POLITECNICO MILANO 1863

Master of Science in Energy Engineering - Renewables and Environmental Sustainability

BIO-ENERGY AND WASTE-TO-ENERGY TECHNOLOGIES *(AY 2017/18)*

Waste management: an introduction

Prof. Mario GROSSO – Department of Civil and Environmental Engineering (DICA)

Course description

Major focus: environmental and engineering aspects in the field of energy production systems from biomass and waste products

Lecture contents organisation:

- general perspective on raw materials and waste applicable as feedstock in bio-energy and waste-to-energy systems
- different types and routes for biomass and waste derived fuels recovery of energy
- process and engineering aspects of direct and indirect energy production from biomass and waste derived fuels (thermochemical, mechanical and biological conversion routes)
- energy and environmental balance of the different system routes within life-cycle assessment approaches (LCA)
- economic aspects

Learning objectives

 # 1 → to understand the framework of energy recovery from waste and biomass (strategies, legislation)

 # 2 → to learn the most important processes for energy and fuels production from waste and biomass

 # 3 → to design some energy conversion systems (WTE plant, anaerobic digestion plant, SRF production plant,...)

 # 4 → to critically assess alternative options for energy recovery, based on energy balances, environmental assessment, economic considerations

A field visit will be organised: bio-refinery, Waste-To-Energy, anaerobic digestion plant (Nov/Dec)

Lecturers

Mario GROSSO
DICA – Environmental Section
Specialist in waste management and treatment

Federico VIGANO'
Department of Energy
Specialist in energy conversion - waste

Lucia RIGAMONTI
DICA – Environmental Section
Specialist in LCA of waste and biomass systems

Elena FICARA
DICA – Environmental Section
Specialist in biological treatments

Giovanni DOLCI
DICA – Environmental Section
Teaching assistant

Course schedule and format

We will have lectures always in classroom G:

- Mon, 13.15 – 17.15
- Wed, 11.15 – 13.15
- Wed, 14.15 – 17.15

Most of the times there will be lectures (total about 65 hours)
Sometimes there will be precepts (total about 25 hours)
Precepts focus on the solution of problems which show the application of the concepts presented in the lectures

Slides and all relevant information are available in the course website: http://beep.metid.polimi.it

Requirements and grading (1)

- Written mid-term exam (**early November**) on the topics presented up to end-October:
  - Time: 1h 30’
  - 2 problems + 2 open questions

- Written final exam:
  - 2 dates in Jan-Feb
  - 3 dates in Jun-Jul-Sep
  - Composed of:
    - Part A: the same topics covered by the mid-term exam;
      Time: 1h
      1 problem + 2 open questions
    - Part B: all the remaining topics;
      Time: 1h
      1 problem + 2 open questions

Requirements and grading (2)

- With a positive result (18+/30) in the mid-term exam:
  - One is expected to take only part B of the final exam (Jan-Feb dates)
  - Upon achievement of a positive result (18+/30) in part B, the final grade will be given 50% by that of the mid-term exam and 50% by that of the final exam, part B
- Otherwise one must take the full final exam
- The result of the mid-term exam will be lost after February 2018 or once one takes the part A of a final exam
- In Jun-Jul-Sep 2018 there will a total of three calls for the full exam
- In all written exams (mid-term and final):
  - No books, notes, cell phone, laptop, tablet are allowed
  - Answers to open questions must be as brief as possible and fit within the given space
- An oral exam can be arranged upon achievement of a positive grade in the written exams: it can change the final score by ±2/30

Course materials and contacts

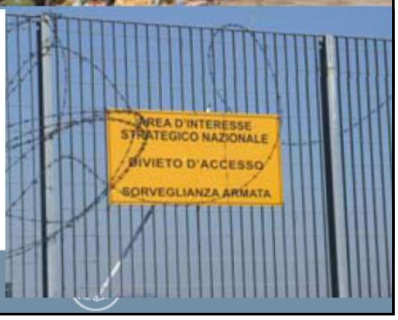
- No official text book exists for this course
- Notes for all the lectures will be posted in advance on the course website
- On the course website you will find full contact details for all the teaching team members

- A suggested comprehensive textbook for the waste management and LCA issues is:
  Thomas H. Christensen (Editor) “Solid Waste Technology & Management”, 2011, WILEY

http://beep.metid.polimi.it

INTRODUCTION

31



INTRODUCTION

33

A landfill?

Main waste streams

- Municipal solid waste
- Industrial waste
- Waste from caves and mines
- Construction and demolition waste
- Agricultural waste

Why is waste sector climbing the environmental agenda?

Compared to water and air, waste is a visible solid material, that occupies space and needs to be moved away.

Despite recent legislation, waste generation has been constantly increasing. Only the recent economic downturn has helped (at least) to stop the growth

→ Transition from **a basic management** to an **integrated one**

→ And from a **linear** to a **circular economy**

Significant attention and concern by the population!

