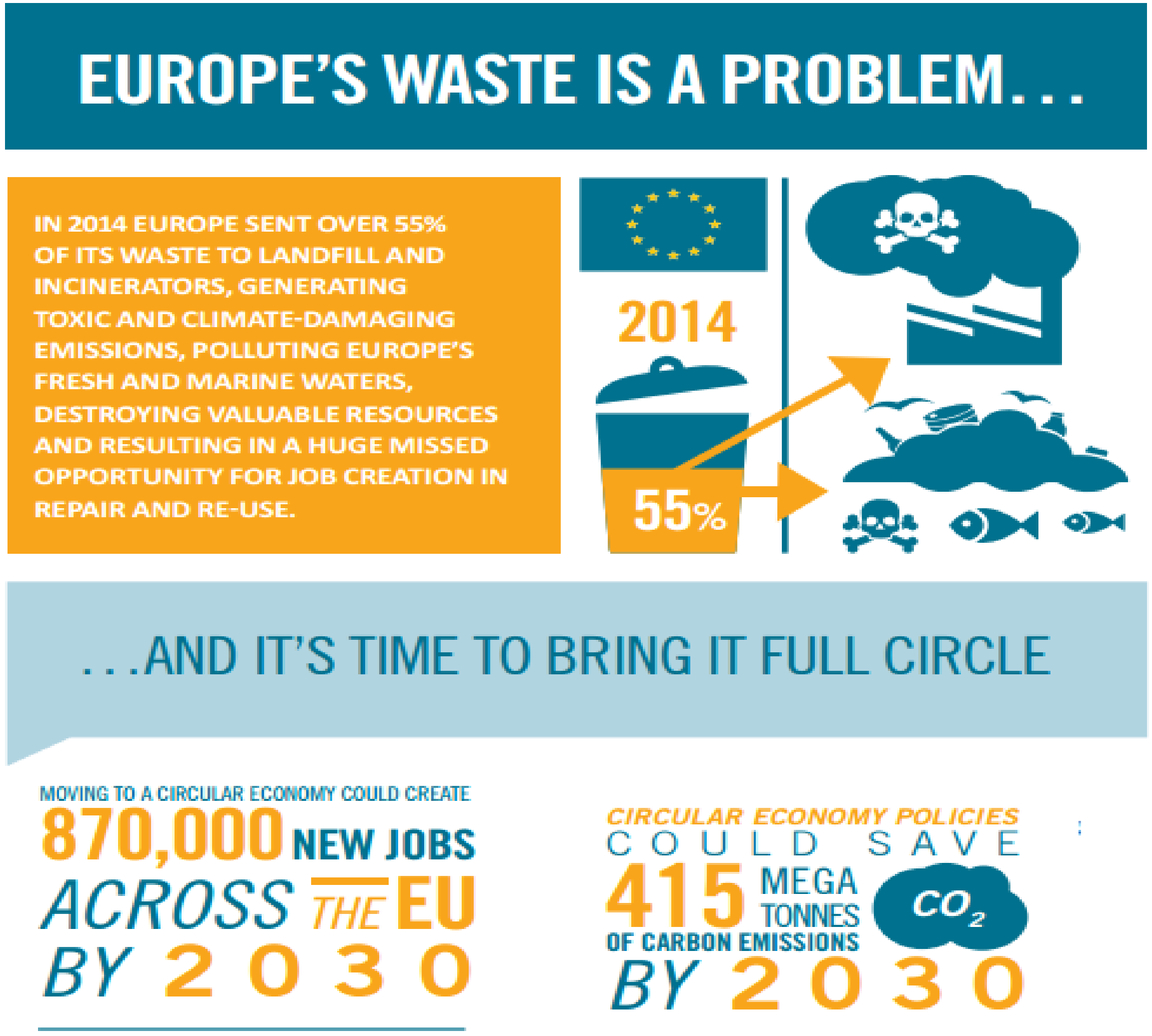
# Bio-waste

- Organic waste is defined as biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants.


https://www.zerowasteeurope.eu/category/press-releases/

# NGOs call the EP to get the Circular Economy Back on Track

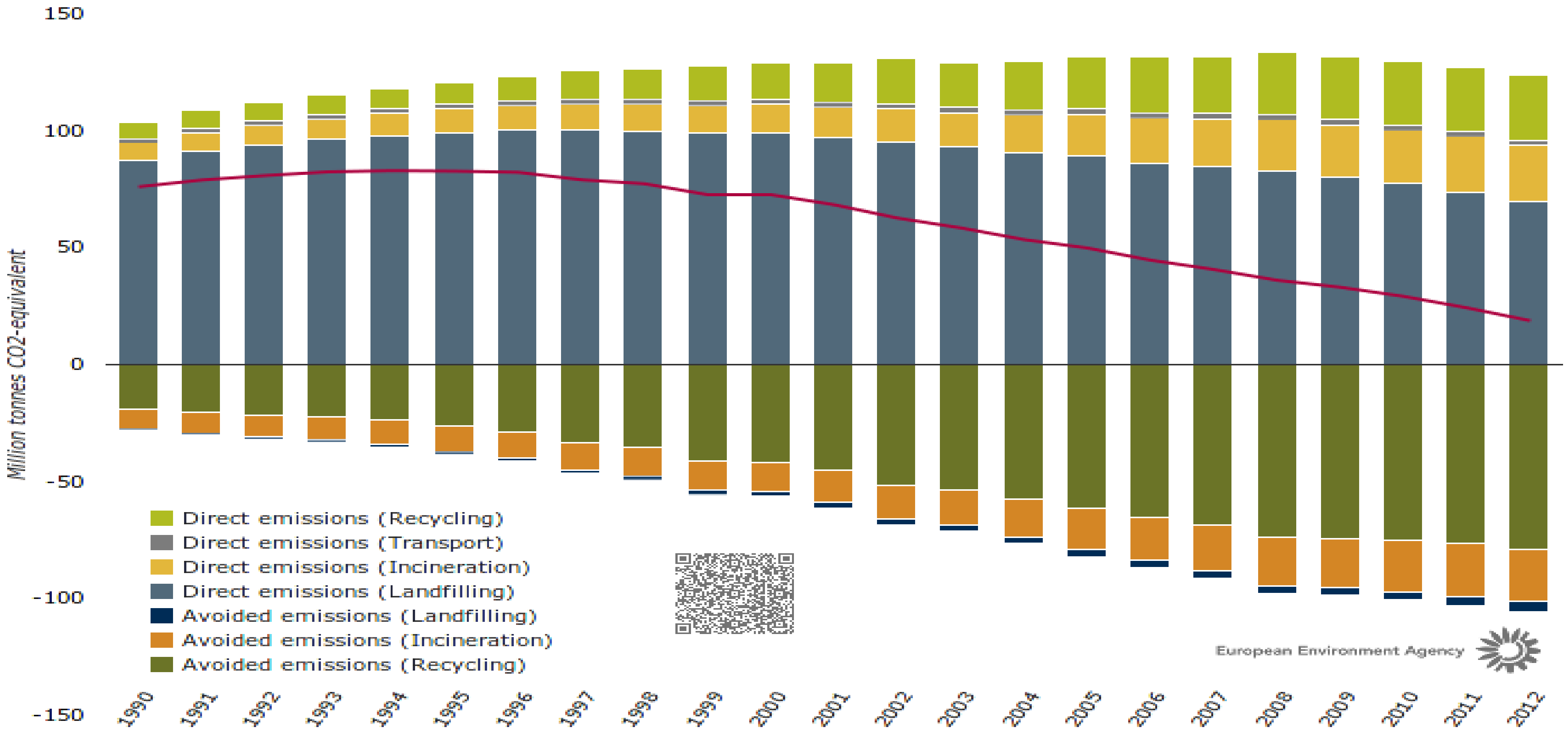




https://www.zerowasteeurope.eu/2016/05/ngos-call-the-ep-to-get-the-circular-economy-back-on-track/

