

Local Climate Action

Waste Management And Recycling Procedures For Waste

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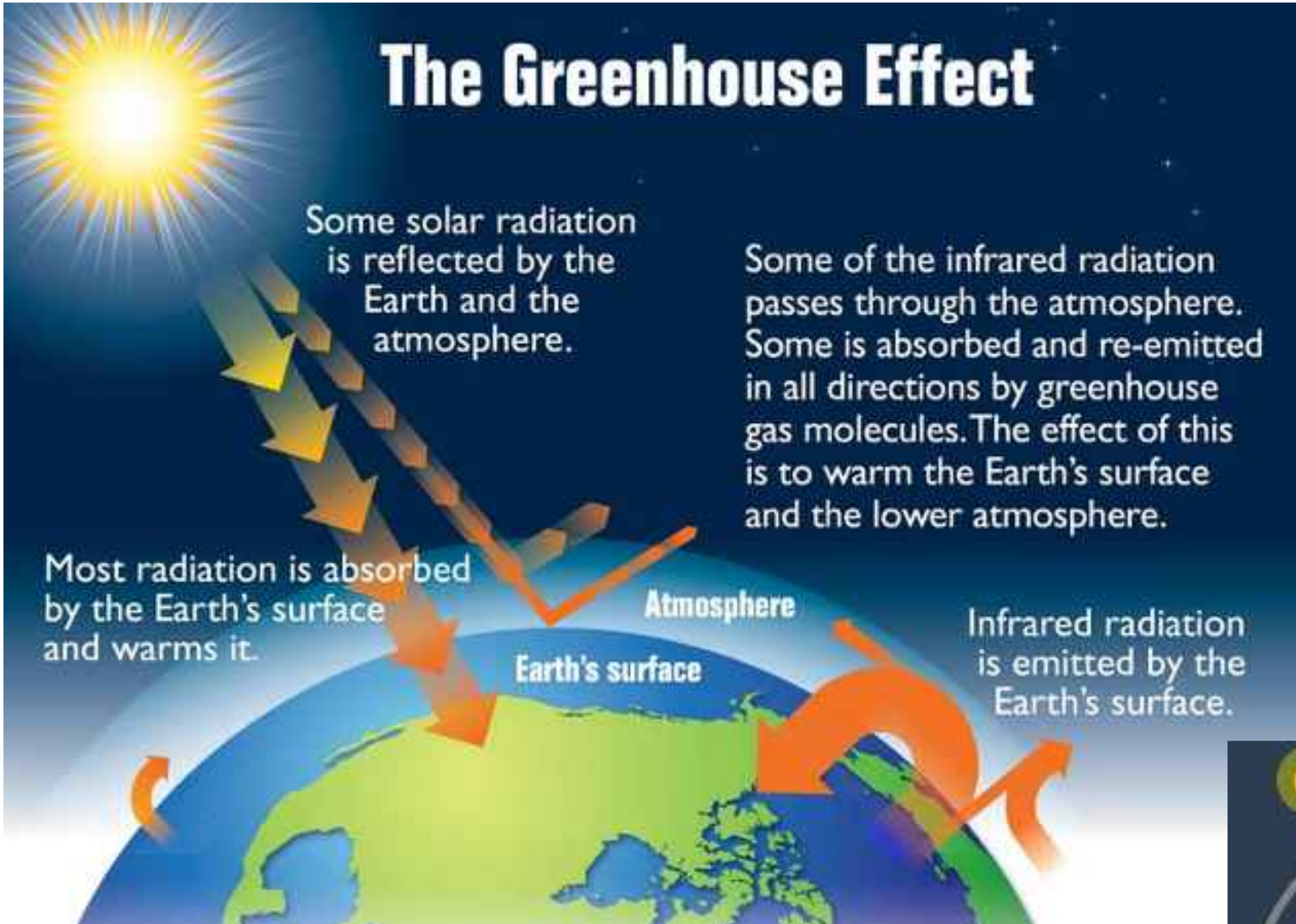
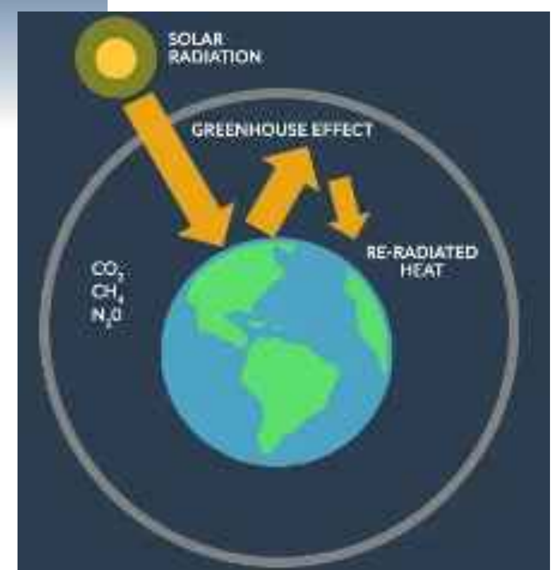
December, 2022


The Greenhouse Effect
Some solar radiation is reflected by the Earth and the atmosphere.
Some of the infrared radiation passes through the atmosphere. Some is absorbed and re-emitted in all directions by greenhouse gas molecules. The effect of this is to warm the Earth's surface and the lower atmosphere.
Most radiation is absorbed by the Earth's surface and warms it.
Atmosphere
Earth's surface
Infrared radiation is emitted by the Earth's surface.


SOLAR RADIATION
GREENHOUSE EFFECT
RE-RADIATED HEAT
CO_2
CH_4
N_2O

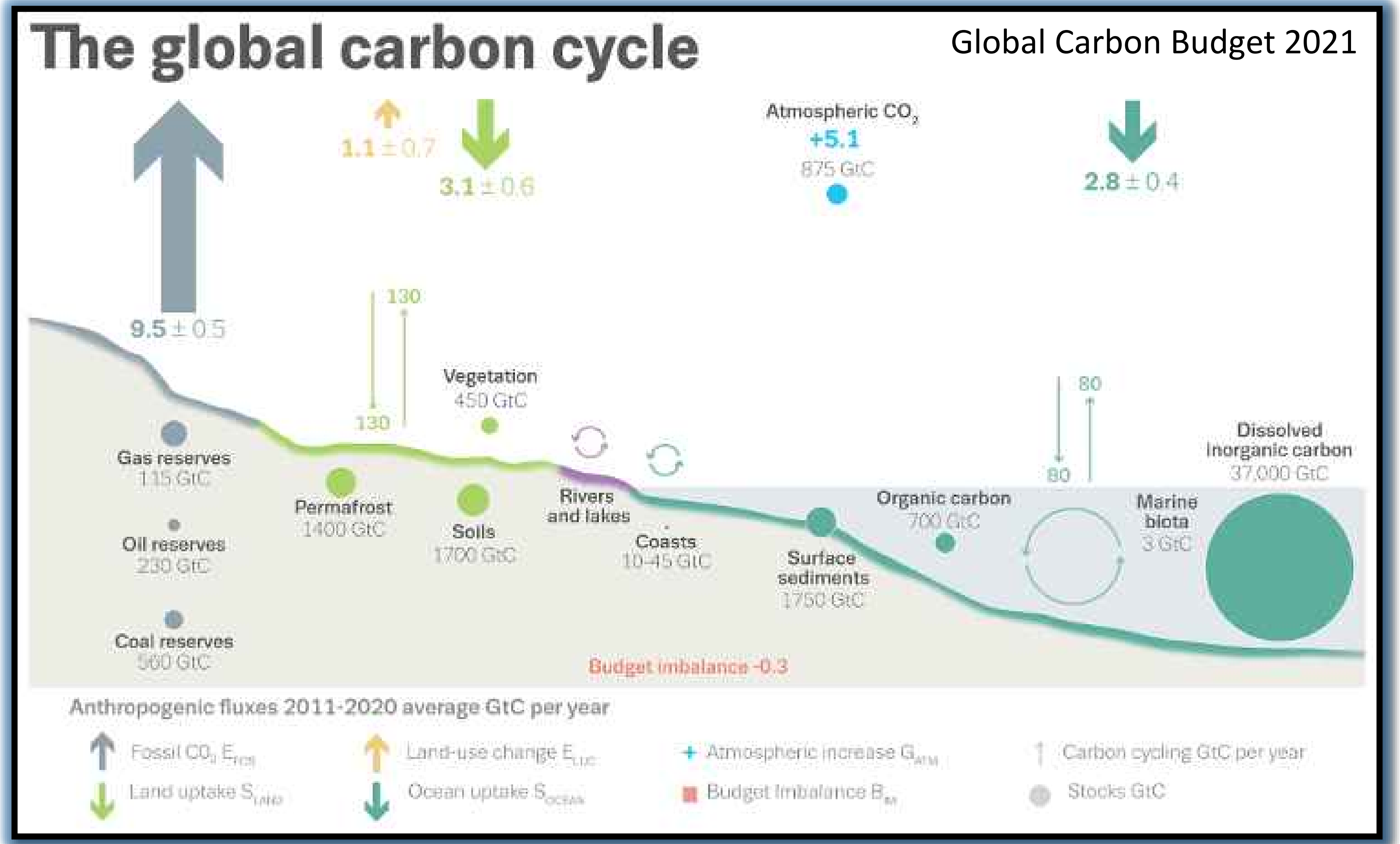
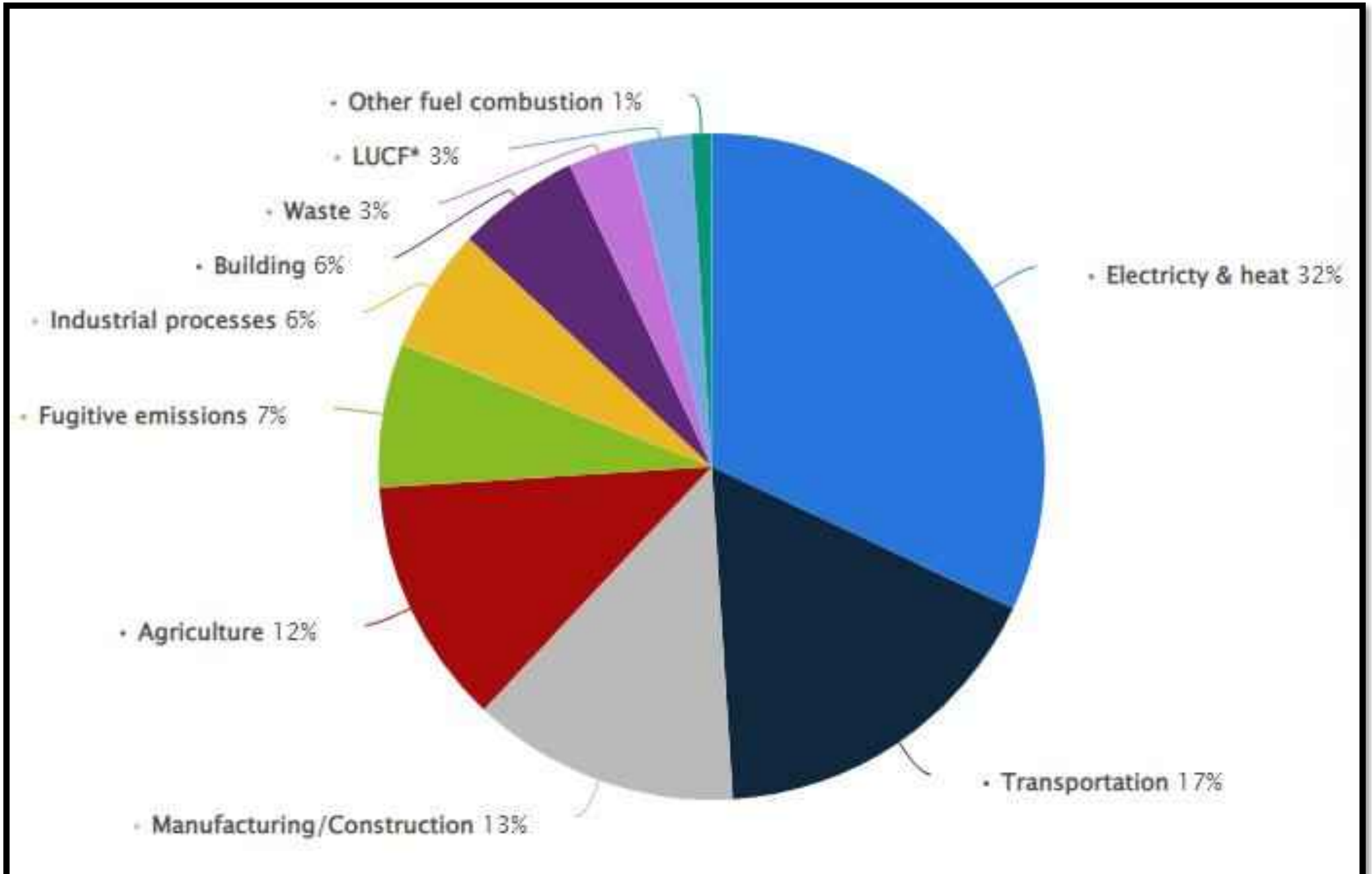
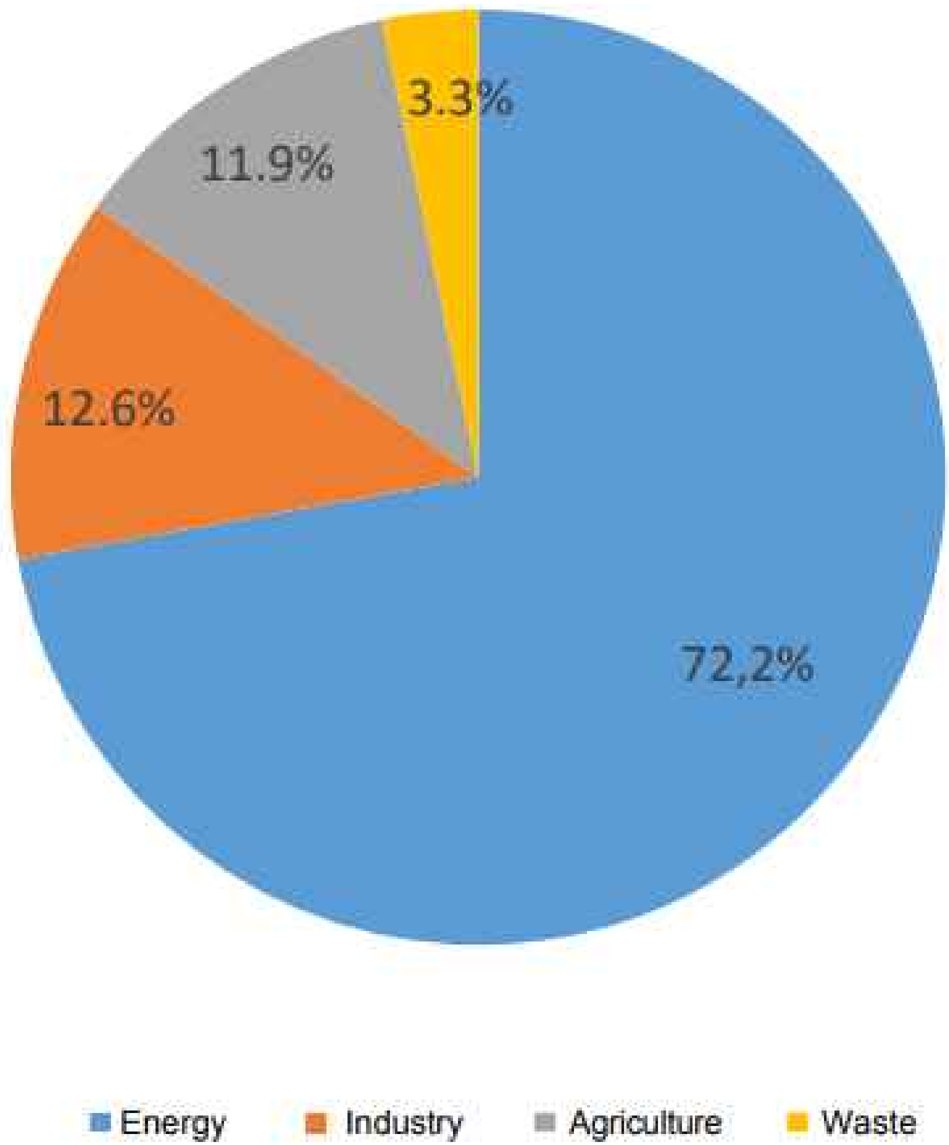


Figure: Schematic representation of the overall perturbation of the global carbon cycle caused by anthropogenic activities, averaged globally for the decade 2011–2020. See legends for the corresponding arrows and units.
The uncertainty in the atmospheric CO2 growth rate is very small (±0.02 GtC yr−1) and is neglected for the figure.
The anthropogenic perturbation occurs on top of an active carbon cycle, with fluxes and stocks represented in the background and taken from Canadell et al. (2022) for all numbers, except for the carbon stocks in coasts which is from a literature review of coastal marine sediments (Price and Warren, 2016).