INTRODUCTION

37

Distribution of waste-to-energy plants (as of year 2013)

M. Grosso

POLITECNICO MILANO 1863

INTRODUCTION

38

Distribution of <u>legal</u> sanitary landfills (as of year 2012)

M. Grosso

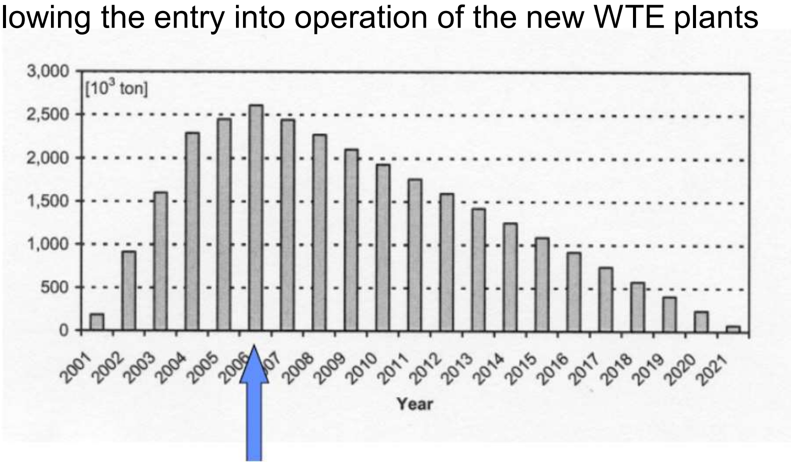
POLITECNICO MILANO 1863

INTRODUCTION

The «ecoballe» storage facilities in Campania region

INTRODUCTION

Campania Region – an estimate of the «ecoballe» disposal following the entry into operation of the new WTE plants



Actually 5.6 million tonnes and just one WTE plant, which is actually not processing the «ecoballe»

INTRODUCTION

<u>Some ideological positions</u>

- Material recycling **as an alternative** to energy recovery
- Energy recovery **as an alternative** to waste prevention policies
- The “highly recycling municipalities” (“Comuni ricicloni”), actually “highly <u>collecting</u> municipalities”
- The waste issue is highly manipulated by the politicians

INTRODUCTION

Waste management is a common target of population protest

- Waste incineration plants are on the top of the list
- “NIMBY” and “BANANA” syndrome
- People are often opposing also “lighter” installations (ex. composting plants due to odours)
- Protests against “door to door” collection systems!

<u>People claim to be “expert” of waste management, which is perceived as an “easy target”</u>

INTRODUCTION

A strategic role on different fronts

- Electric energy production from renewable sources (Green Certificates)
- Renewable methane (biomethane) fed to the grid
- Greenhouse gases reduction policies
- Energy saving policies (White Certificates)
- Circular economy

Recent trends in waste management

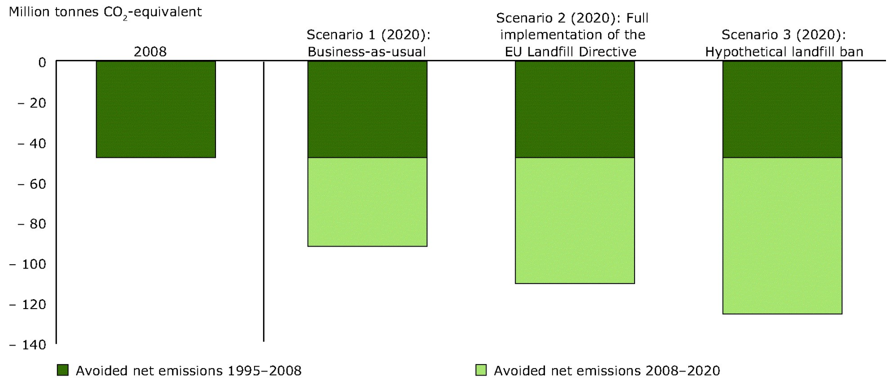
- ✓ Diversion from landfill (1999/31 EU Directive)
- ✓ Waste prevention
- ✓ Increased recycling of packaging materials, with a focus on **quality**
- ✓ Source separation of kitchen waste and its anaerobic digestion for biogas production
- ✓ High efficiency in energy recovery from waste, with a focus on **flexibility**

A sound waste management can contribute to the reduction of greenhouse gases emissions

Recent trends in waste management

50

Net emission reductions from MSW management in the EU in 2008 and 2020 compared to 1995