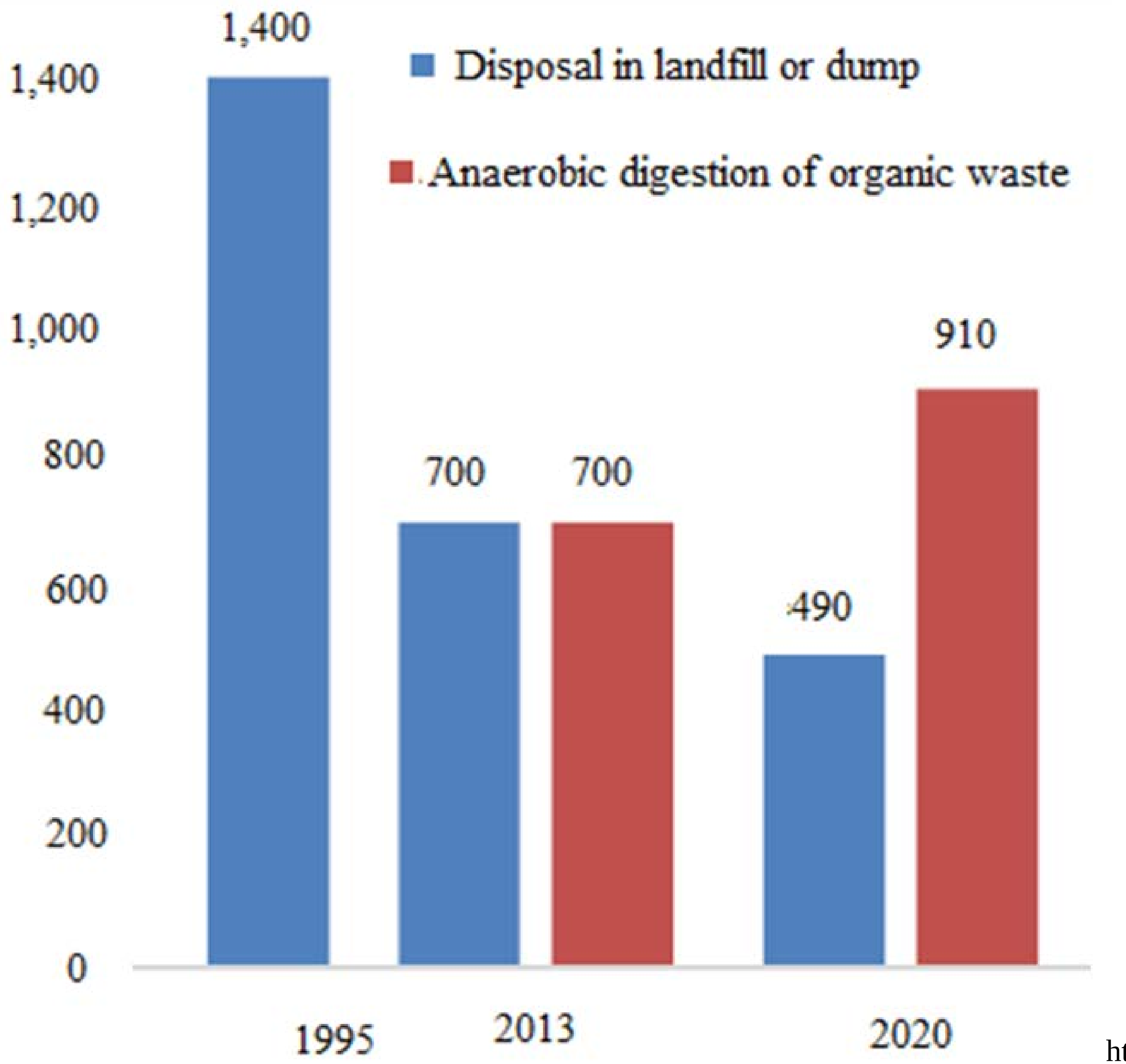
https://www.zerowasteeurope.eu/wp-content/uploads/2016/05/10-KEY-STEPS.pdf

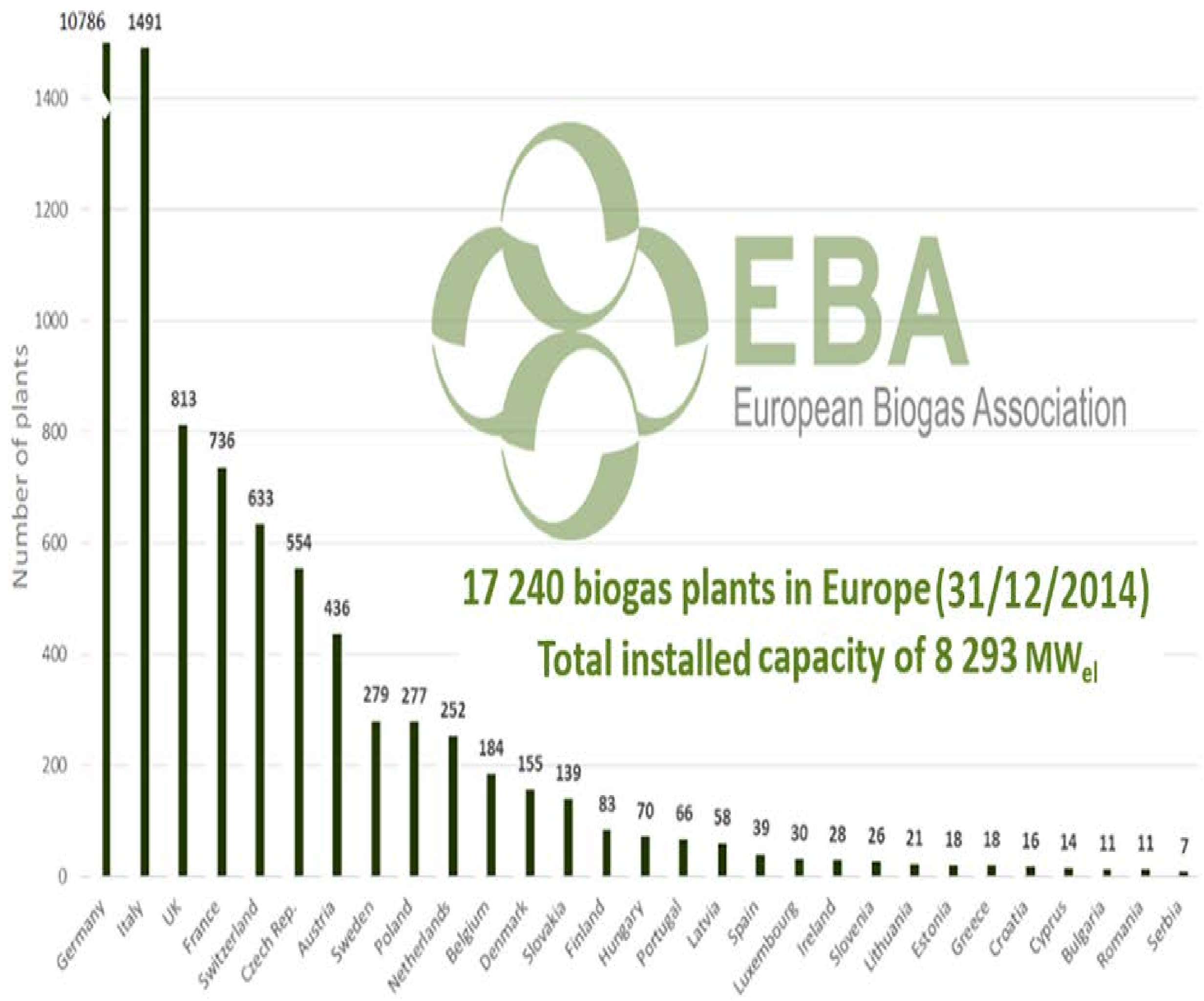
# Greenhouse gas emissions from municipal waste management in the EU-27




http://www.eea.europa.eu/data-and-maps/daviz/ghg-emissions-from-municipal-waste-1/chart_1.png/download