Distribution of greenhouse gas emissions worldwide in 2019, by sector



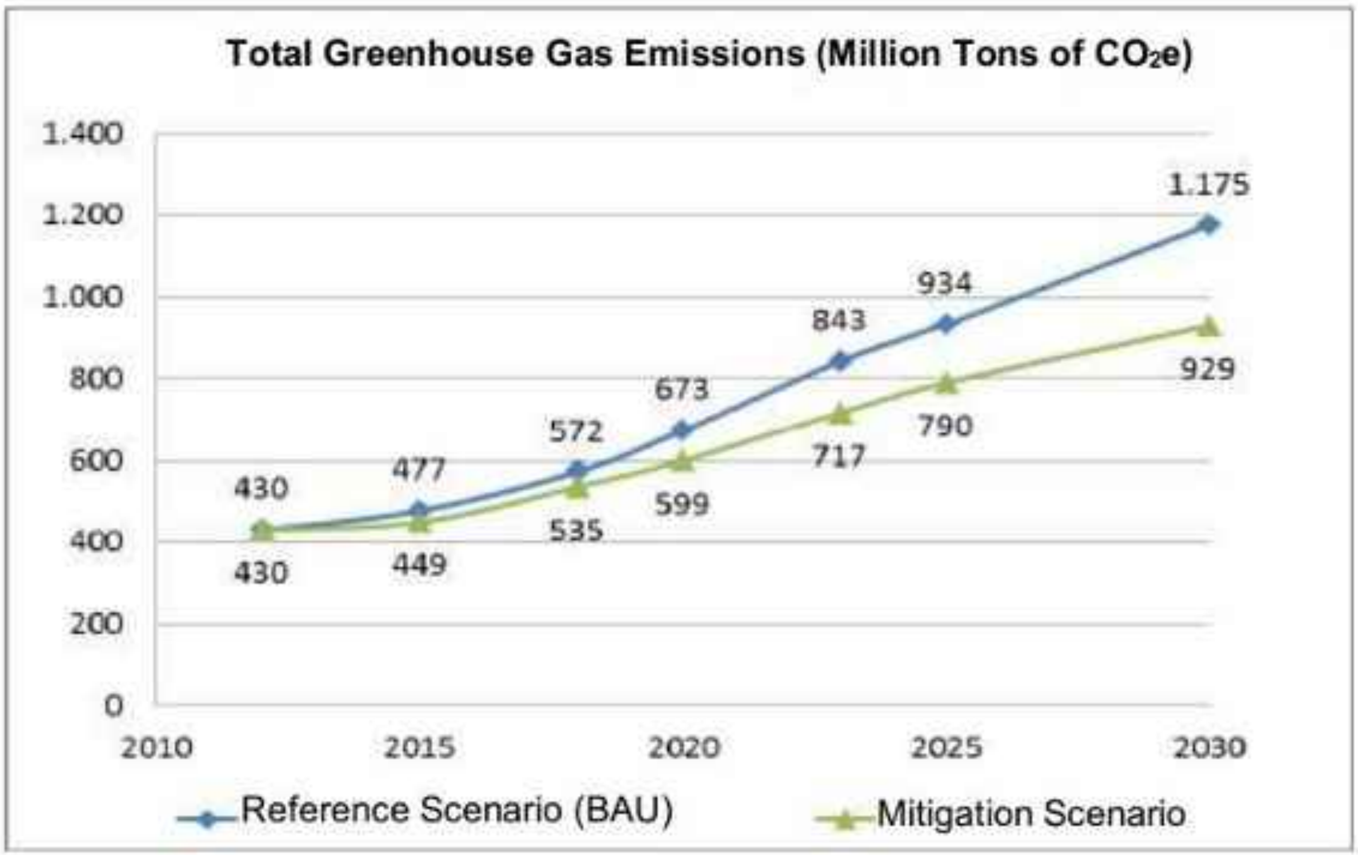
Shares of Turkey’s Greenhouse Gas Emissions in 2017
(United Nations Framework Convention on Climate ChangeUNFCCC, 2019a)



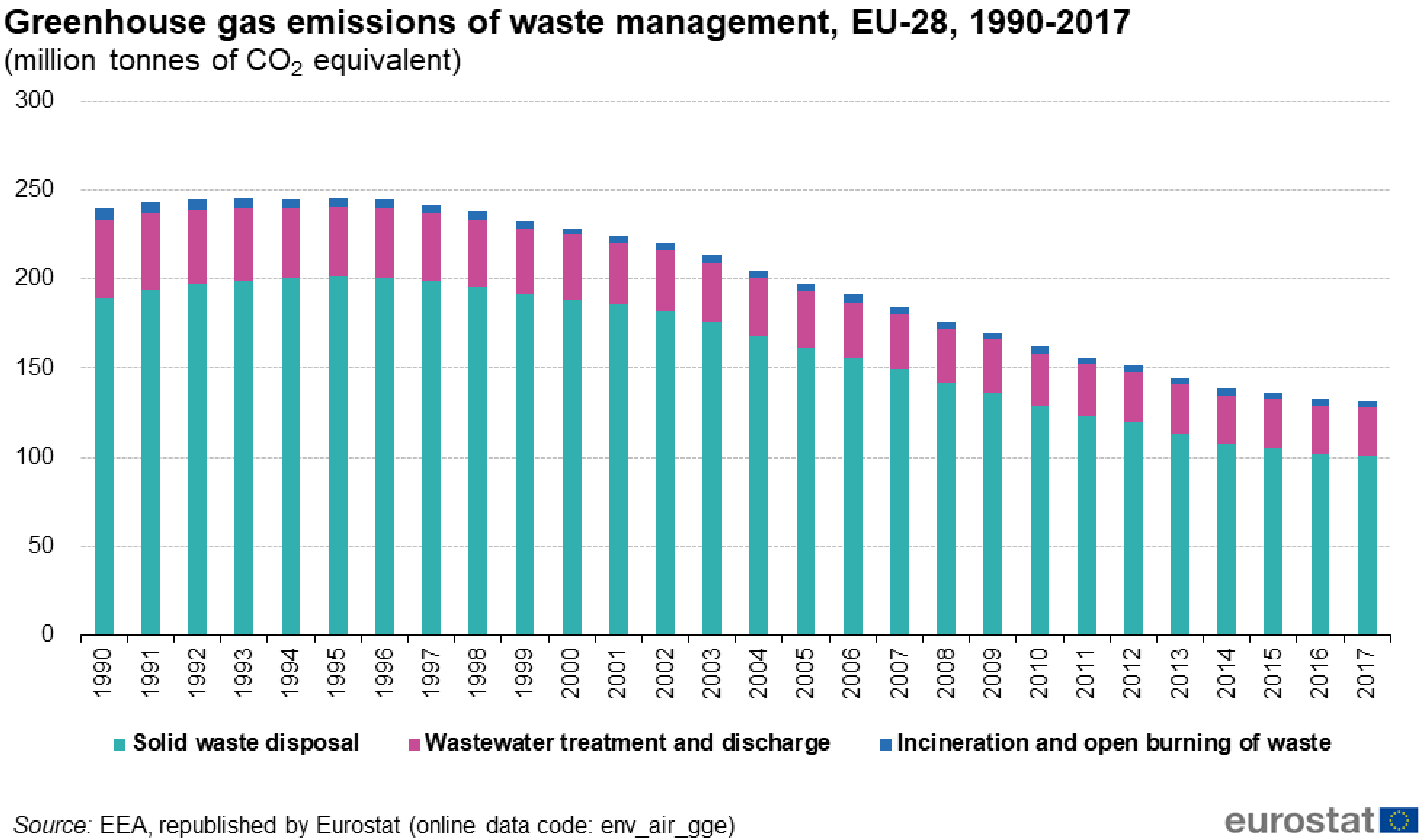
Turkey announced at COP27 (2022) an updated Nationally Determined Contribution (NDC), setting 2038 as an emission peak year.

The new scenario presented as a success translates into increasing today's greenhouse gas emissions by more than 30% until 2030, by not planning to reduce emissions in absollute terms – aka from today **(https://caneurope.org/turkeys-new-climate-target-does-not-take-the-countrys-2053-net-zero-goal-seriously/)**

Turkey's INDC Targets (UNFCCC, 2019b)