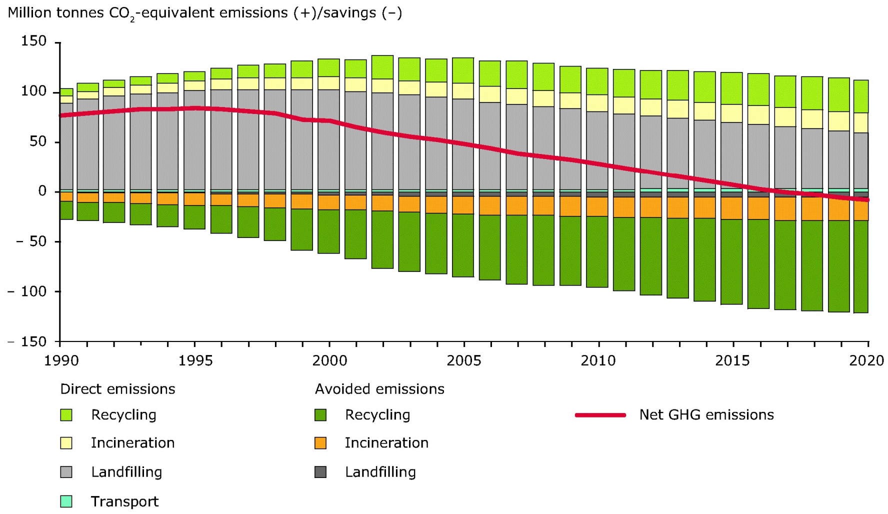


Source: ***Waste opportunities — Past and future climate benefits from better municipal waste management in Europe (EEA, 2011)***

Recent trends in waste management

51

Modelled GHG emissions from MSW management in the EU — business-as-usual scenario

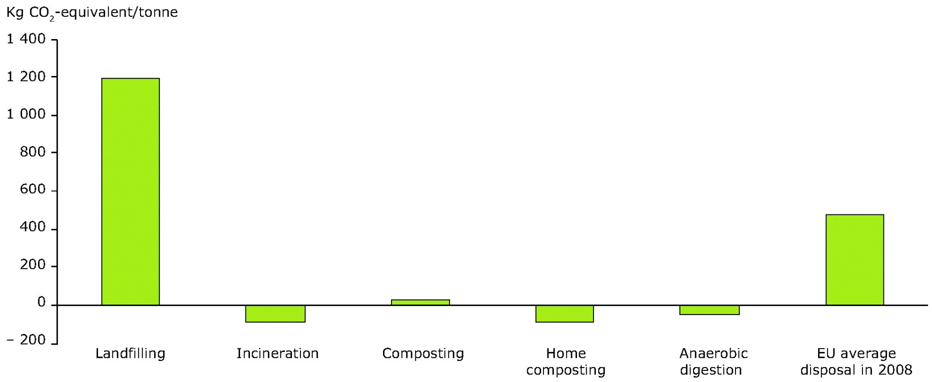


Source: ***Waste opportunities — Past and future climate benefits from better municipal waste management in Europe (EEA, 2011)***

Recent trends in waste management

52

Net emissions (kg CO_2-equivalent) per treatment option for one tonne of kitchen and garden waste



Source: ***Waste opportunities — Past and future climate benefits from better municipal waste management in Europe (EEA, 2011)***

INTRODUCTION

53

Global challenges

According to the ISWA Global Waste Management Outlook (Sept. 2015), worldwide:

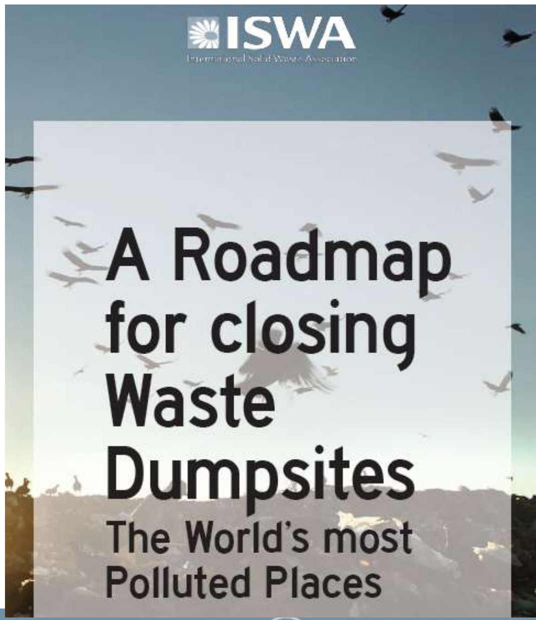
- around 2 billion people lack access to regular waste collection
- around 3 billion people lack access to controlled disposal services

Economic costs to society of inaction are 5-10 times higher than the financial costs of proper waste management