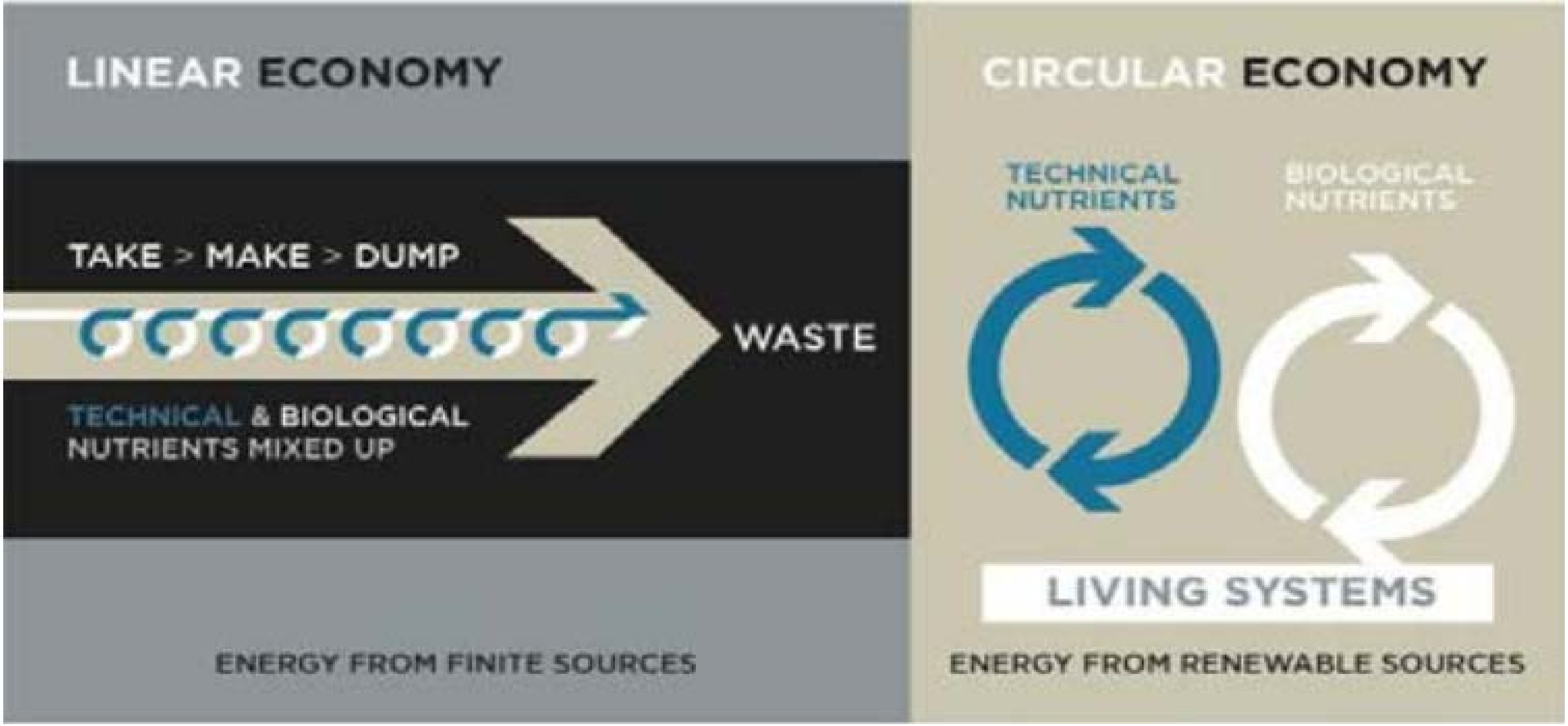
# Intended quantity of biodegradable municipal waste to anaerobic digestion




http://european-biogas.eu/wp-content/uploads/2016/01/Graph-1-Biogas-plants.png

# From linear to circular economy



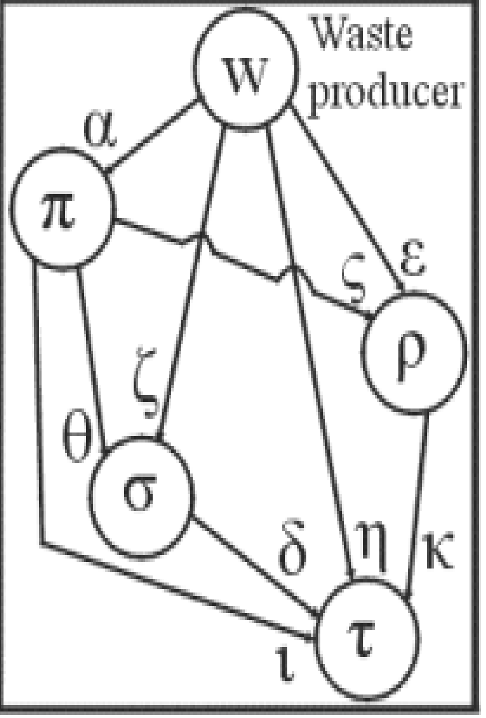

https://www.academia.edu/6240106/Zero_Waste_and_the_Circular_Economy_The_Future_of_Resource_Management

# Multi-objective optimization problem?

$$\max ER_j = \sum_{\nu}\sum_{\rho}(A_j^E \cdot c_\rho^\nu) + \sum_{\xi}\sum_{\sigma}(\Gamma_j^E \cdot d_\sigma^\xi) + \sum_{o}\sum_{\tau}(E_j^E \cdot e_\tau^o)$$

$$\max FT = \sum_{\mu}\sum_{\pi}\left[CFF_\varphi^\mu \cdot \varphi_\pi^\mu + CFV_\varphi^\mu \cdot b_\pi^\mu\right] + \sum_{\nu}\sum_{\rho}\left[CFF_\chi^\nu \cdot \chi_\rho^\nu + CFV_\chi^\nu \cdot c_\rho^\nu\right] + \sum_{\xi}\sum_{\sigma}\left[CFF_\psi^\xi \cdot \psi_\sigma^\xi + CFV_\sigma^\xi \cdot d_\sigma^\xi\right] + \sum_{o}\sum_{\tau}\left[CFF_\omega^o \cdot \omega_\tau^o + CFV_\omega^o \cdot e_\tau^o\right]$$

| Typology of existing/proposed facility (i) | Sub-typology of facility (j) | Capacity of facility [$\Delta E_j^i$, (t/d)] | Wastes' input at facility (t/d) | Mass reduction at facility (%) | Residues output from facility (t/d) | Binary decision variables (0, 1) | Wastes' flows from producers to facilities and wastes'/residues' flows from facilities to other facilities/landfills |
|---|---|---|---|---|---|---|---|
| Transfer station | μ | k | b | | t | $\varphi^\mu_\pi$ | |
| Material recovery | ν | g | c | $f_{MRF}$ | s | $\chi^\nu_\rho$ | |
| Energy recovery | ξ | h | d | $f_{WTE}$ | q | $\psi^\xi_\sigma$ | |
| Landfill | o | u | e | | | $\omega^o_\tau$ | |




$$\min GHE = \sum_{\xi}\sum_{\sigma}(\Gamma_\xi^{GHE} \cdot d_\sigma^\xi) + \sum\sum(E_o^{GHE} \cdot e_\tau^o)$$

$$\min FIDI = \sum_{o}\sum_{i}\sum_{\tau}\eta_{i\tau}^o \cdot \omega_\tau^o + \sum_{\mu}\sum_{o}\sum_{\pi}\sum_{\tau}\iota_{\pi\tau}^{\mu o} \cdot \omega_\tau^o + \sum_{\xi}\sum_{o}\sum_{\sigma}\sum_{\tau}\delta_{\sigma\tau}^{\xi o} \cdot \omega_\tau^o$$

$$\max MR_j = \sum_{\nu}\sum_{\rho}(A_j^M \cdot c_\rho^\nu) + \sum_{\xi}\sum_{\sigma}(\Gamma_j^M \cdot d_\sigma^\xi)$$