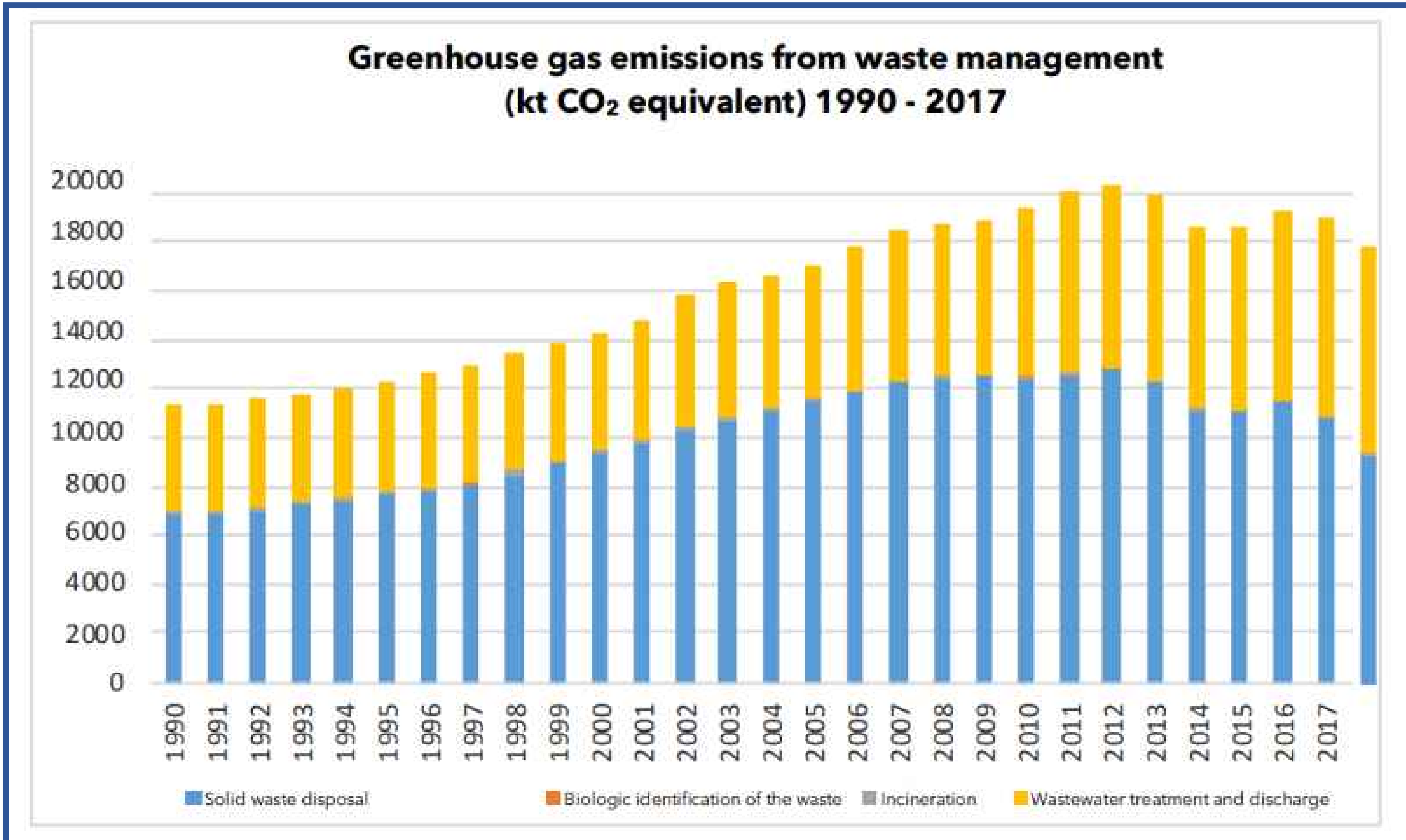


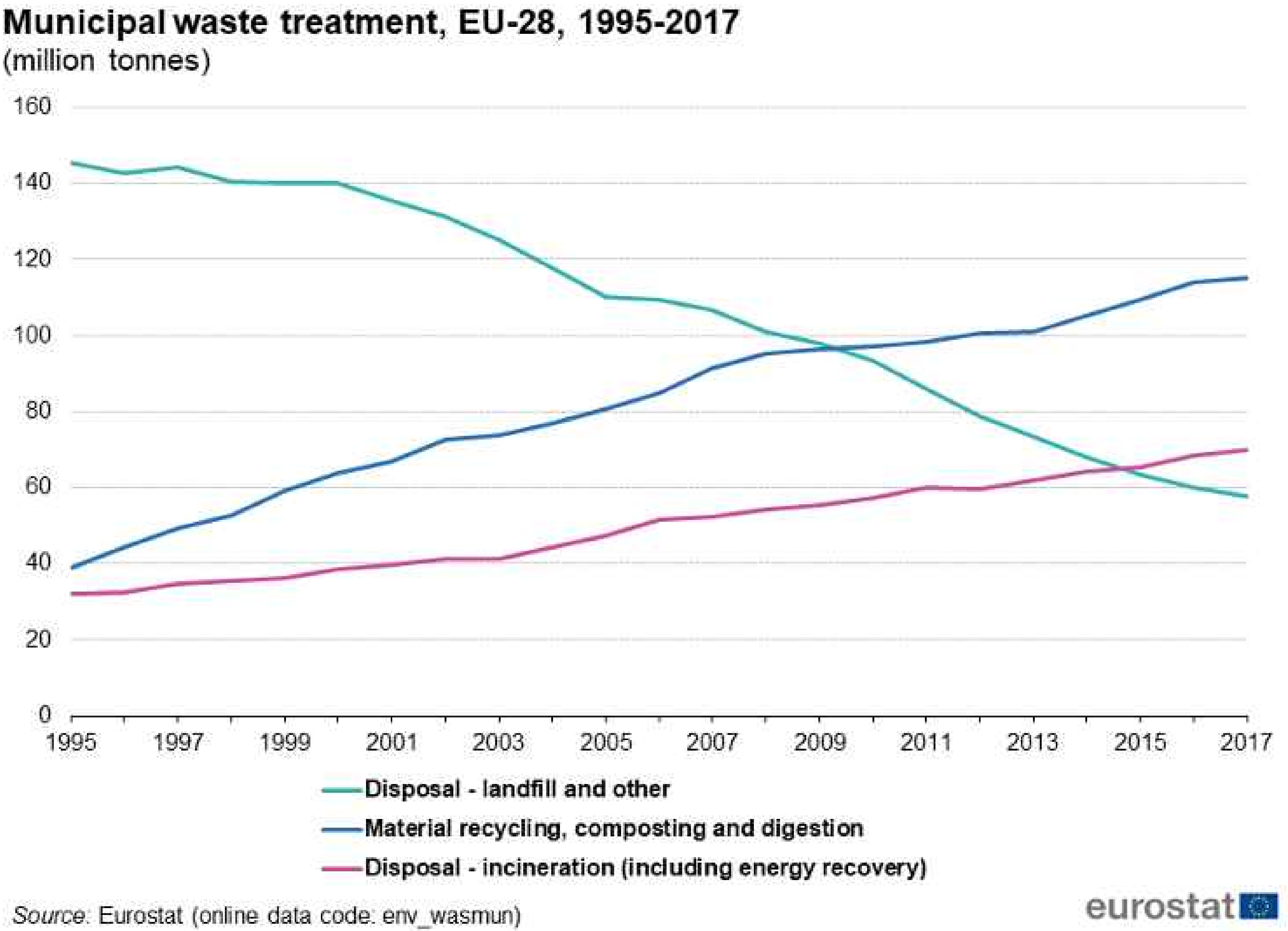
https://unfccc.int/sites/default/files/NDC/2022-06/The_INDC_of_TURKEY_v.15.19.30.pdf



Waste is the fourth largest source sector of emissions, accounting for 3% of total greenhouse gas emissions in 2017. Most emissions come from combusting fuels (77%), followed by agriculture (10%) and industrial processes (8%).

Greenhouse Gas Emissions in Turkey from Waste (UNFCCC, 2019a)

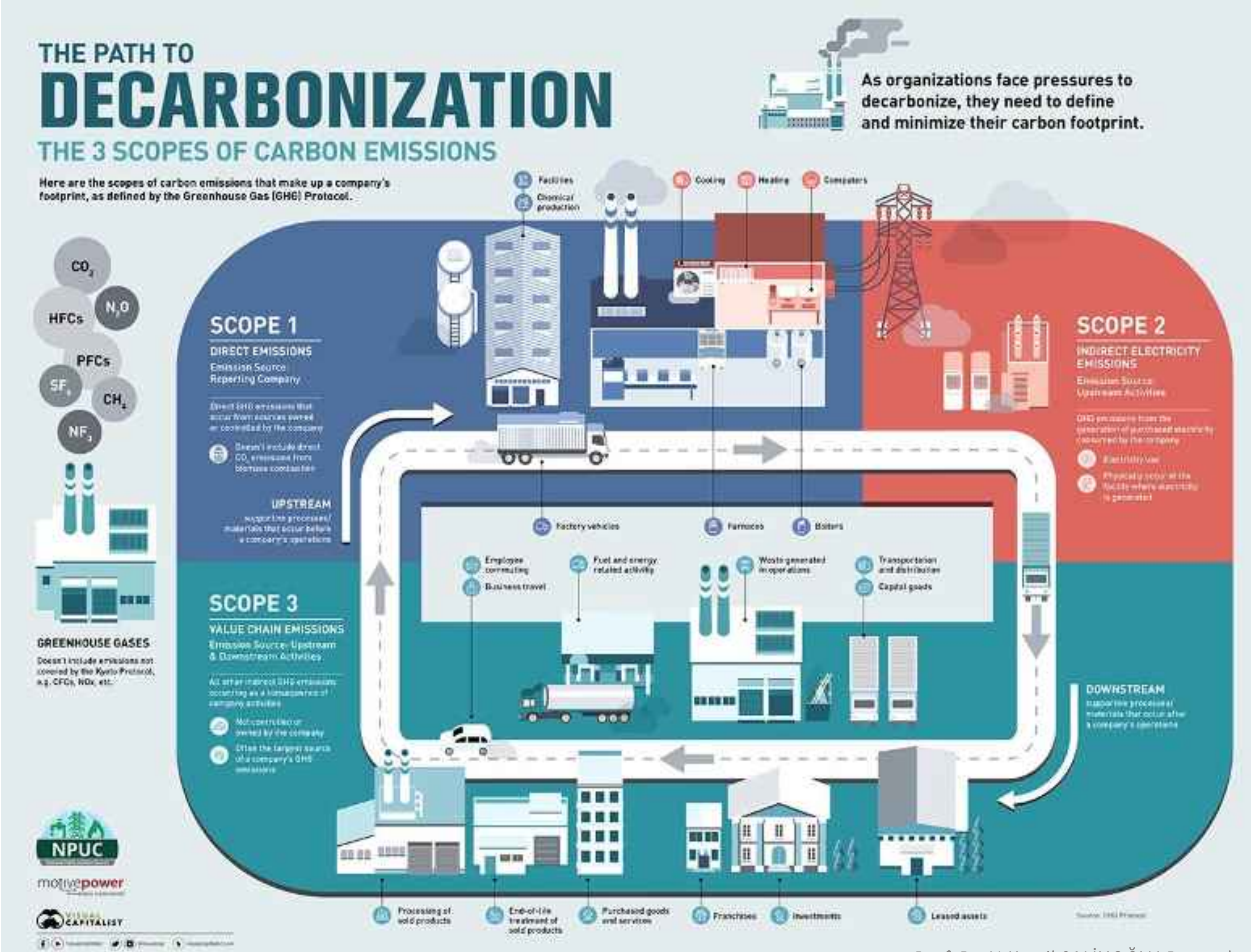



Municipal waste treatment, EU-28, 1995-2017
(million tonnes)
160
140
120
100
80
60
40
20
0
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
2017
Disposal - landfill and other
Material recycling, composting and digestion
Disposal - incineration (including energy recovery)
Source: Eurostat (online data code: env_wasmun)
eurostat

The reduction in emissions from solid waste disposal follows from an increase in the recovery of landfill gas and a reduction in the amount of landfilling. With more waste being recycled, less of it needs to be landfilled or incinerated, which contributes to protecting the climate.

The emissions from solid waste disposal are reduced further by the mandatory installation of landfill gas recovery at new sites. Changing the treatment of waste is just one example of how creating a more circular economy helps to reduce emissions and fight climate change.

https://ec.europa.eu/eurostat/web/products-eurostat-news/-/DDN-20200123-1


THE PATH TO
DECARBONIZATION
THE 3 SCOPES OF CARBON EMISSIONS
Here are the scopes of carbon emissions that make up a company's footprint, as defined by the Greenhouse Gas (GHG) Protocol.
As organizations face pressures to decarbonize, they need to define and minimize their carbon footprint.
CO2
HFCs
N2O
PFCs
SF6
CH4
NF3
GREENHOUSE GASES
Doesn't include emissions not covered by the Kyoto Protocol, e.g. CFCs, NOx, etc.
Facilities
Chemical production
Cooling
Heating
Computers
SCOPE 1
DIRECT EMISSIONS
Emission Source: Reporting Company
SCOPE 2
INDIRECT ELECTRICITY EMISSIONS
SCOPE 3
VALUE CHAIN EMISSIONS
Emission Source: Upstream & Downstream Activities
UPSTREAM
DOWNSTREAM
Factory vehicles
Furnaces
Boilers
Employee commuting
Business travel
Fuel and energy related activity
Waste generated in operations
Transportation and distribution
Capital goods
Processing of sold products
End-of-life treatment of sold products
Purchased goods and services
Franchises
Investments
Leased assets
NPUC
motivepower
VISUAL CAPITALIST

Comparison of Solid Waste Technologies

World Bank, Decision Maker's Guides for Solid Waste Management Technologies, 2018.

	Sanitary Landfill	Composting	Anaerobic Digestion	Incineration
Basic Process	Disposal	Biological treatment	Biological treatment	Thermal treatment
Ideal Types of Waste	Municipal solid waste, construction and demolition waste, wastewater sludge, non-hazardous industrial wastes	Food waste (including wastes from households, restaurants and markets), fats/ oils/ grease, paper and cardboard, landscaping and garden waste (e.g. hedge-clippings, leaves)	Food waste (including wastes from households, restaurants and markets), fats/ oils/grease, slaughterhouse waste (depending local regulations), and garden waste	Mixed municipal solid waste, medical waste, demolition wood, auto shredder residue, dried sewage sludge, and some industrial solid wastes
Waste to Avoid	Medical	Non-biodegradable wastes (plastic, glass, metal, inerts)	Non-biodegradable wastes (plastic, glass, metal, inerts), tree clippings	Yard leaves or source-separated food waste
Waste composition threshold for organic fraction or moisture content (%)	--	High as possible	>50%	<50%
Mass Reduction of Waste (%)	--	50%	50%	80-85%
Land Requirement	Generally large	0.065 – 10.8	1.61 – 6.45	Much smaller than that

Comparison of Solid Waste Technologies

	Sanitary Landfill	Composting	Anaerobic Digestion	Incineration
Proven Technology/ Market Maturity	+++	++	++	++
Operational complexity	Requires specialized training, careful maintenance, and post-closure care	Proper training required	Proper training required	Technically complex, requires highly skilled training and careful maintenance
Pre-processing of Feedstock	No	Preferred	Yes	Yes
Average Range of Waste Throughput (tonnes/day)	50-10,000	2.5 - 300	0.5 - 500	5 – 1000 (common range is 200 – 700)
Primary output	Landfill gas (where recovered), leachate	Compost	Methane, digestate	Air and ash
Secondary output	Electricity and/or heat (where landfill gas is recovered)	--	Electricity and/or heat; liquid or solid fertilizer	Heat and sometimes electricity
Energy conversion efficiency (kWh/ tonne of municipal solid waste)	65 (landfill gas)	--	165 - 245	500 - 600

(continued)

Comparison of Solid Waste Technologies

(continued)

	Sanitary Landfill	Composting	Anaerobic Digestion	Incineration
Capital costs (US$/ annual tonne)	5 - 52 (US$/tonne over lifetime)	30 - 400	220 - 660	190 – 1000
Operating costs (US$/tonne)	7 – 30 (but can be as high as 120)	12 - 100	22 - 57	12- 55
Greenhouse Gas Emissions	Significant; can be captured by landfill gas recovery	Reduced	Significant; captured and used to generate energy	Considered renewable or climate-neutral
Carbon Finance potential	Yes (where landfill gas is recovered)	Yes	Yes (where biogas is recovered)	Yes (where energy is recovered)
CDM (Carbon finance methodology)	AMS-III.G.	AMS-III.F. AMS-III.AF.	AMS-III.A.O.	AMS-III.E.

AMS-III.AG.: Switching from high carbon intensive grid electricity to low carbon intensive fossil fuel

AMS-III.F. : Avoidance of methane emissions through composting

AMS-III.AO.: Methane recovery through controlled anaerobic digestion

AMS-III.E.: Avoidance of methane production from decay of biomass through controlled combustion, gasification or mechanical/thermal treatment

https://cdm.unfccc.int/methodologies/DB/F5U41CTG7ENWK9RSSL5BV1LUPDG76W

Greenhouse Gas Emissions from Waste According to IPCC Guidelines (ibid)

$$PE_y = PE_{y,comb} + PE_{y,transp} + PE_{y,power} \quad (1)$$

Where:

PE_y	Project activity direct emissions in the year y (tCO_2e)
$PE_{y,comb}$	Emissions through combustion and gasification of non-biomass carbon of waste and RDF/SB in the year y (tCO_2e)
$PE_{y,transp}$	Emissions through incremental transportation in the year y (tCO_2e)
$PE_{y,power}$	Emissions through electricity or diesel consumption in the year y (tCO_2e)

18. The expected annual quantity (tonnes) and composition of the waste combusted, gasified or mechanically/thermally treated by the project activity during the crediting period shall be described in the project design document, including the biomass and non-biomass carbon content of the combusted or gasified waste and RDF/SB ($Q_{biomass}$ and $Q_{non\text{-}biomass}$).