INTRODUCTION

Global challenges

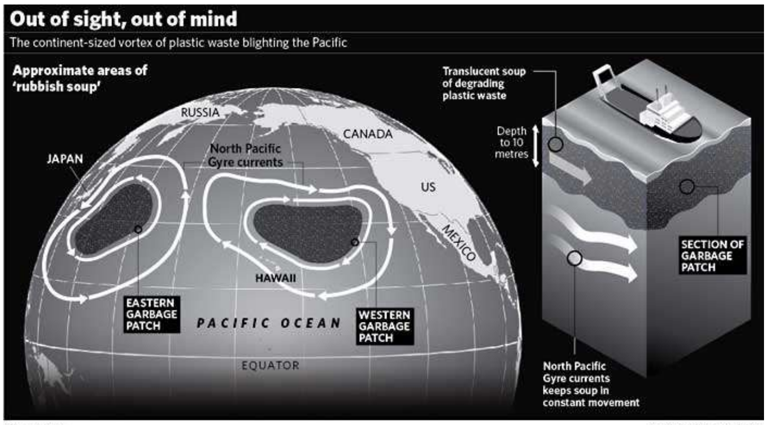
- Dumpsites



INTRODUCTION

Global challenges

- Littering



Source: Greenpeace

Graphic: John Papasian, John Bradley

INTRODUCTION

Wrap-up

- **there is no unique and optimal solution** for waste management
- solutions need to be **tailor made**, based on the peculiar features of each territory
- effective solutions always come from a **balanced and appropriate mix** of different available options (waste preventions, material recovery, energy recovery, safe disposal)
- **“ideological”** oppositions lead to immobility and to emergency

Introduction to waste management and energy recovery

1. Waste definition
2. Legislation applicable to waste
3. Waste generation and collection
4. Introduction to the integrated waste management
5. Options for energy recovery from waste

Waste definition – general

59

"waste" means **any substance or object which the holder discards** or intends or is required to discard *(EU Directive 2008/98, Art. 3)*

A waste can be **hazardous** when it displays one or more of the hazardous properties listed in **Annex III**

We distinguish between:

- ✓ Municipal waste (collected from private households and "similar" activities)
- ✓ Industrial waste
- ✓ Waste from caves and mines
- ✓ Construction and demolition waste (C&D)
- ✓ Agricultural waste

M. Grosso POLITECNICO MILANO 1863

Waste definition – general

60

Annex III - properties of waste which render it hazardous

HP1 'Explosive'
HP2 'Oxidizing'
HP3 'Flammable'
HP4 'Irritant'
HP5 'Specific Target Organ Toxicity (STOT)/Aspiration Toxicity'
HP6 'Acute toxicity'
HP7 'Carcinogenic'
HP8 'Corrosive'
HP9 'Infectious'
HP10 'Toxic for reproduction'
HP11 'Mutagenic'
HP12 Waste which releases toxic gases in contact with water or an acid
HP13 'Sensitising'
HP14 'Ecotoxic'
HP15 Waste capable of exhibiting a hazardous property listed above not directly displayed by the original waste

M. Grosso POLITECNICO MILANO 1863

Waste definition – the European List of Wastes

- ✓ All waste types generated in the EU are grouped into 20 major categories, based on their origin and characteristics
- ✓ The different types of waste in the List are fully defined by a six-digit code, with two digits each for chapter, sub-chapter and waste type
- ✓ The List is used to categorize items and substances when they become waste, but does not itself define items and substances as waste

Example

20 00 00 → chapter "Municipal wastes (household waste and similar commercial, industrial and institutional wastes) including separately collected fractions"

20 01 00 → sub-chapter "Separated collection"

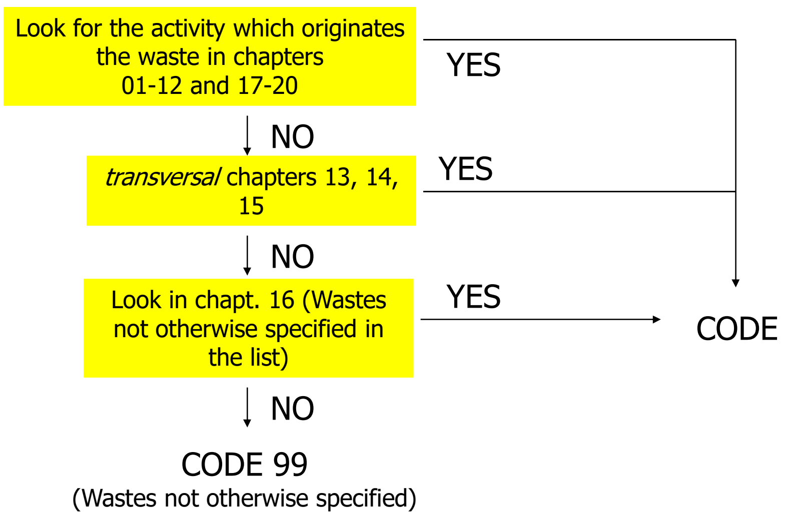
20 01 02 → glass separately collected

Waste definition – the European List of Wastes (updated by 2014/955/EC)