Source: http://www.tjer.net/site/issue1/Civl28103_Latest.pdf

# Mixed constraints problem?

(a) Service demand, i.e. the produced amount of wastes is equal to the sum of capacities from the facilities of the system

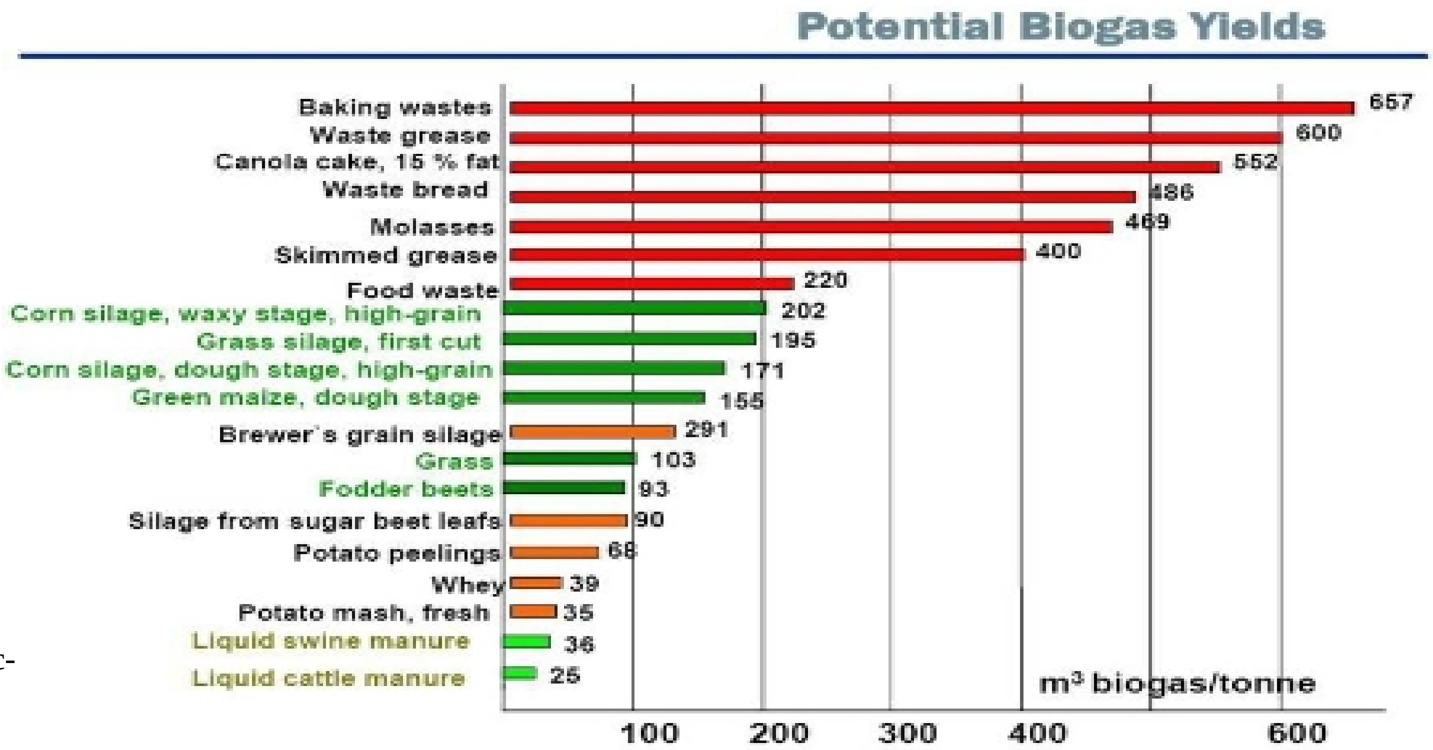
$$a_i = \sum_{\mu}\sum_{\pi}\alpha^{\mu}_{i\pi} + \sum_{\nu}\sum_{\rho}\varepsilon^{\nu}_{i\rho} + \sum_{\xi}\sum_{\sigma}\zeta^{\xi}_{i\sigma} + \sum_{o}\sum_{\omega}\eta^{o}_{i\omega}$$

(b) Facility capacity.

(c) Mass input-output relation at facilities.

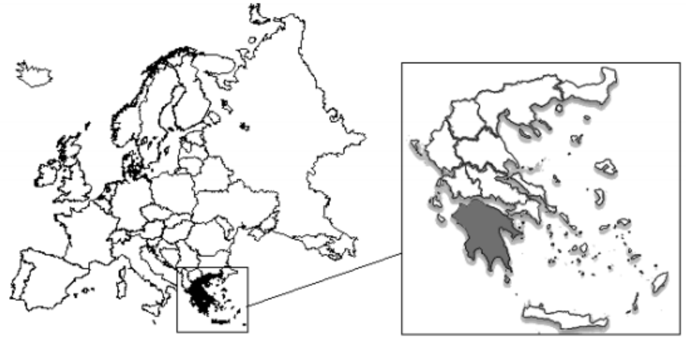
(d) Compactor- and truck-capacity, maximum allowed gross truck weight and speed limits. Solid wastes were allowed to either leave transfer stations uncompressed (in the case that they are sent to material recovery facilities, by mostly open- containers), or compressed (in the cases they are sent to waste-to energy facilities or landfills).

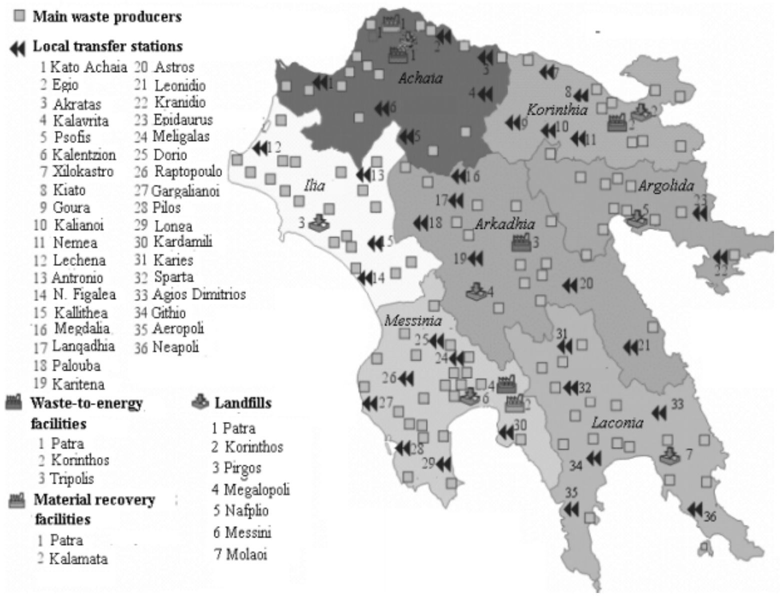
$$\min GHE = \sum_{\xi}\sum_{\sigma}(\Gamma^{GHE}_{\xi}\cdot d^{\xi}_{\sigma}) + \sum\sum(E^{GHE}_{o}\cdot e^{o}_{\tau})$$