The expected consumption of auxiliary fuel for the incineration, gasification, mechanical/thermal treatment process (Q_{fuel}) should also be reported in the project design document. CO_2 emissions from the combustion of the non-biomass (i.e., fossil) carbon content of the wastes and RDF/SB and from the auxiliary fossil fuel consumed will be estimated assuming the complete oxidation of carbon to CO_2 in the combustion.

$$PE_{y,comb} = Q_{y,non-biomass} * 44/12 + Q_{y,fuel} * EF_{y,fuel} \quad (2)$$

Where:

$Q_{y,non-biomass}$	Non-biomass carbon of the waste and RDF/SB combusted/gasified in the year y (tonnes of carbon)
$Q_{y,fuel}$	Quantity of auxiliary fossil fuel used in the year y (tonnes)
$EF_{y,fuel}$	CO_2 emission factor for the combustion of the auxiliary fossil fuel (tonnes CO_2 per tonne fuel, according to latest IPCC Guidelines)

The United Nations Framework Convention on Climate Change (UNFCCC)

Indicative simplified baseline and monitoring methodologies for selected small-scale CDM project activity categories

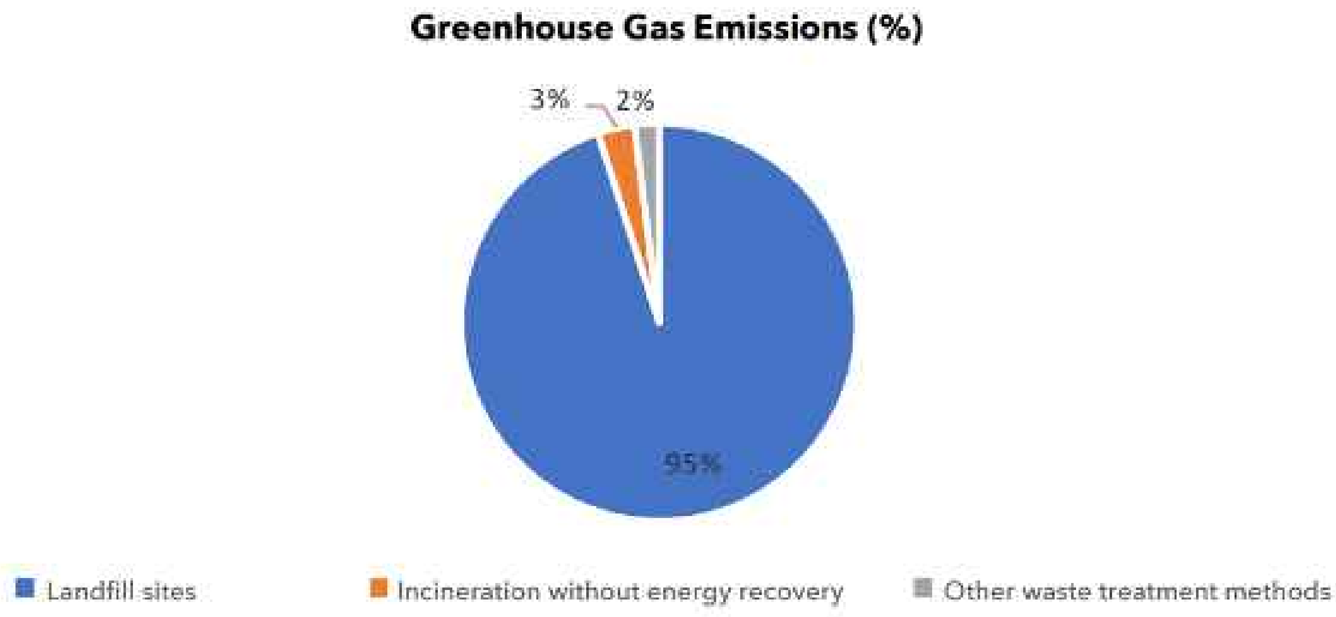
https://cdm.unfccc.int/

$$PE_{y,transp} = (Q_y / CT_y) * DAF_w * EF_{CO2} + (Q_{y,ash} / CT_{y,ash}) * DAF_{ash} * EF_{CO2} + (Q_{y,RDF/SB} / CT_{y,RDF/SB}) * DAF_{RDF/SB} * EF_{CO2} \quad \textbf{(3)}$$

Where:

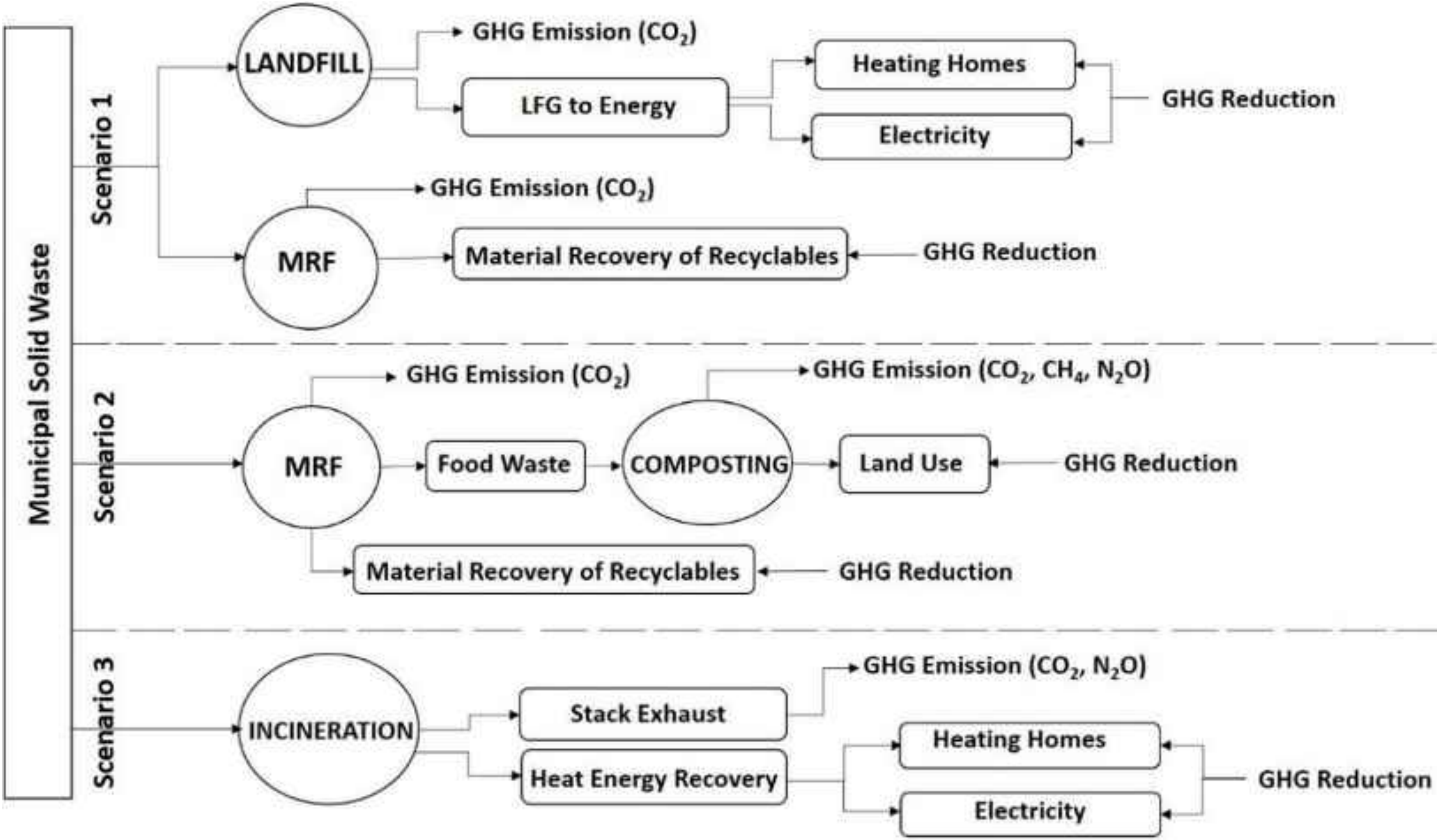
Q_y	Quantity of waste combusted, gasified or mechanically/thermally treated in the year *y* (tonnes)
CT_y	Average truck capacity for waste transportation (tonnes/truck)
DAF_w	Average incremental distance for waste transportation (km/truck)
EF_{CO2}	CO_2 emission factor from fuel use due to transportation (tCO_2/km, IPCC default values or local values)
$Q_{y,ash}$	Quantity of combustion and gasification residues and residues from mechanical/thermal treatment produced in the year *y* (tonnes)
$CT_{y,ash}$	Average truck capacity for residues transportation (tonnes/truck)
DAF_{ash}	Average distance for residues transportation (km/truck)
$Q_{y,RDF/SB}$	Quantity of RDF/SB produced in the year *y* (tonnes)
$CT_{y,RDF/SB}$	Average truck capacity for RDF/SB transportation (tonnes/truck)
$DAF_{RDF/SB}$	Aggregate average distance for RDF/SB transportation to the storage in the production site as well as to the end user sites (km/truck)

Greenhouse Gas Emissions from Waste (%) (European Environment Agency, 2014)



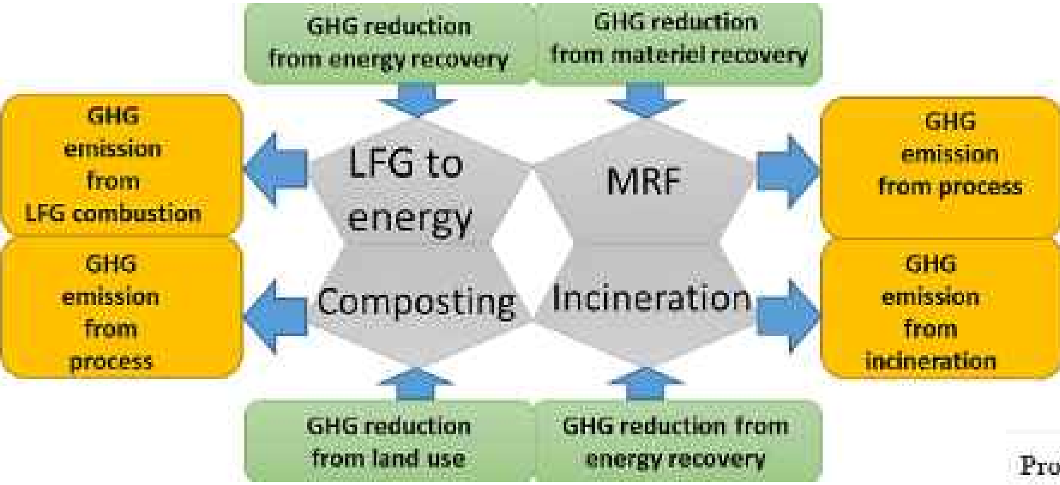
Greenhouse Gas Emissions in Turkey from Waste - 2017 (ktCO2/year) (UNFCCC, 2018)

	Total CO_2 equivalent
Solid waste disposal	9,079
Biological treatment of waste	14
Incineration	4
Wastewater treatment and discharge	8,258
Total	17,355



System boundaries of landfilling, LFG to energy, composting, MRF and incineration processes.

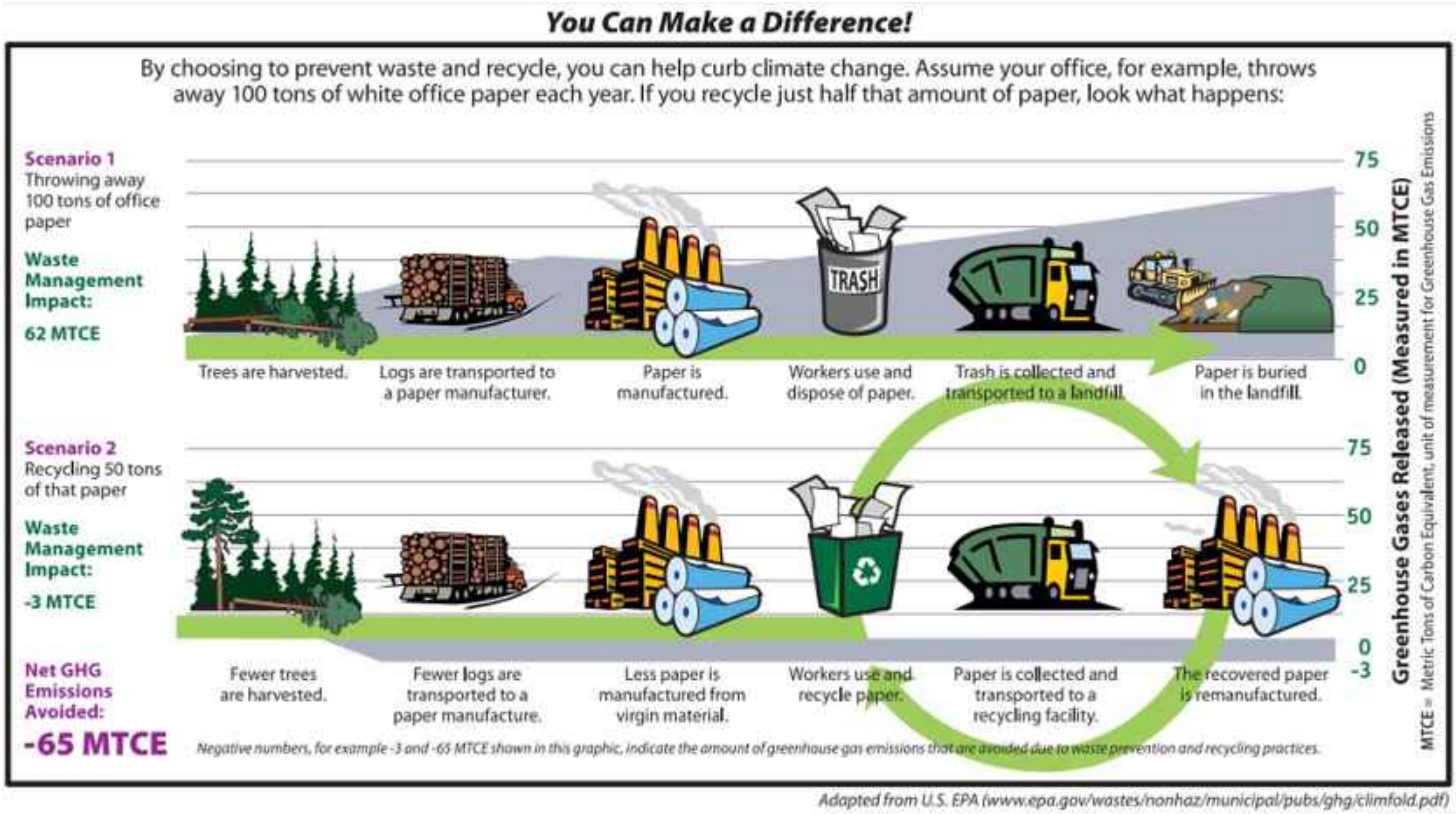
C. Yaman, Environmental Development 33 (2020)



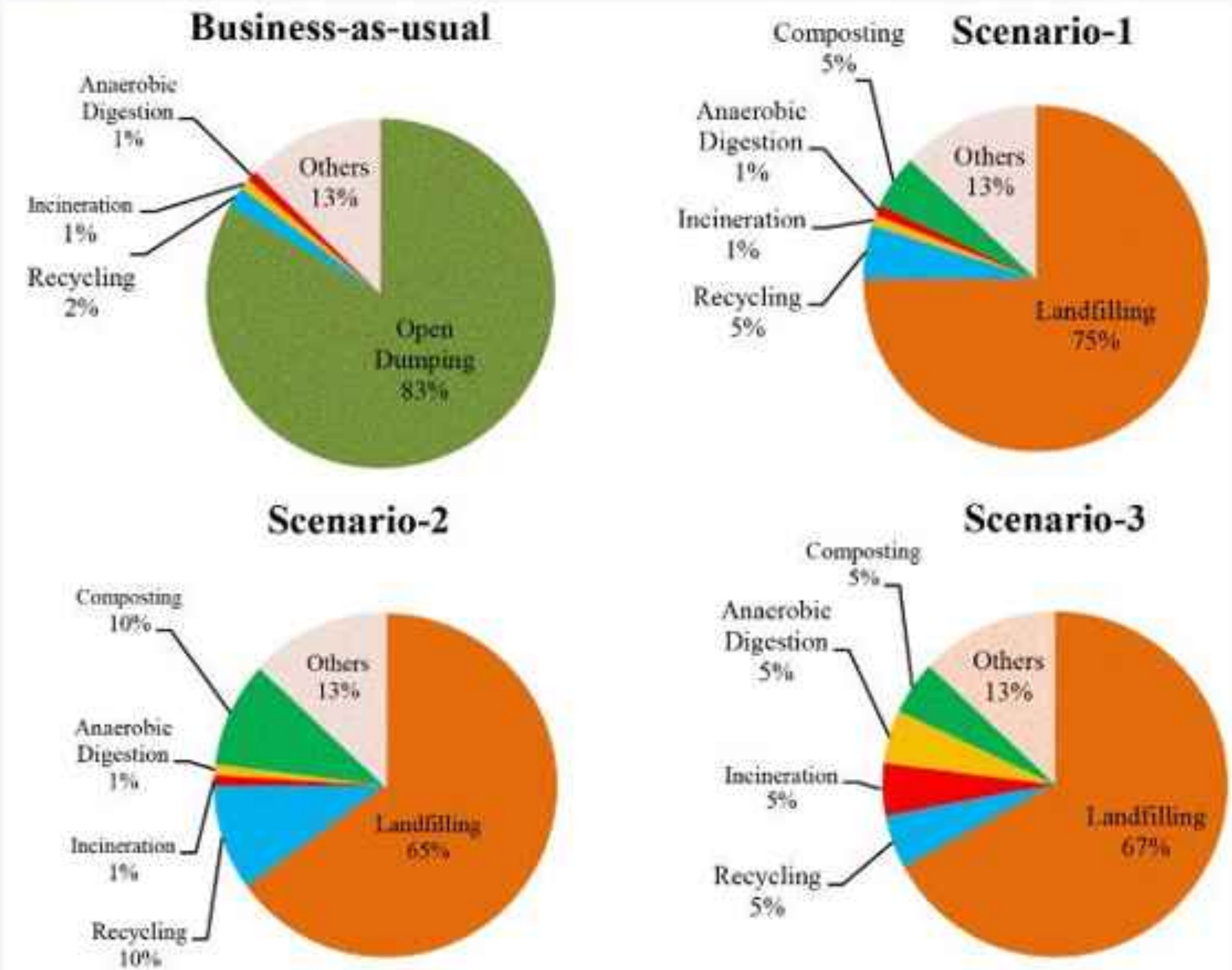
Process	Scenario 1	Scenario 2	Scenario 3
Material Recovery Facility (MRF)	Yes	Yes	No
Composting	No	Yes	No
Combustion	No	No	Yes
Landfilling with LFG recovery	Yes	No	No

- Largest net GHG reduction was through conversion of waste to energy via incineration.
- Plastics should be carefully treated because of their higher GHG potential.
- Composting has resulted in net GHG generation.
- Landfill disposal should be replaced by thermal conversion technologies.
- MRF, LFG to energy and incineration processes have resulted in net GHG savings.