01 Wastes resulting from exploration, mining, quarrying, physical and chemical treatment of minerals
02 Wastes from agriculture, horticulture, aquaculture, forestry, hunting and fishing, food preparation and processing
03 Wastes from wood processing and the production of panels and furniture, pulp, paper and cardboard
04 Wastes from the leather, fur and textile industries
05 Wastes from petroleum refining, natural gas purification and pyrolytic treatment of coal
06 Wastes from inorganic chemical processes
07 Wastes from organic chemical processes
08 Wastes from the manufacture, formulation, supply and use of coatings, adhesives, sealants and printing inks
09 Wastes from the photographic industry
10 Wastes from thermal processes
11 Wastes from chemical surface treatment and coating of metals and other materials
12 Wastes from shaping and physical and mechanical surface treatment of metals and plastics
13 Oil wastes and wastes of liquid fuels (except edible oils, 05 and 12)
14 Waste organic solvents, refrigerants and propellants (except 07 and 08)
15 Waste packaging; absorbents, wiping cloths, filter materials and protective clothing not otherwise specified
16 Wastes not otherwise specified in the list
17 Construction and demolition wastes (including excavated soil from contaminated sites)
18 Wastes from human or animal health care and/or related research
19 Wastes from waste management facilities, off-site waste water treatment plants and the preparation of water intended for human consumption and water for industrial use
20 Municipal wastes including separately collected fractions

Waste definition – the European List of Wastes

Procedure to assign the ELW code



Waste definition – in Italy

According to the Italian law *(Decree 152/06 and subsequent modifications and integrations)* a slightly different definition applies:

→ Based on the origin: *Municipal waste vs. "special" waste*

→ Based on the characteristics: *hazardous vs. non-hazardous waste*

All four combinations apply!

European legislation on waste

3 categories

- "Horizontal" legislation
  - ✓ Sets the general framework of waste management, including definitions and general principles
- Legislation on waste treatments
  - ✓ landfill, incineration
  - ✓ IPPC Directive (BREFs – BAT Reference Documents)
- Legislation on selected waste streams
  - ✓ Packaging waste, end-of-life vehicles, waste of electrical and electronic equipment, used oils, etc.

The Waste Framework Directive 2008/98/CE

Key definitions

'prevention': measures taken before a substance, material or product has become waste, that reduce:

(a) the quantity of waste, including through the re-use of products or the extension of the life span of products

(b) the adverse impacts of the generated waste on the environment and human health;

(c) the content of harmful substances in materials and products

're-use': any operation by which products or components that are not waste are used again for the same purpose for which they were conceived

The Waste Framework Directive 2008/98/CE

Key definitions

'recovery': any operation the principal result of which is waste serving a useful purpose by replacing other materials [...] (Annex II):

R1 Use principally as a fuel or other means to generate energy

R2 Solvent reclamation/regeneration

R3 Recycling/reclamation of organic substances which are not used as solvents (including biological transformation processes)

R4 Recycling/reclamation of metals and metal compounds

R5 Recycling/reclamation of other inorganic materials

[...]

The Waste Framework Directive 2008/98/CE

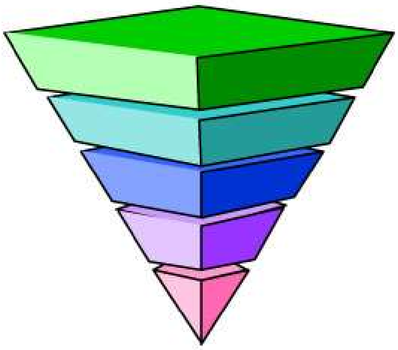
Key definitions

'preparing for re-use': checking, cleaning or repairing recovery operations, by which products or components of products that have become waste are prepared so that they can be re-used without any other pre-processing

'recycling': any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes. It includes the reprocessing of organic material but does not include energy recovery and the reprocessing into materials that are to be used as fuels or for backfilling operations

'disposal'; any operation which is not recovery even where the operation has as a secondary consequence the reclamation of substances or energy (Annex I)

The waste hierarchy according to the 2008/98/EC Directive (Art. 4)



Source: http://www.sepa.org.uk

When applying the waste hierarchy, Member States shall take measures to encourage the **options that deliver the best overall environmental outcome**. This may require **specific waste streams departing from the hierarchy** where this is justified by **life-cycle thinking** on the overall impacts of the generation and management of such waste

The Waste Framework Directive 2008/98/CE

Reuse and recycling targets (Art. 11)

By the year 2020:

✓ the preparing for re-use and the recycling of waste materials such as at least paper, metal, plastic and glass from households [...], shall be increased to a minimum of overall 50% by weight

✓ the preparing for re-use, recycling and other material recovery, including backfilling operations using waste to substitute other materials, of non-hazardous construction and demolition waste [...] shall be increased to a minimum of 70% by weight

The Waste Framework Directive 2008/98/CE

Prevention of waste (Articles 9 and 29)

1. Member States shall establish waste prevention programmes

Such programmes shall be integrated either into the waste management plans or into other environmental policy programmes, as appropriate, or shall function as separate programmes.