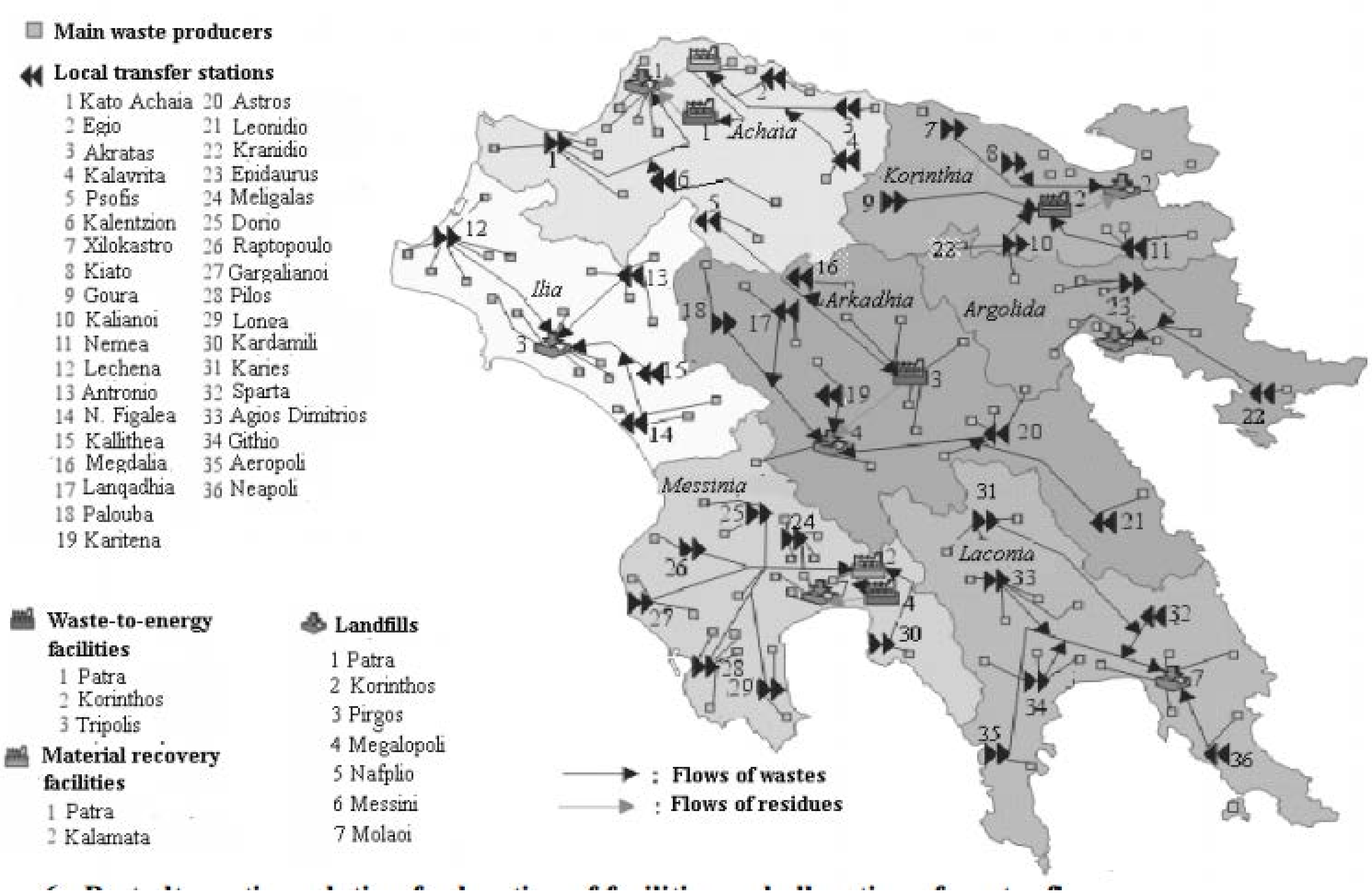



http://www.farmingesolutions.co.uk/renewable-technologies/anaerobic-digestion/

# Are there existing and candidate facilities? Which is the best alternative solution?

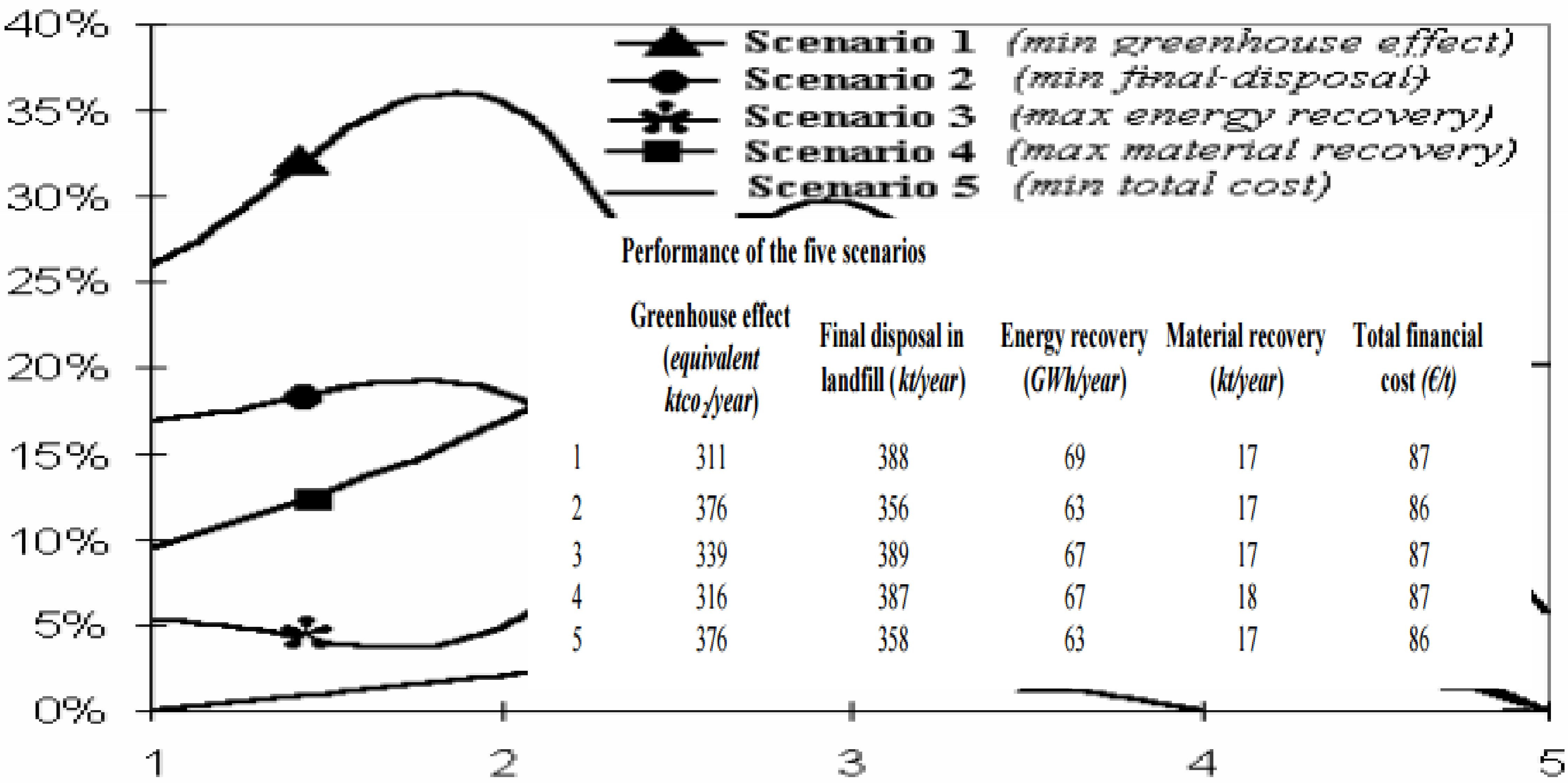







Source: http://www.tjer.net/site/issue1/Civl28103_Latest.pdf

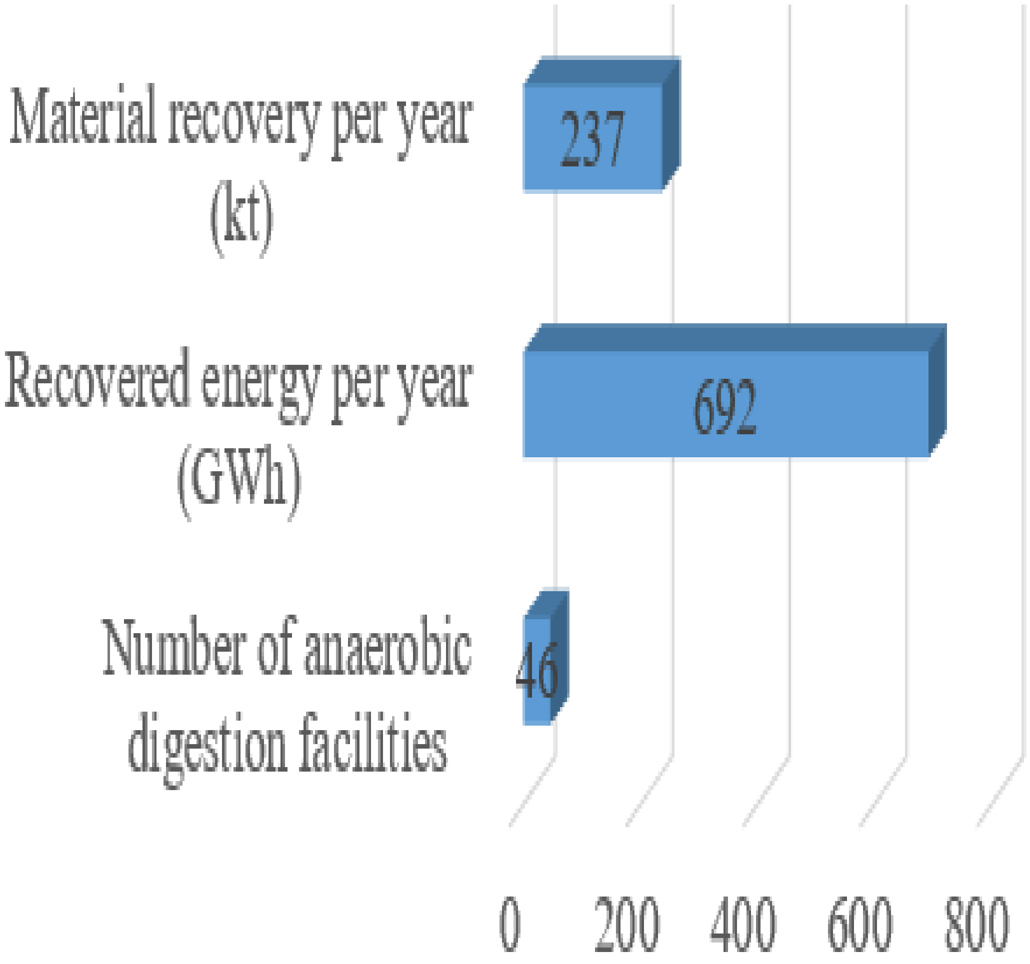
# Do we need MCDA analysis with GIS?