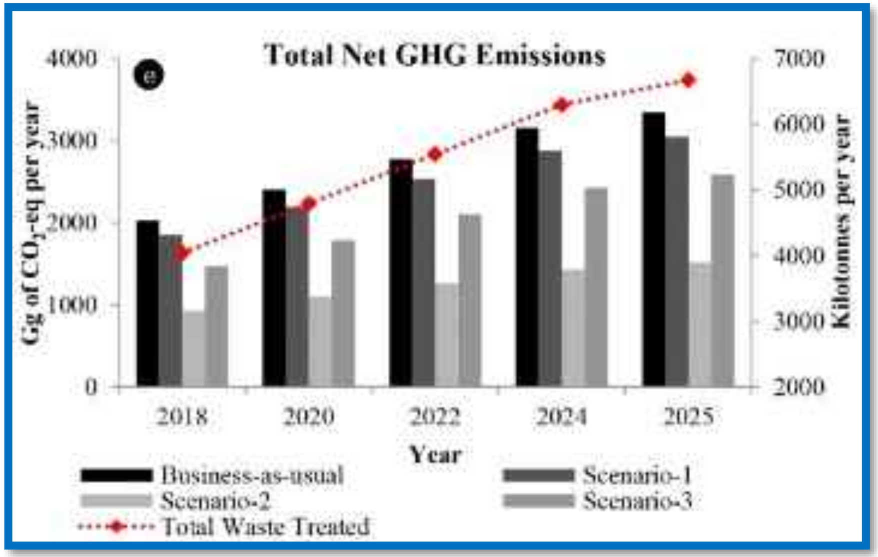
C. Yaman, Environmental Development 33 (2020)


You Can Make a Difference!
By choosing to prevent waste and recycle, you can help curb climate change. Assume your office, for example, throws away 100 tons of white office paper each year. If you recycle just half that amount of paper, look what happens:
Scenario 1
Throwing away 100 tons of office paper
Waste Management Impact:
62 MTCE
Trees are harvested.
Logs are transported to a paper manufacturer.
Paper is manufactured.
TRASH
Workers use and dispose of paper.
Trash is collected and transported to a landfill.
Paper is buried in the landfill.
Scenario 2
Recycling 50 tons of that paper
Waste Management Impact:
-3 MTCE
Fewer trees are harvested.
Fewer logs are transported to a paper manufacture.
Less paper is manufactured from virgin material.
Workers use and recycle paper.
Paper is collected and transported to a recycling facility.
The recovered paper is remanufactured.
Net GHG Emissions Avoided:
-65 MTCE
75
50
25
0
-3
Greenhouse Gases Released (Measured in MTCE)
MTCE = Metric Tons of Carbon Equivalent, unit of measurement for Greenhouse Gas Emissions
Negative numbers, for example -3 and -65 MTCE shown in this graphic, indicate the amount of greenhouse gas emissions that are avoided due to waste prevention and recycling practices.
Adapted from U.S. EPA (www.epa.gov/wastes/nonhaz/municipal/pubs/ghg/climfold.pdf)

Waste disposal methods related to business-as-usual and an alternative approach with three different scenarios during 2018–2025.



Tun and Juchelková, Environmental Engineering Research 2019; 24(4): 618-629.



The current waste management sector of Myanmar generates approximately 2,000 Gg of CO2-eq per year in 2018, trending around 3,350 Gg of CO2-eq per year in 2025.

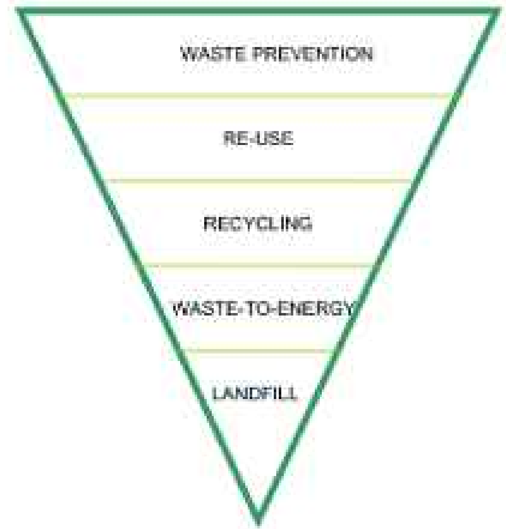
The Scenario-2 (10% recycling, 10% composting, 65% landfilling and the currently applied waste-to-energy power plants) could offer the least environmental impacts, along with the lowest GHG emissions and the highest waste resource recovery.

The GHG emissions from the business-as-usual waste management could be reduced by 50% by this scenario during 2018–2025.

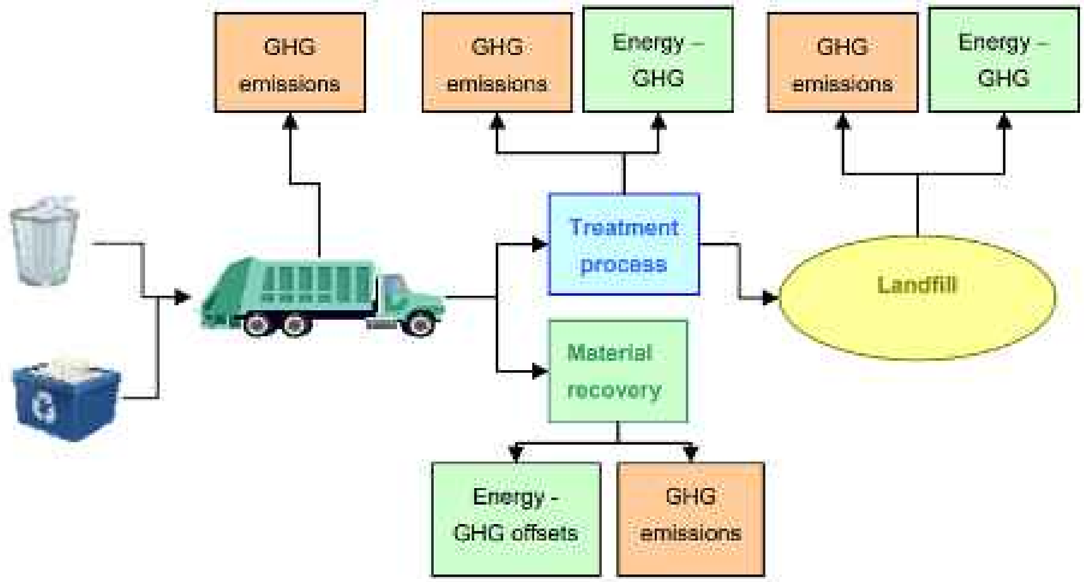
Comparison of the Waste Disposal Methods

Waste disposal methods	Separation work	Cost	Working skills and technologies	Availability of raw material resources	Energy benefits	Economic benefits	Environmental impact
Business-as-usual	As-usual	Low	Normal	Low	Average	Average	High
Scenario-1	Needed	Low	Normal	High	Average	Average	Comparatively lower
Scenario-2	Highly needed	High	Highly needed	Comparatively higher	High	High	Comparatively much lower
Scenario-3	Highly needed	Comparatively higher	Highly needed	Comparatively higher	Comparatively higher	High	Comparatively much lower

Therefore, if the local governments in Myanmar could efficiently cooperate with the public, private sectors, research institutions and non-government organizations, these achievable similar scenarios could be implemented for reducing the environmental impacts and increasing the waste resource recovery in the years to come.



The waste hierarchy



Simplified schematic of waste management system and GHG emissions (applicable to urban waste management)

The waste sector can save or reduce GHG emissions through several activities:

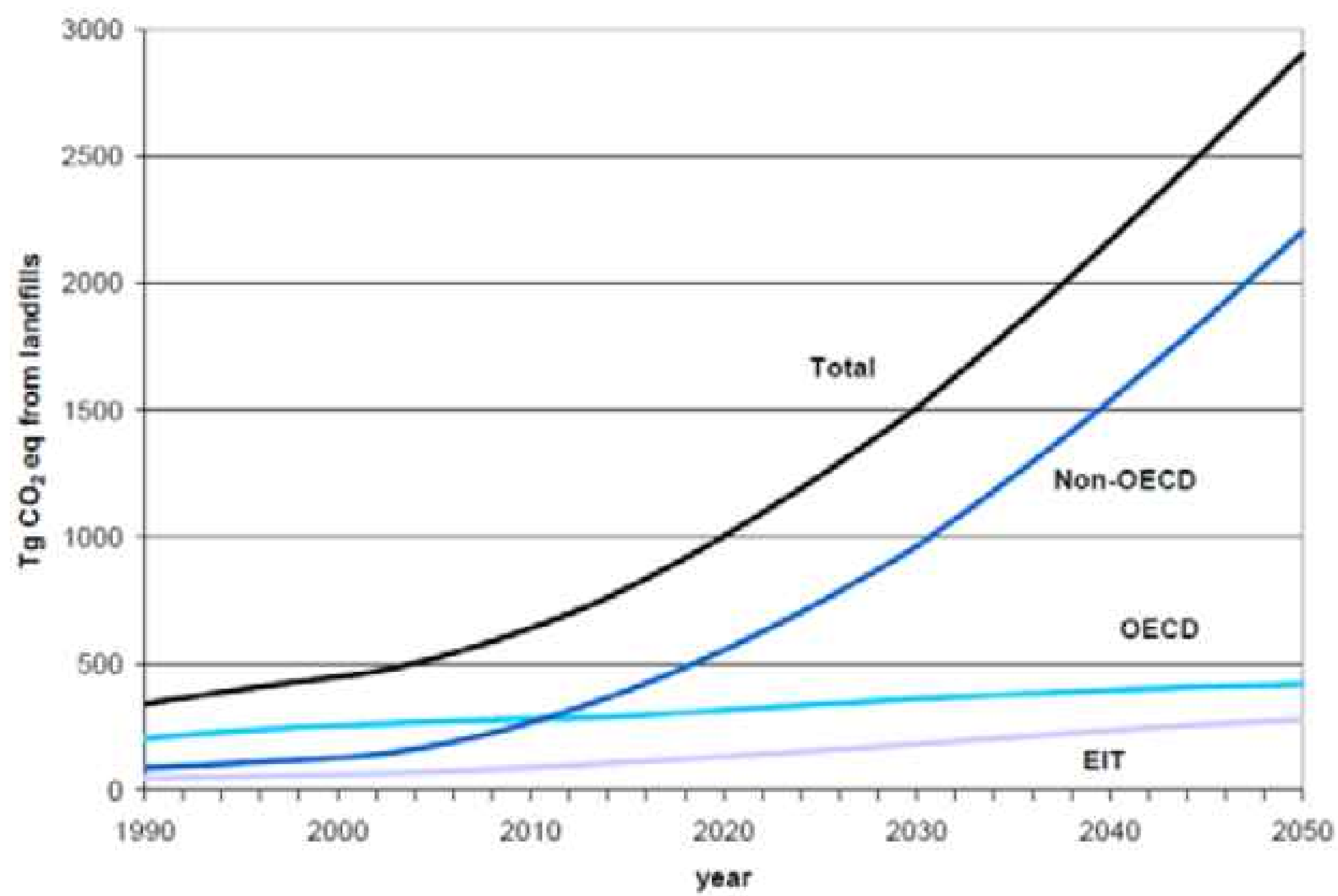
- Avoiding the use of primary materials for manufacturing through waste avoidance and material recovery (i.e. the GHG emissions associated with the use of primary materials – mostly energy-related – are avoided)

- Producing energy that substitutes or replaces energy derived from fossil fuels (i.e. The emissions arising from the use of waste as a source of energy are generally lower than those produced from fossil fuels).

- Storing carbon in landfills (i.e. carbon-rich materials that are largely recalcitrant in anaerobic landfill conditions, such as plastics and wood) and through application of compost to soils.