2. The programmes shall set out the waste prevention objectives. Member States shall describe the existing prevention measures and evaluate the usefulness of the examples of measures indicated in Annex IV or other appropriate measures

The aim of such objectives and measures shall be to break the link between economic growth and the environmental impacts associated with the generation of waste

The Waste Framework Directive 2008/98/CE

Extended producer responsibility (Article 8)

1. Member States may take legislative or non-legislative measures to ensure that any natural or legal person who professionally develops, manufactures, processes, treats, sells or imports products has extended producer responsibility

Such measures may include an acceptance of returned products and of the waste that remains after those products have been used, as well as the subsequent management of the waste and financial responsibility for such activities. These measures may include the obligation to provide publicly available information as to the extent to which the product is re-usable and recyclable

2. Member States may take appropriate measures to encourage the design of products in order to reduce their environmental impacts and the generation of waste in the course of the production and subsequent use of products, and in order to ensure that the recovery and disposal of products that have become waste take place in accordance with Articles 4 and 13

The Waste Framework Directive 2008/98/CE

End-of-waste status (Article 6)

End-of-waste criteria specify when certain waste ceases to be waste and obtains a status of a product (or a secondary raw material)

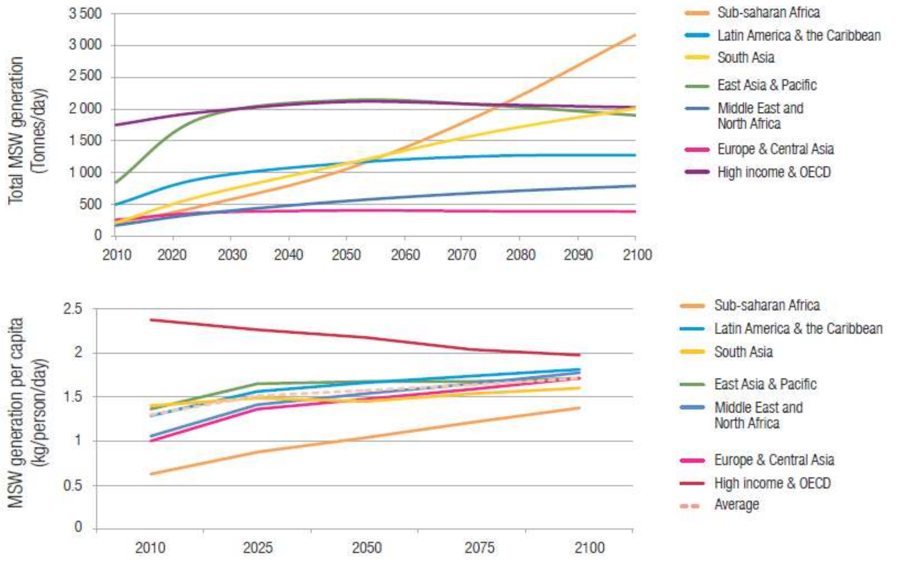
Certain specified waste shall cease to be waste when it has undergone a recovery (including recycling) operation and complies with specific criteria to be developed in line with certain legal conditions, in particular:

- ✓ the substance or object is commonly used for specific purposes
- ✓ **there is an existing market or demand for the substance or object**
- ✓ the use is lawful (substance or object fulfils the technical requirements for the specific purposes and meets the existing legislation and standards applicable to products)
- ✓ the use will not lead to overall adverse environmental or human health impacts

So far, EoW criteria exist for **iron, steel and aluminium scrap**, **glass cullet** and **copper scrap**

Waste generation in the world

75



Source: Global Waste Management Outlook (ISWA, 2015)

Waste generation in the world

76

Estimated world waste generation and collection for 2006

WASTE CATEGORIES	Quantities Produced (tonnes)	Quantities Collected (tonnes)
World total municipal waste	1.7 to 1.9 billion	1.24 billion
Manufacturing industry non-hazardous waste	1.2 to 1.67 billion	1.2 billion
Manufacturing industry hazardous waste for a selection of countries	490 million	300 million
Total	3.4 to 4 billion	2.74 billion