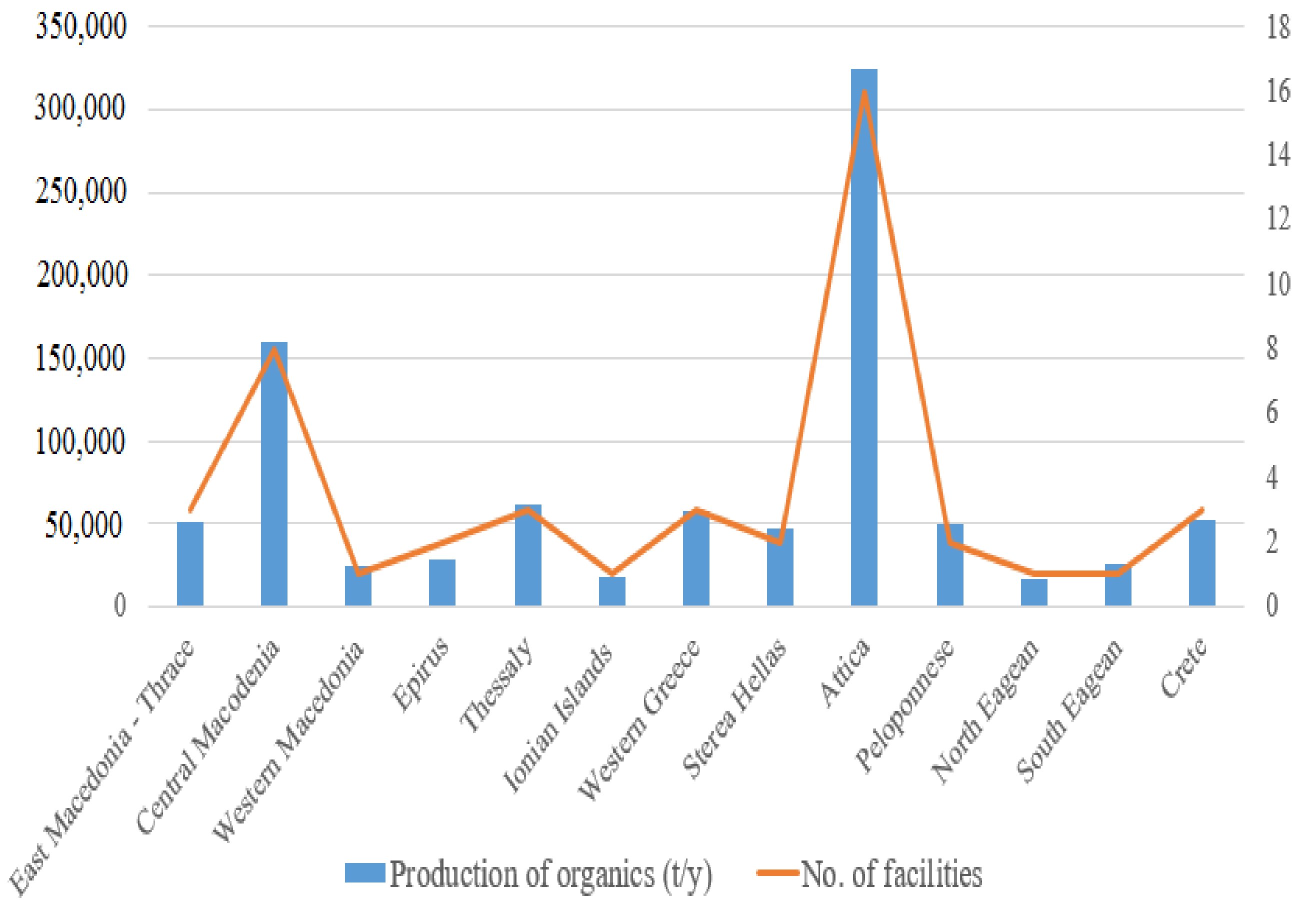



Performance of the five scenarios

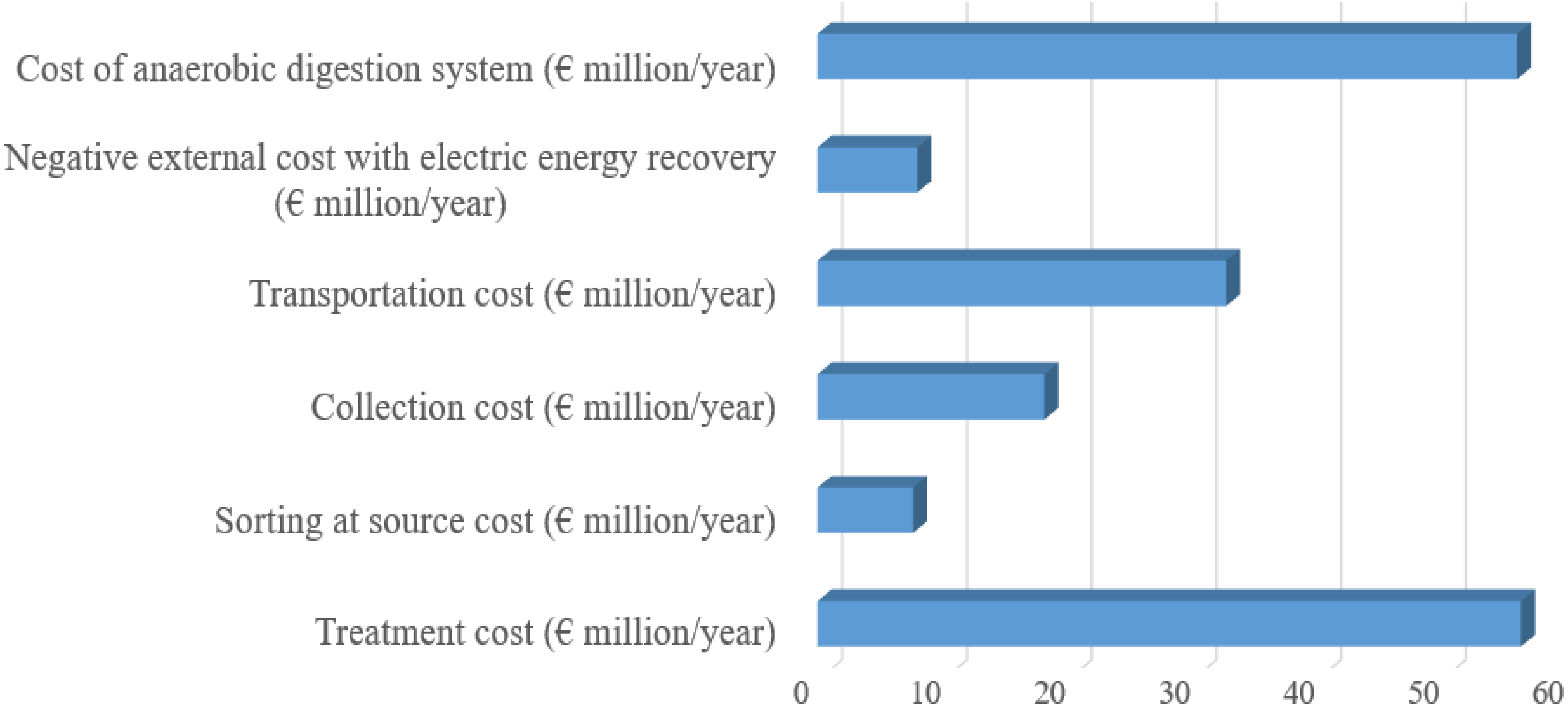
| | Greenhouse effect (*equivalent ktco$_2$/year*) | Final disposal in landfill (*kt/year*) | Energy recovery (*GWh/year*) | Material recovery (*kt/year*) | Total financial cost (*€/t*) |
|---|---|---|---|---|---|
| 1 | 311 | 388 | 69 | 17 | 87 |
| 2 | 376 | 356 | 63 | 17 | 86 |
| 3 | 339 | 389 | 67 | 17 | 87 |
| 4 | 316 | 387 | 67 | 18 | 87 |
| 5 | 376 | 358 | 63 | 17 | 86 |

# Number of anaerobic digestion facilities and recovered energy and material

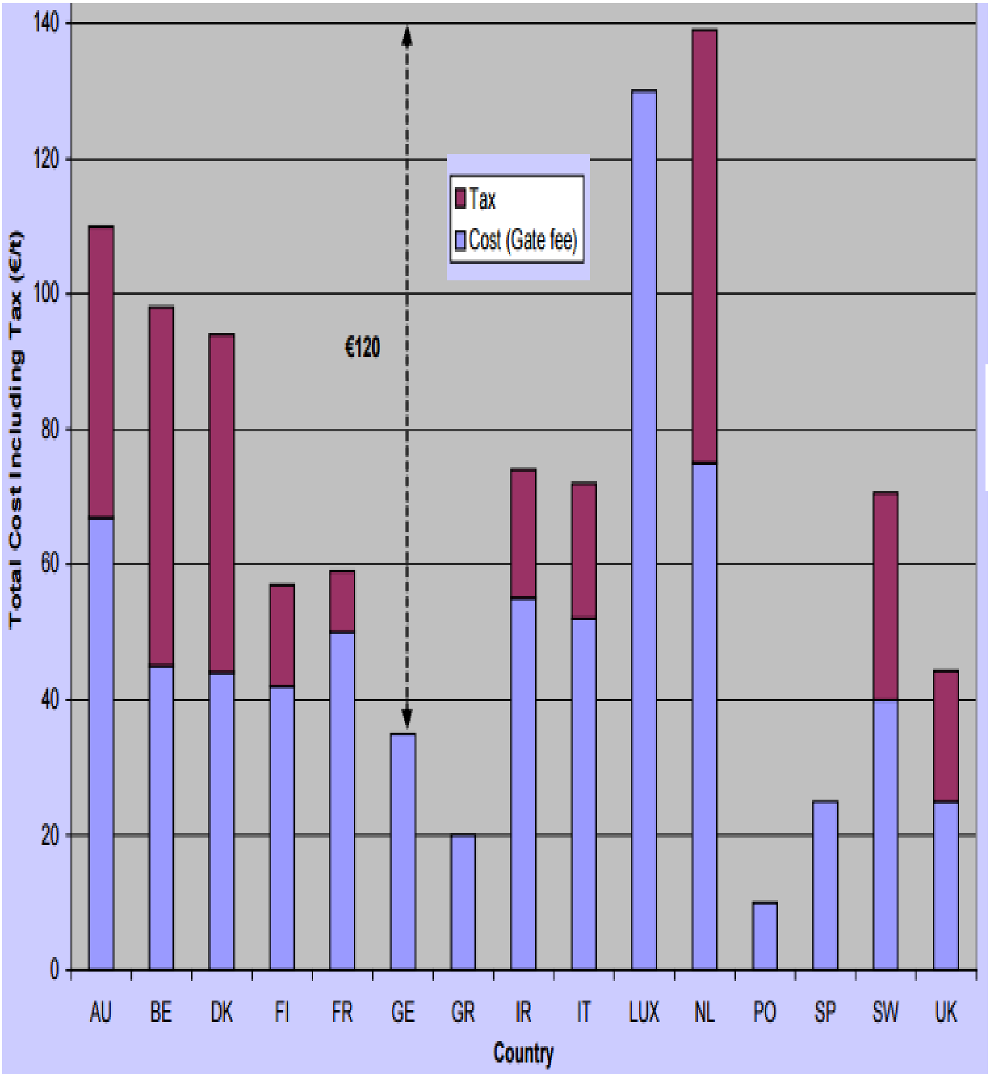


# Cost of anaerobic digestion system



# Cost of landfilling and biodegradable disposal




| Year | Biodegradable municipal waste in 1995 (kt) | Disposal to earth [landfill, dump (t)] | Organic waste (kt) | Organic waste disposal in landfills or dumps (kt) | Anaerobic digestion of organic waste (kt) |
|---|---|---|---|---|---|
| **1995** | 2,100 | 2,100 | 1,400 | 1,400 | 0 |
| **2013** | | | | 700 | 700 |
| **2020** | | | | 490 | 910 |

http://ec.europa.eu/environment/waste/compost/presentations/hogg.pdf

# Circular economy aspects in Catalonia


| | Compost Nutrients | Nutrient Demand* | |
|---|---|---|---|
| | | Winter Cereal | Horti-culture |
| Organic Matter | 350 kg/t | | |
| Available N | 10 kg/t | 40 kg/ha | 200 kg/ha |
| Posphorus (P2O5) | 18 kg/t | 80 kg/ha | 80 kg/ha |
| Potassium (K2O) | 13kg/t | 60 kg/ha | 300 kg/ha |
| Compost Demand t/ha | | 6-10 t/ha | 20 t/ha |

## 4 Facilities


**PROs**
- Requires less area
- Allows better management of emissions / odors
- Allows recovery of energy (biogas)
- Fuel for vehicles

**CONs**
- High costs (investment /management)
- More sofisticated and sensitive technology
- Requires high input quantities
- Requires homogeneous input
- More feasible on the industrial scale