UNEP, Waste and Climate Change: Global trends and strategy framework, 2010

Monni et al (2006) projected emissions from the waste sector to 2050, assuming continuation of current trends in waste management (a business as usual (BAU) scenario). (1 Tg=1 000 000 Ton)



Methane emissions from different regions - BAU scenario (source: Monni et al 2006)

OECD: Organisation for Economic Co-operation and Development,
EIT : Economies in Transition

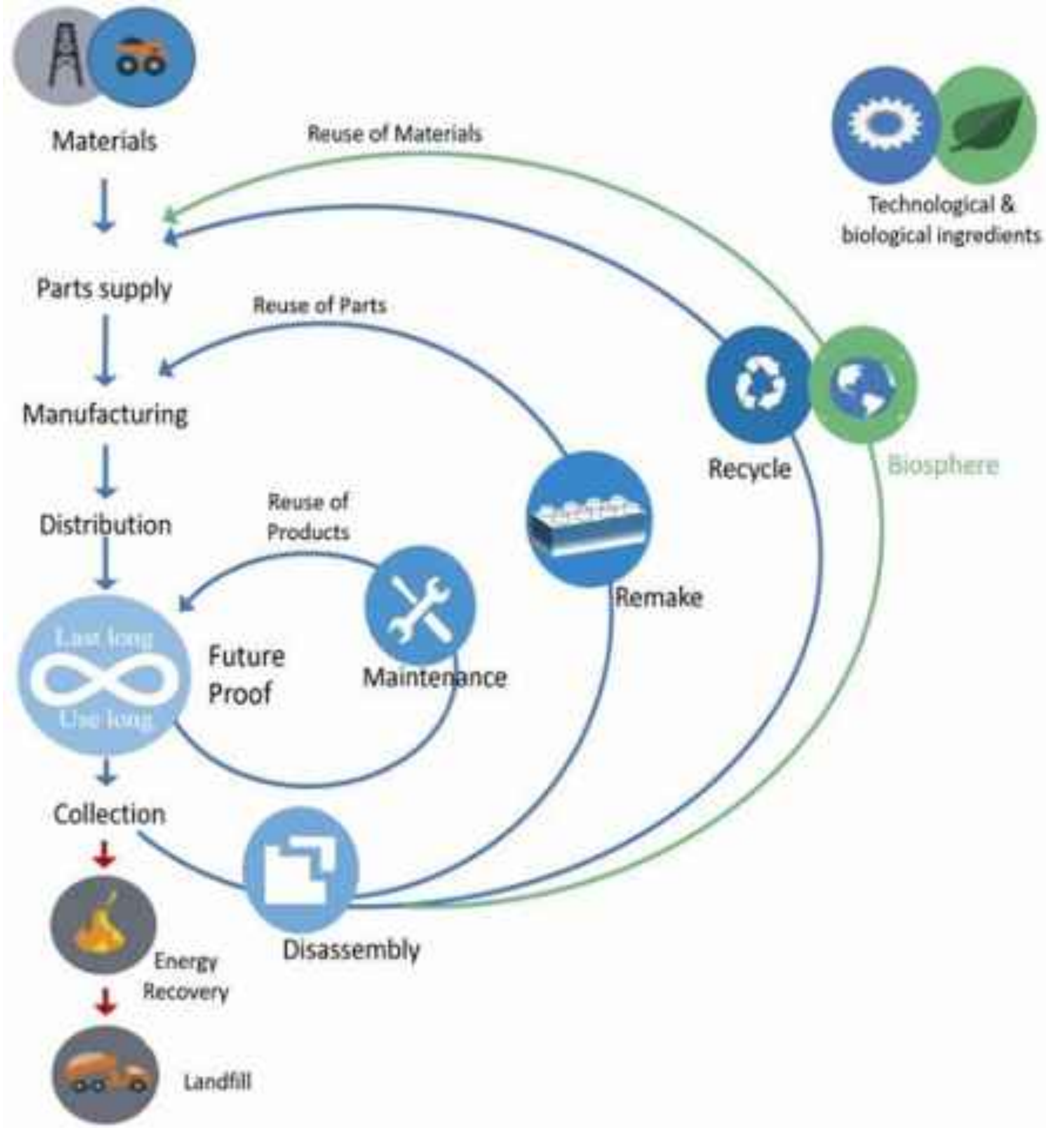
So what is the solution?

“The Greatest Threat to Our Planet Is the Belief That Someone Else Will Save It”.

Robert Swan OBE

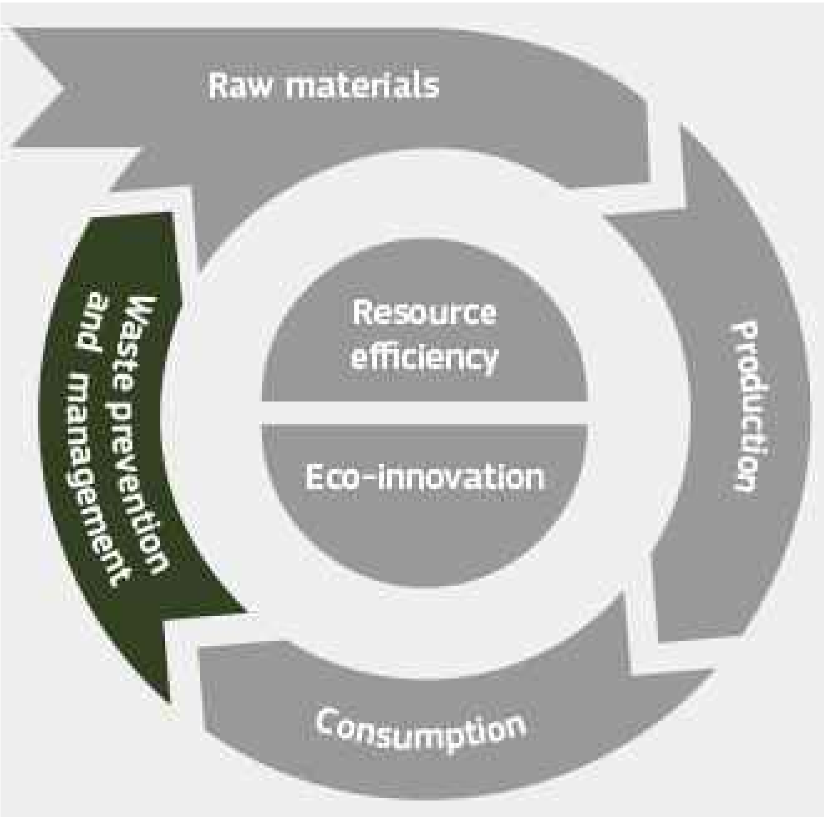
The world's first person to walk to both the North and South Poles.

CIRCULAR ECONOMY
RESOURCES
MANUFACTURING
RECYCLING
CONSUMPTION & USE
WASTE
LINEAR ECONOMY
RESOURCES
WASTE
TAKE
MAKE
DISPOSE



Materials
Reuse of Materials
Technological & biological ingredients
Parts supply
Reuse of Parts
Manufacturing
Recycle
Biosphere
Distribution
Reuse of Products
Remake
Last long
Use long
Future Proof
Maintenance
Collection
Energy Recovery
Disassembly
Landfill

Waste prevention and management – **European Union Joint Research Center**



The waste hierarchy

https://ec.europa.eu/environment/green-growth/waste-prevention-and-management/index_en.htm

The European Green Deal aims to pave the way for the EU to become carbon neutral by 2050 and to decouple economic growth from resource use. The transition to a circular economy is a key part of this endeavour.

Objectives

Measures that will be introduced under the new action plan aim to

- make sustainable products the norm in the EU
- empower consumers and public buyers
- focus on the sectors that use most resources and where the potential for circularity is high such as: electronics and ICT, batteries and vehicles, packaging, plastics, textiles, construction and buildings, food, water and nutrients
- ensure less waste
- make circularity work for people, regions and cities
- lead global efforts on circular economy


THE WASTE HIERARCHY
Avoid
1
Maximinum conservation of resources
Reuse
2
Reusing materials
Recycle
3
recycling & reprocessing materials
Waste to energy
4
energy recovery prior to disposal
Disposal of waste
5
zero conservation of resources


METHODS OF WASTE DISPOSAL
BYJU'S
Landfill
Incineration
Waste Compaction
Biogas Generation
Composting
Vermicomposting

Waste-to-Energy in Europe in 2018

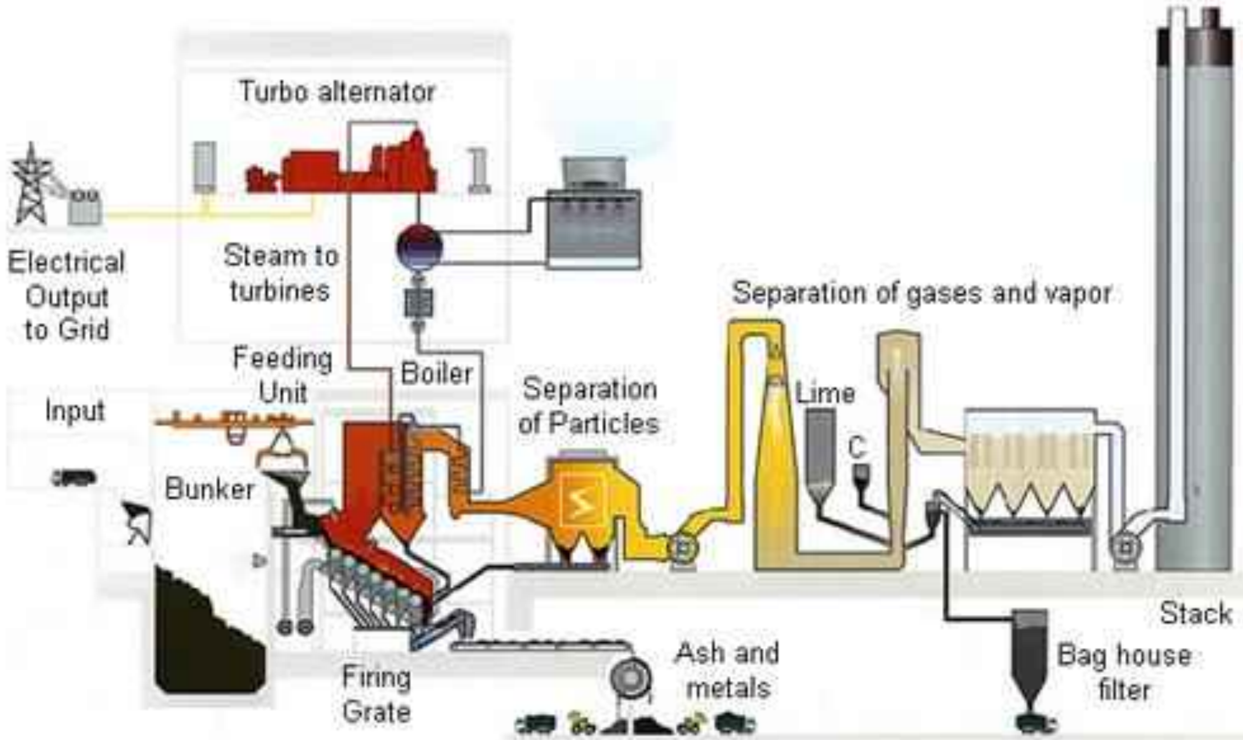
- WtE Plants operating in Europe (not including hazardous waste incineration plants) : **492**
- Waste thermally treated in WtE plants (in million tonnes): **96**

Data supplied by CEWEP members and national sources

* Includes plant in Andorra and SAICA plant

CEWEP Confederation of European Waste-to-Energy Plants

Atık Yakma



İSTAÇ Atık Yakma Tesisi
3000 Ton / Gün Atık
Yakma kapasitesi

Sectoral Reference Document on
Best Environmental Management Practice (BEMP) for the Waste Management Sector, 2020

14.4.2020 | EN | Official Journal of the European Union | L 115/1

II

(Non-legislative acts)

DECISIONS

COMMISSION DECISION (EU) 2020/519

of 3 April 2020

on the sectoral reference document on best environmental management practices, sector environmental performance indicators and benchmarks of excellence for the waste management sector under Regulation (EC) No 1221/2009 on the voluntary participation by organisations in a Community eco-management and audit scheme (EMAS)

(Text with EEA relevance)

THE EUROPEAN COMMISSION,

This Sectoral Reference Document addresses two types of organisations of the waste management sector: waste management companies (public and private), including companies implementing producer responsibility schemes, and waste authorities (public administrations in charge of waste management, mainly at local level).

— 38.1 — waste collection;

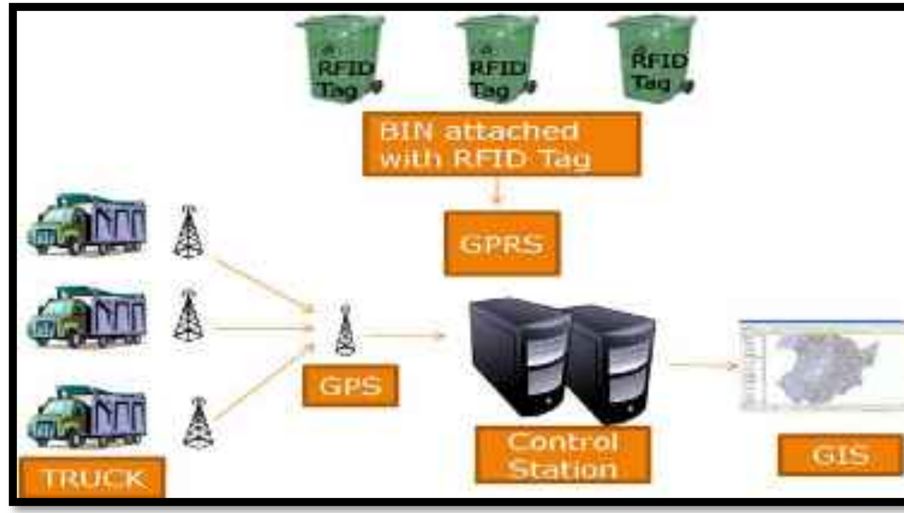
— 38.2 — waste treatment and disposal;

— 38.3 — materials recovery;

Strategy BEMPs

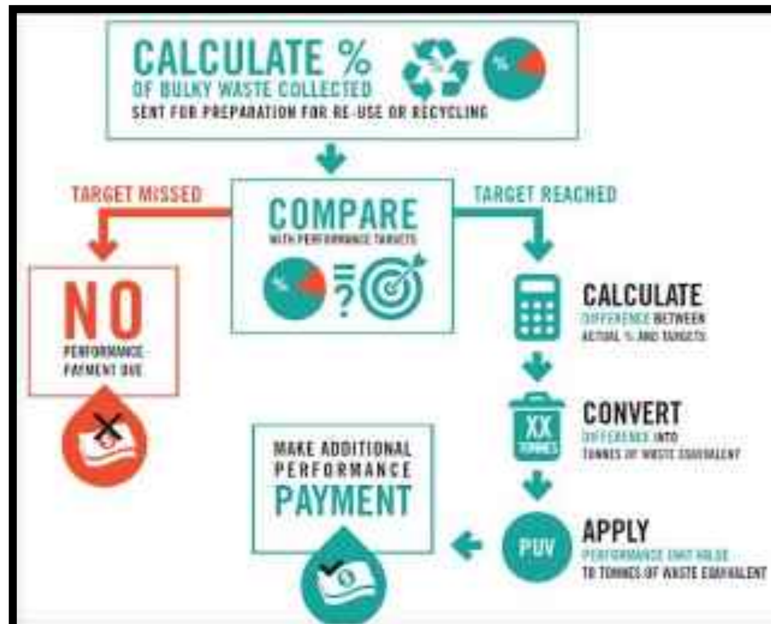
3.2.1. Cost benchmarking

3.2.2. Advanced waste monitoring



3.2.3. Pay-as-you-throw

3.2.4. Performance-based waste management contracting



Sectoral Reference Document on Best Environmental Management Practice for the Waste Management Sector, 2020