Source: CyclOpe

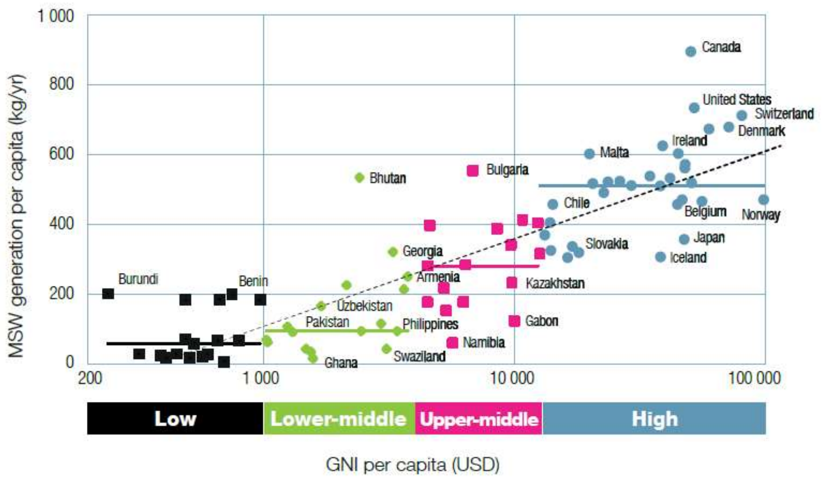
M. Grosso

POLITECNICO MILANO 1863

Waste generation in the world

78

Waste generation vs. GDP



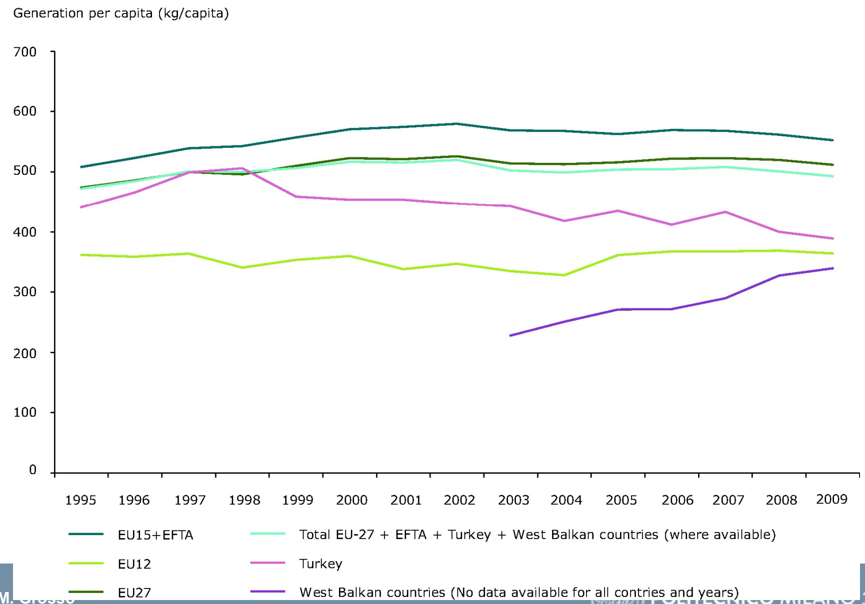
Source: Global Waste Management Outlook (ISWA, 2015)

M. Grosso

POLITECNICO MILANO 1863

Municipal waste generation in the EU

79



Source: EEA

M. Grosso — POLITECNICO MILANO 1863

Municipal waste generation in the EU

80

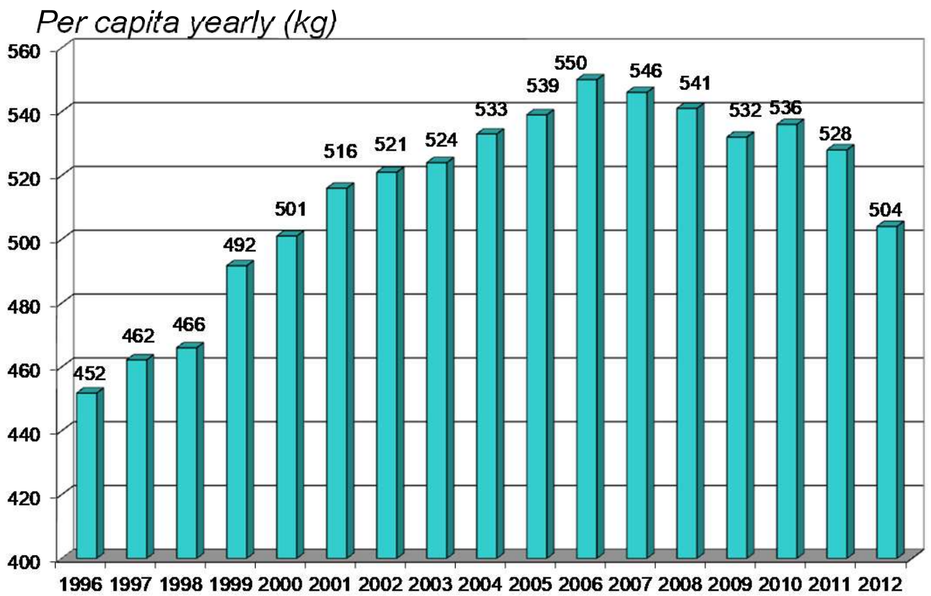
Generation per capita (kg/capita)	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
EU-15 + EFTA	508	523	539	543	557	571	575	580	569	568	563	569	568	562	553
EU-12	362	359	364	341	354	360	338	347	335	328	362	368	368	369	364
EU-27	474	486	500	496	510	523	521	526	514	513	516	522	523	520	512
Total EU-27 + EFTA	477	489	503	499	513	526	524	530	518	517	520	527	529	523	515
Turkey	441	466	499	506	459	454	454	447	443	418	435	412	433	400	389
West Balkan countries (no data available for all countries and years)									228	251	271	272	290	328	340
Total EU-27 + EFTA + Turkey + West Balkan countries (where available)	472	485	501	500	507	517	516	520	503	499	504	504	508	501	493
EU-15															
Austria	437	516	532	532	563	580	576	608	607	618	618	653	596	599	591
Belgium	451	450	463	456	463	475	470	486	467	486	479	483	495	489	489
Denmark	565	618	587	592	626	664	657	664	671	695	736	740	790	830	831
Finland	413	410	447	466	484	502	465	458	466	469	478	494	506	521	480
France	475	486	496	507	507	514	526	530	506	519	530	536	543	542	535
Germany	623	641	658	647	638	642	632	640	601	587	565	564	582	589	587
Greece	302	337	362	377	392	407	416	422	427	432	437	442	447	452	457
Ireland	512	522	544	554	577	599	699	692	730	737	731	794	780	729	662
Italy	454	457	468	472	498	509	516	522	521	535	540	552	548	543	540
Luxembourg	587	585	604	625	646	654	646	653	678	679	672	683	695	697	701
Netherlands	548	562	588	591	597	613	613	620	609	624	624	622	629	624	611
Portugal	384	398	404	422	441	471	471	443	449	444	450	463	468	515	517
Spain	510	535	560	565	613	658	654	639	649	603	592	594	583	556	547
Sweden	386	385	416	430	428	428	442	467	470	464	481	496	516	513	482
United Kingdom	498	511	532	542	569	577	591	599	592	603	583	586	570	544	526