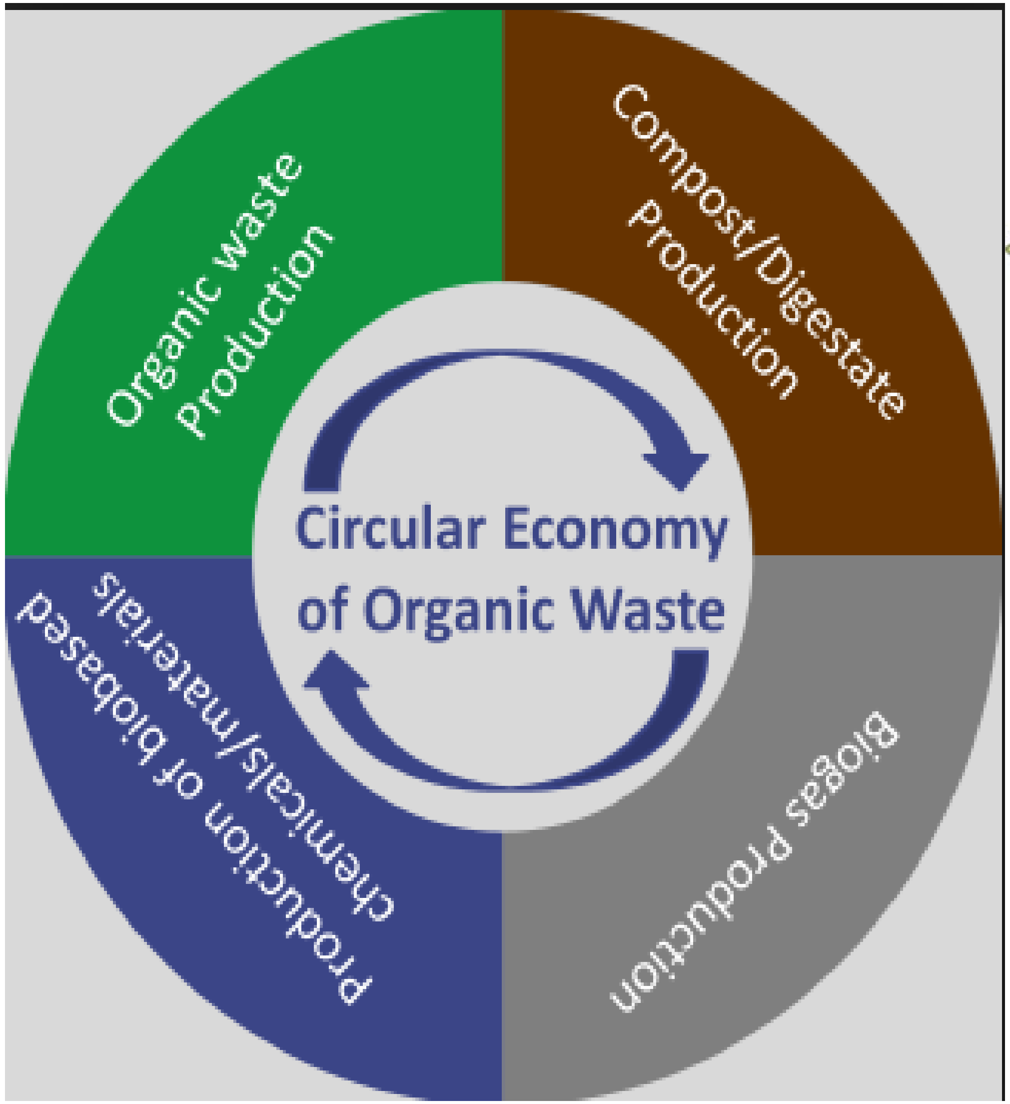
## 20 Facilities


**PROs**
- Simple, robust technology
- Flexibility (capacity/modules)
- Biological process less complicated
- Process allows and requires input of woody materials (green waste)
- Lower costs (investment/management) than AD

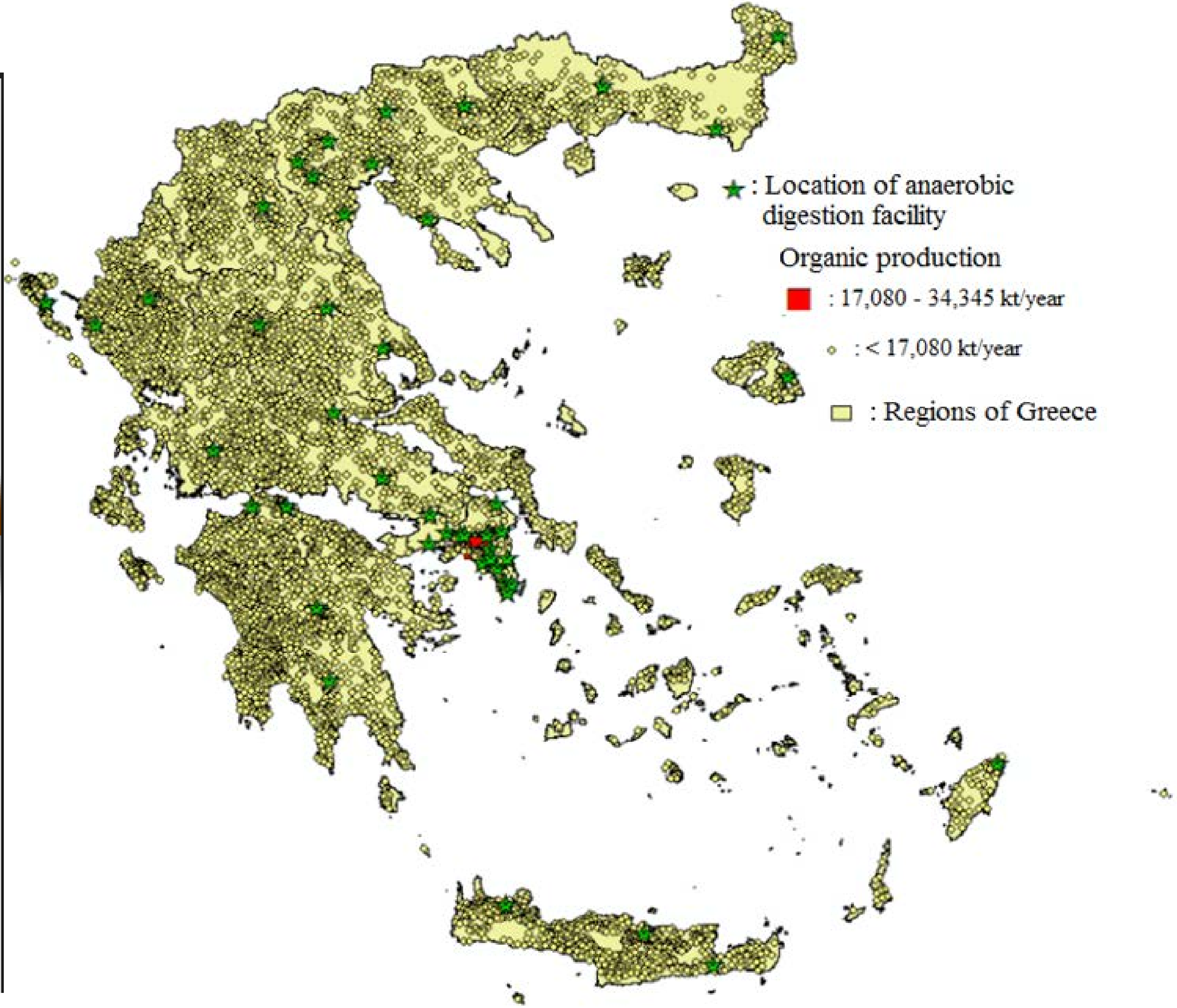
**CONs**
- Slower process

http://www.slideshare.net/residuscat/separate-collection-ang-biological-treatment-of-food-and-biowaste-in-a-circular-economy

# Circular economy aspects in Greece




www.compostnetwork.info



# Conclusions

- Forty six (46) anaerobic digestion facilities were proposed
- The energy recovery was calculated to 692 $GW_h$
- The recovered material, in the form of compost, yielded to 237 kt.
- The total negative external cost for managing the 910 kt of bio-waste in Greece, was estimated to €8 million for the year 2020
- The cost for the treatment of organic waste was 56.4 M €, while the cost for its source separated collection was calculated to €7.7 million.
- Tools for implementing circular economy:
  - Linear integer programming and Multi-Objective programming (among others).
  - GIS
  - Anaerobic digestion databases

# Thank you for your attention!


https://www.academia.edu/6240106/Zero_Waste_and_the_Circular_Economy_The_Future_of_Resource_Management

www.veolia.com