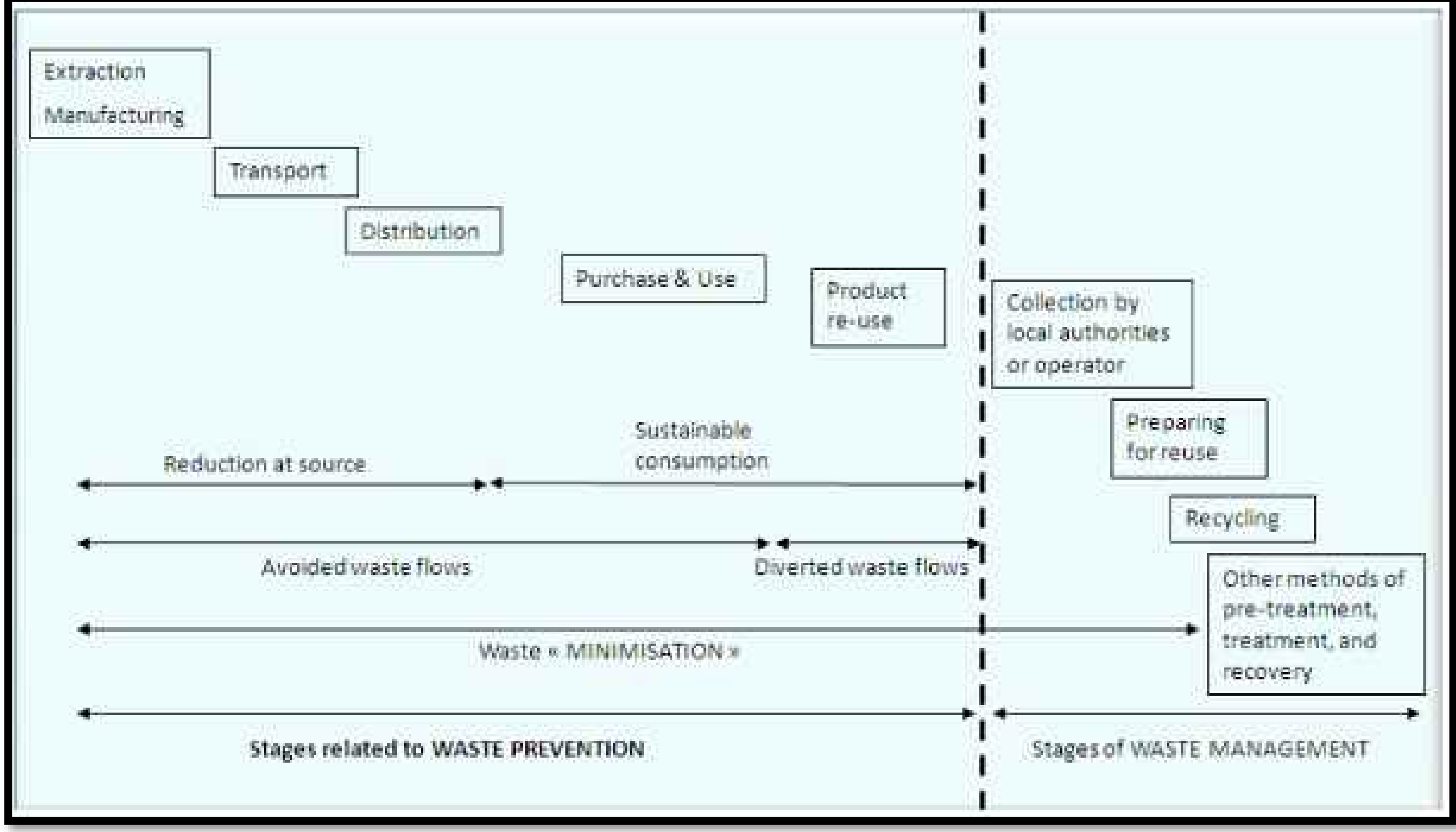
Strategy BEMPs

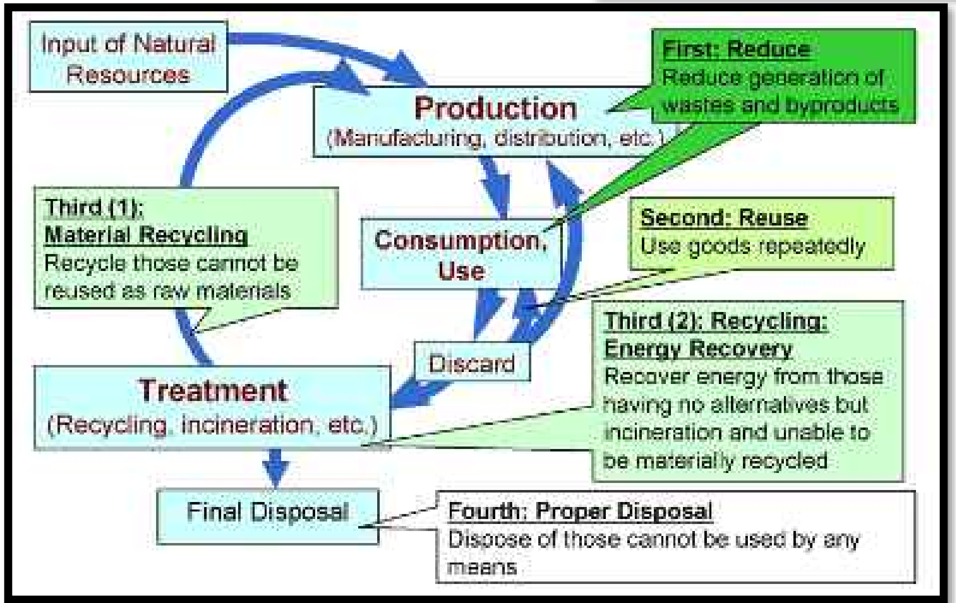
3.2.5. Awareness-raising

3.2.7. Home and community composting

BEMPs for waste prevention

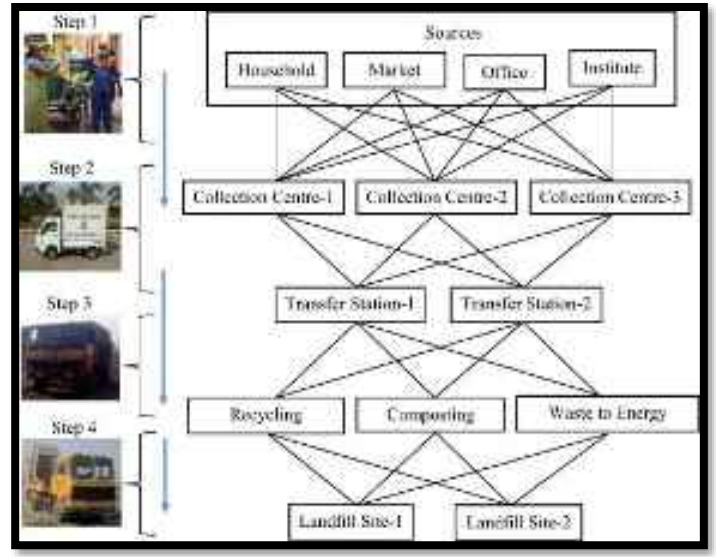
3.2.8. Local waste prevention programmes



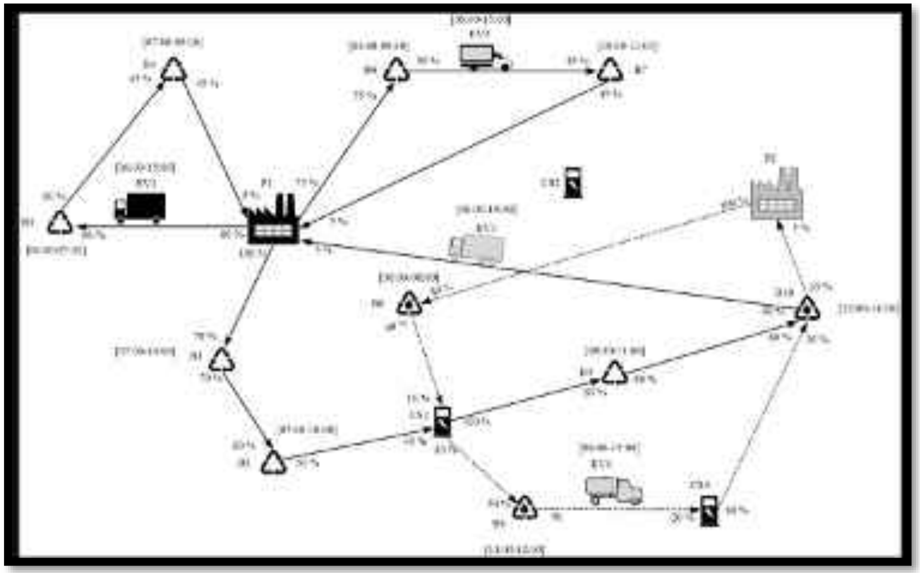


3.2.9. Schemes fostering the re-use of products and the preparation for re-use of waste

BEMPs for waste collection



3.2.10. Waste collection strategy



3.2.13. Logistic optimisation for waste collection

3.2.14. Low-emission vehicles

BEMPs for extended producer responsibility schemes

3.2.15. Best use of incentives by producer responsibility organisations

BEMPs for waste treatment

3.2.16. Sorting of co-mingled light packaging waste to maximise recycling yields for high-quality output

(a) (b) (c) (d)

Selection of topics for EU in Green Deal

Local Climate Action Waste Management And Recycling Procedures For Waste

End-of-waste: boosting the market for secondary raw materials

End-of-waste criteria determine when waste-derived materials have been sufficiently processed so that they can lose their waste status and enjoy the same internal market freedoms as primary raw materials.

Towards a circular and sustainable use of nutrients

Many waste or residue materials produced in Europe contain valuable nutrients, which are underutilised and often generate environmental pollution. Nutrient recycling allows to solve these problems.

Circular economy of batteries

The new Batteries Regulation aims to ensure that batteries placed on the EU market fit into the circular economy and are sustainable and safe throughout their entire life cycle.

More value from plastic recycling

Europe needs to further improve the recycling of plastics. The mapping of the plastic flows in the economy allows to identify the bottlenecks for more circularity.

The many lives of lubricant oils

What are the advantages of recycling waste oils and which processes generate the maximum benefits for environment and society?

Simpler waste collection for better recycling

How municipal waste collection can be improved for better recycling.

Revisiting the definition of recycling

The JRC works on more accurate methodologies for calculating recycling.

Construction and demolition waste

Improving the management of the construction and demolition waste is a priority because it represents ca. 40% of the waste generated in EU.

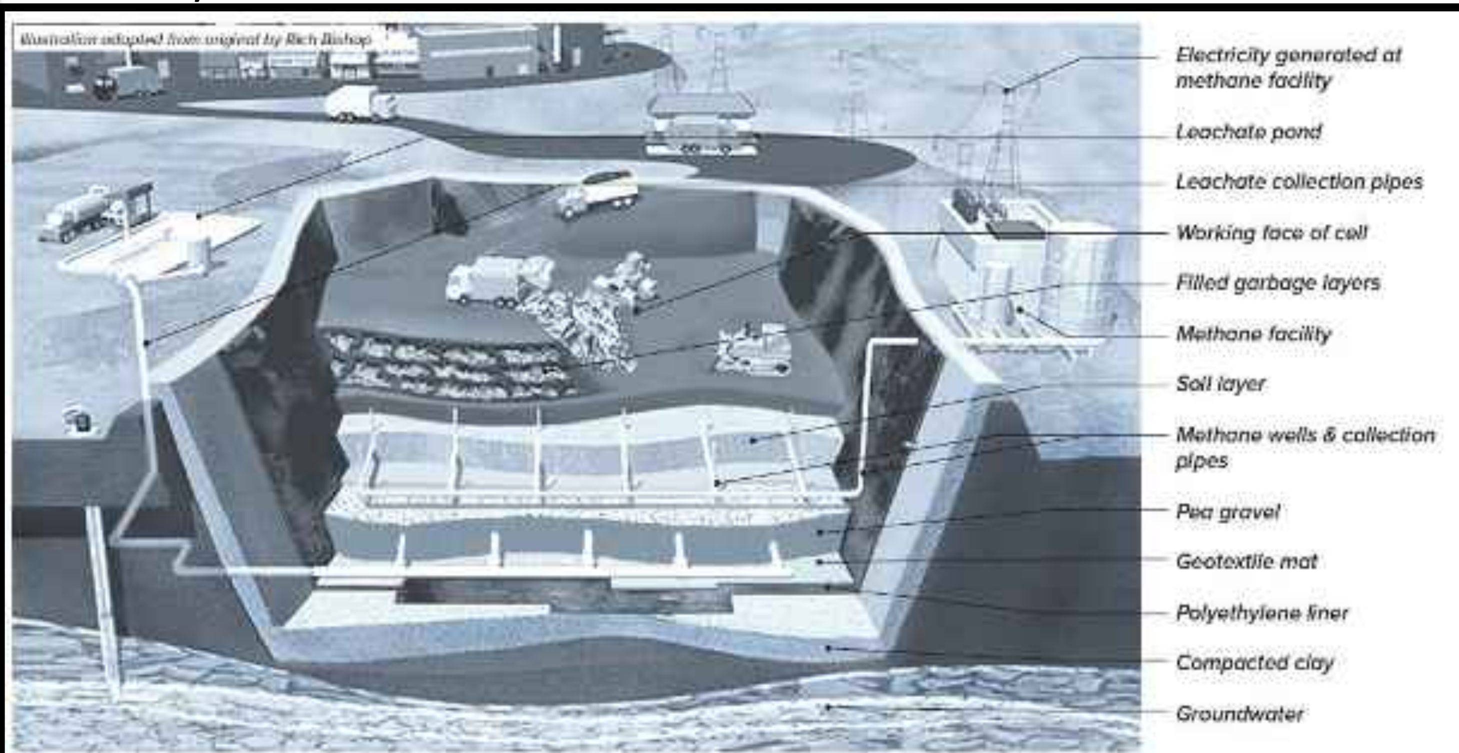
Textiles' impact on environment

The consumption and sustainability of textiles is in the spotlights of policy makers.

Sanitary landfills are a mature and proven waste management technique.

Nevertheless, they are still fairly uncommon in low- and some middle-income countries due to the costs involved in infrastructure and operation and inadequate regulatory oversight.

In these areas, it is more common to find uncontrolled or open dumps that lack basic environmental controls, putting public health and safety at risk.

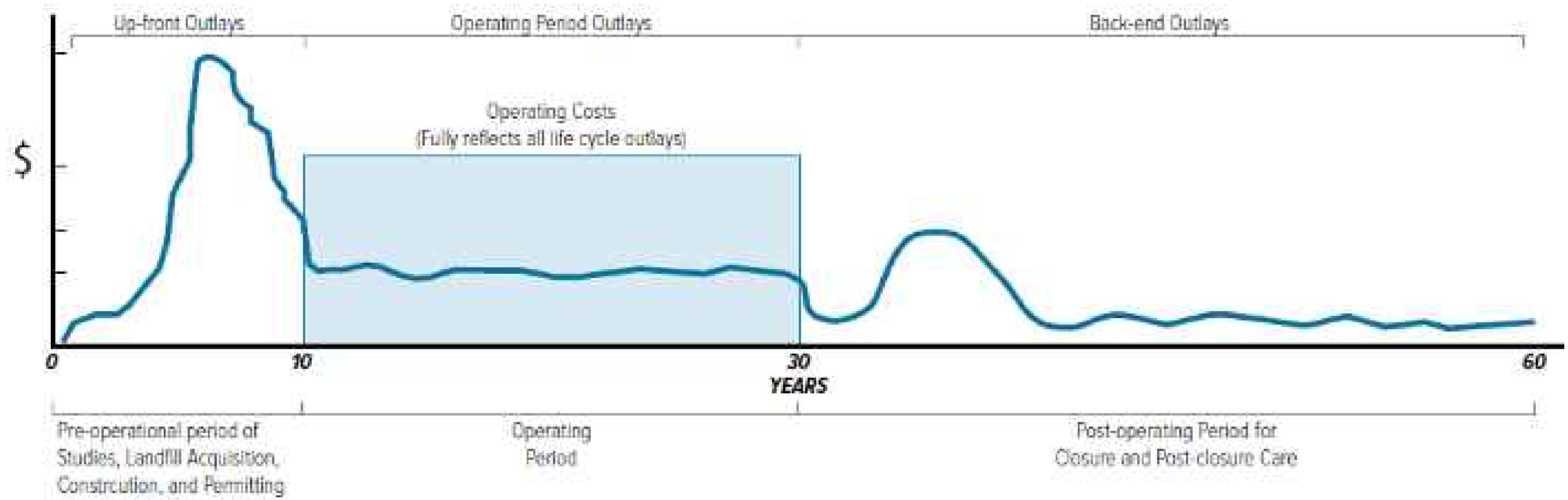


Schematic diagram of a sanitary landfill

SANITARY LANDFILLS

Upfront Capital	Operations and Maintenance	Closure and Post-Closure
Costs vary considerably by size, region, regulations, design sophistication, etc. • Studies and design (e.g., site selection, topographic survey, social impact assessment) • Land acquisition • Preparation of the site • Closure of open dumps • Regulatory approval • Construction and equipment	• Labor • Safety equipment • Machinery and vehicles (e.g., compactors) • Venting of gases and drainage, leachate treatment • Monitoring equipment • Periodic changes to the site (e.g., roads, cell development and closures, excavations) • Power, fuel	Post-closure costs can continue for up to 30 years after landfill closure • Final closure (e.g., landfill cap) • Drainage system • Green cover and landscaping • Monitoring costs for landfill gas and groundwater contamination

c



Landfill life-cycle costs and outlays
Source: US Environmental Protection Agency, 2014

COMPOSTING

- Composting on a municipal scale requires segregating the organic waste from other waste materials to ensure a high-quality end product.
- Composting differs from the natural decaying process because levels of oxygen, moisture, temperature, nutrients and the chemical environment are monitored and controlled at a facility.

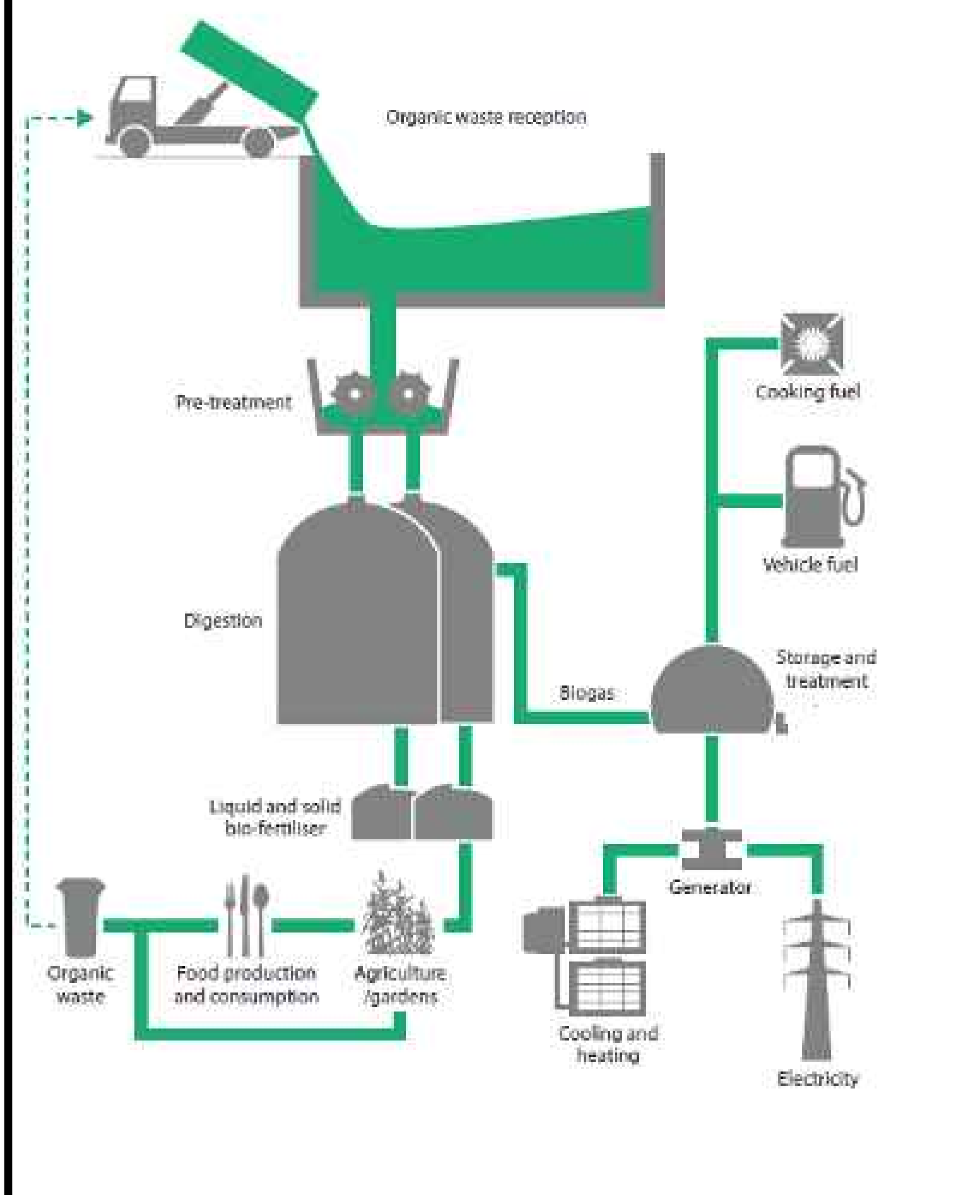
COMPOSTING

	Windrow/Static Piles	In-Vessel
Scale of operation	Large/ regional/ municipal	Small/ neighborhood/ community
Processing capacity (tonnes per day)	1 – 1,000	20 – 350
Space/land requirement	High	Small, can increase for windrow drying or maturing of compost
Time required	Several weeks	Few days to weeks depending on the specifications of the unit. However, the compost might need to sit an additional 2-4 weeks prior to use
Odor	Can be significant if not well aerated	Air purification system confines odor to the vessel
Leachate production	Low	Minimal
Sensitivity to weather	If feedstock freezes, the decomposition process stalls	Functions in all climates
Capital cost (US$/tonne)	40-60	300-500
Operating cost (US$/tonne)	12	130

ANAEROBIC DIGESTION

Anaerobic Digestion is a proven technology that has been used for many years to treat animal waste and municipal and industrial wastewater.

More recently, it is being used to convert the organic content of municipal solid waste (MSW) to useable products.

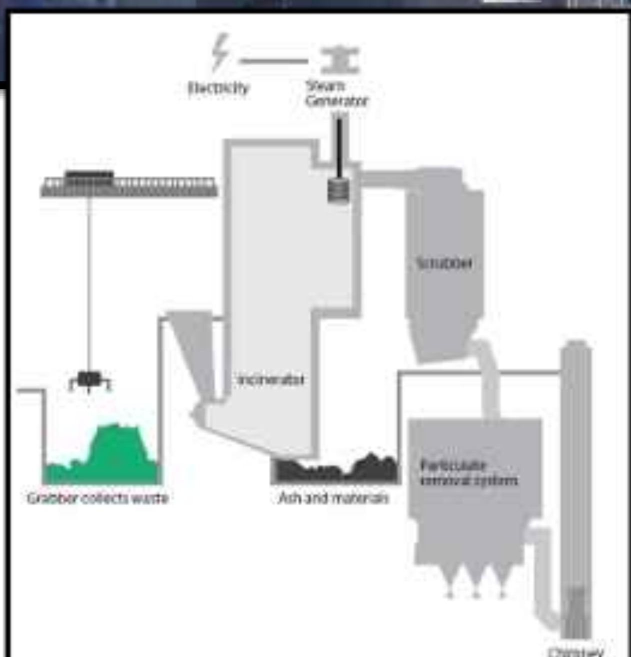


Schematic of fertilizer and energy generation from organic MSW in AD

	Anaerobic Digestion	
	Capital Expenditures (US$/annual tonne) *(1)*	Operational Expenditures (US$/tonne)
Europe	$345-600	$31-57
United States	$220-660	$22-55

(1) Annual tonne is the capital cost of the facility divided by the annual processing capacity

Fixed O&M costs	Variable O&M costs
• Include labor, maintenance, routine equipment replacement, etc. • Usually calculated as a percentage of capital costs • Range from 2.1 to 7% of installed cost of AD systems	• Include non-biomass fuel, unplanned maintenance and equipment replacement • Vary based on the output of the system and are usually expressed as a value per unit of output (e.g., $/kWh) • Approximately $4.2/MWh on average



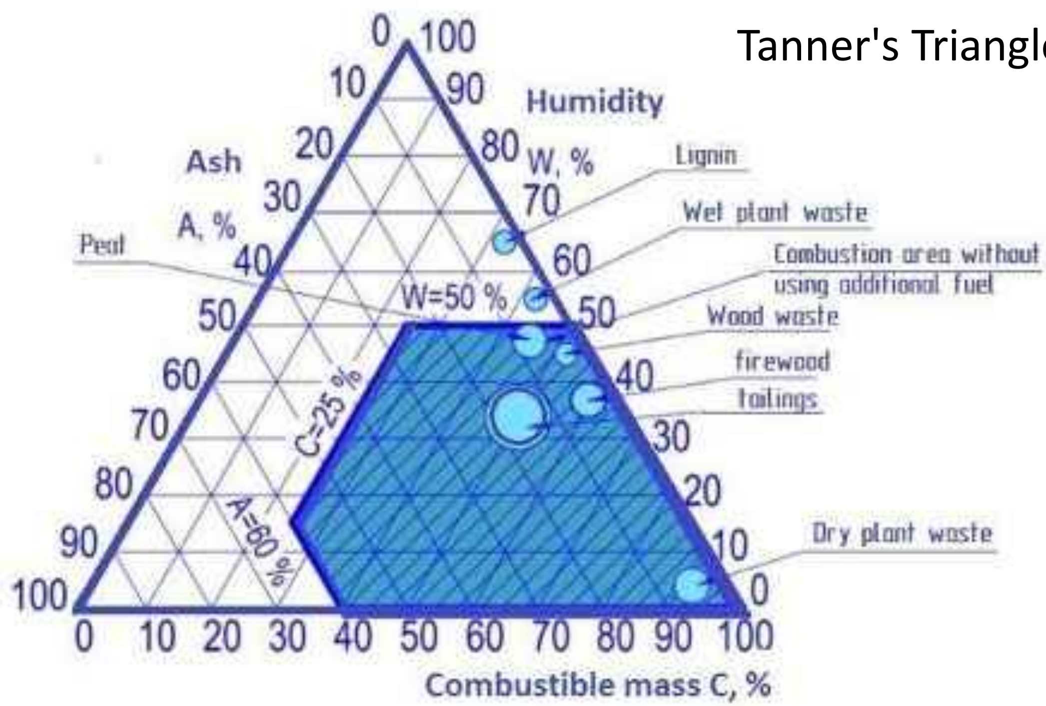
Schematic diagram of incineration facility

INCINERATION WITH ENERGY RECOVERY

Although incineration technology has matured over the last few decades, it is still relatively expensive, and thus primarily used in high-income countries.

Incineration has been implemented successfully in jurisdictions with land (or landfill) scarcity, high technical capacity, significant financial resources, strong environmental regulations and typically a low or separated organic waste fraction.

Tanner's Triangle



World Bank, Decision Maker's Guides for Solid Waste Management Technologies, 2018.

	Incineration Expenditures	
	Capital Expenditures (1) (US$/annual tonne) (2)	Operational Expenditures (3) (US$/tonne) (4)
Europe	$600-1000	$25-30
United States	$600-830	$44-55
China	$190-400	$12-22

(1) In Europe and US, predominantly mass-burn/moving grate technology is used for waste incinerator with energy recovery (waste-to-energy). In China many incinerators use circulating fluidized bed (CFB) technology which reflects the lower end of investment cost although moving grate incinerators are also becoming more common.

(2) Annual tonne is the capital cost of the facility divided by the annual processing capacity of the facility

(3) Operating costs without accounting for revenues range between $100-200/tonne. The figures presented in the table are typical operating costs (net gate fees) taking into account revenues for electricity and/or heat sales and other revenues. In the EU, also including subsidies to energy from waste in some countries, these revenues are typically about $100/tonne, hence the resulting operating costs. In US feed-in tariffs for electricity are typically lower, below $50/MWh.

(4) Mixed waste in the US and the EU is relatively low in organics and water content and hence high in calorific value. As a consequence, operating costs for waste with high organics often seen in lower income countries could substantially increase operating costs due to lower revenues

Capital Costs	
• Land and buildings acquisitions • Design and construction of the facility and related systems (steam turbine, APC, etc.) • Environmental and social impact assessments	• Approvals and licensing • Machinery and equipment • Training and monitoring equipment

REVENUE OPPORTUNITY

Revenues can be obtained from tipping fees, sale of electricity, metals recovery, and carbon finance.

Costs are sometimes also calculated based on the per kilo-watt generation electricity from the facility. Comparative costs of thermal treatment options are shown below ($/kW for a 15 MW output)

Incineration with energy recovery	$7,000-10,000
Gasification (conventional)	$7,500-11,000
Gasification (plasma arc)	$8,000-11,500
Pyrolysis	$8,000-11,500

PYROLYSIS AND GASIFICATION

Pyrolysis and gasification, two technologies referred to as Advanced Thermal Treatment (ATT) technologies, convert waste primarily into a synthetic gas or fuel.

Capital costs for ATT technologies range between $15-80 million for facilities that receive 25-100 kilo-tonnes per annum of MSW.

Operating costs can vary from $3-3.7 million (roughly $35/tonne) for a 100,000 tonne/year facility.

Both ATT technologies burn waste in a zero- or low-oxygen environment and provide several waste management benefits:

(1) quick and large reduction in mass and volume of waste, thus prolonging landfill life;

(2) destruction of toxic substances; and

(3) Energy production.

Decision Maker's Guides for Solid Waste Management Technologies

	Pyrolysis	Gasification	Incineration with energy recovery
Air Supply	Total absence of oxygen	Low oxygen	Significant oxygen
Temperature Range (°C)	300-800	>750	>850
External heat source	Required	Required	Not required
Pre-treatment of Feedstock	Required (removal of glass, metals, inerts)	Required (removal of glass, metals, inerts)	Not required unless waste has organic fraction to be dried
Products	Syngas, char, tar	Syngas, char, ash	Steam, gas, ash
Outputs	Syngas converted to liquid fuel to produce electricity, heat, or use in a gas engine or as a chemical feedstock	Syngas converted to liquid fuel to produce electricity, heat, or use in a gas engine or as a chemical feedstock	Heat, electricity
Scale of application	Range from small scale (30,000 tonnes/year) to large scale (500,000 tonnes/year)	Range from small scale (30,000 tonnes/year) to large scale (500,000 tonnes/year)	Generally large scale (73,000+ tonnes/year)
Efficiency of energy conversion to a steam boiler	10-20%	10-20%	19-24%


thank you