Source: EEA

M. Grosso — POLITECNICO MILANO 1863

Municipal waste generation in Italy

81

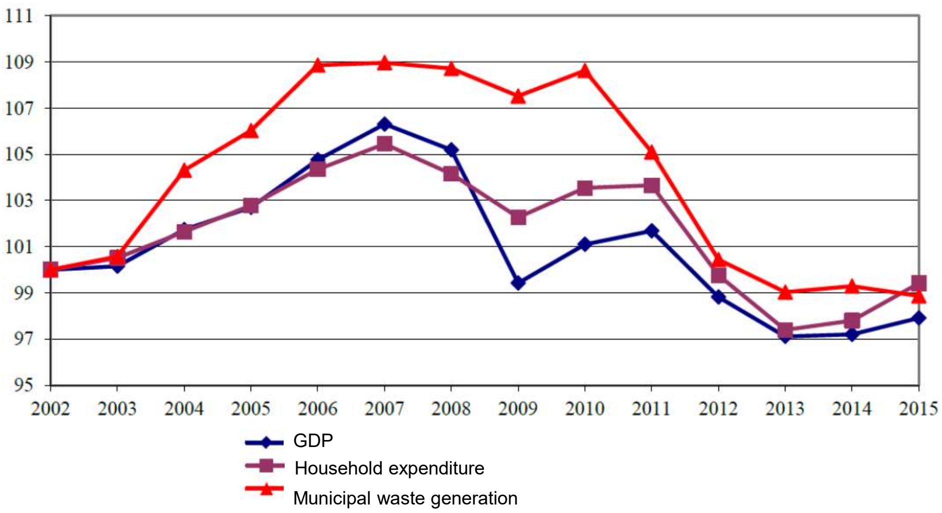


M. Grosso

POLITECNICO MILANO 1863

Municipal waste generation in Italy

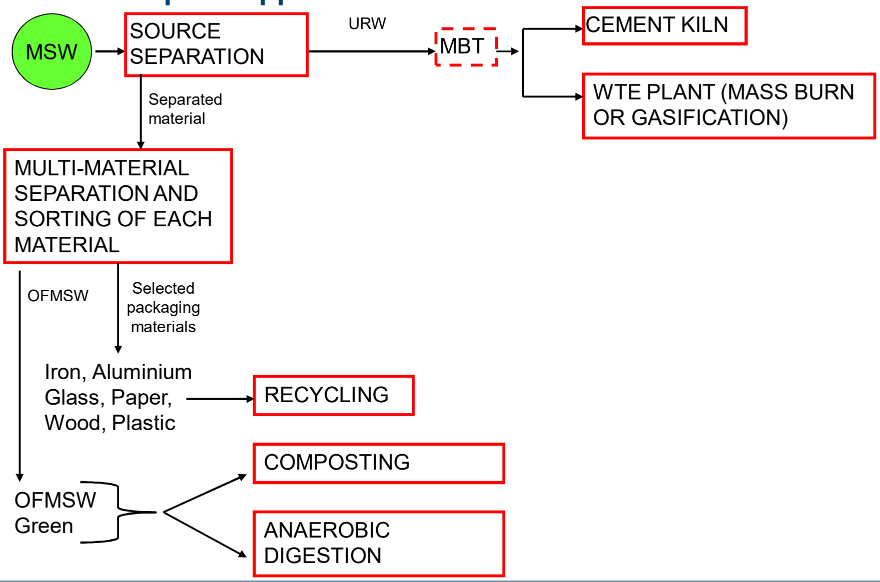
82



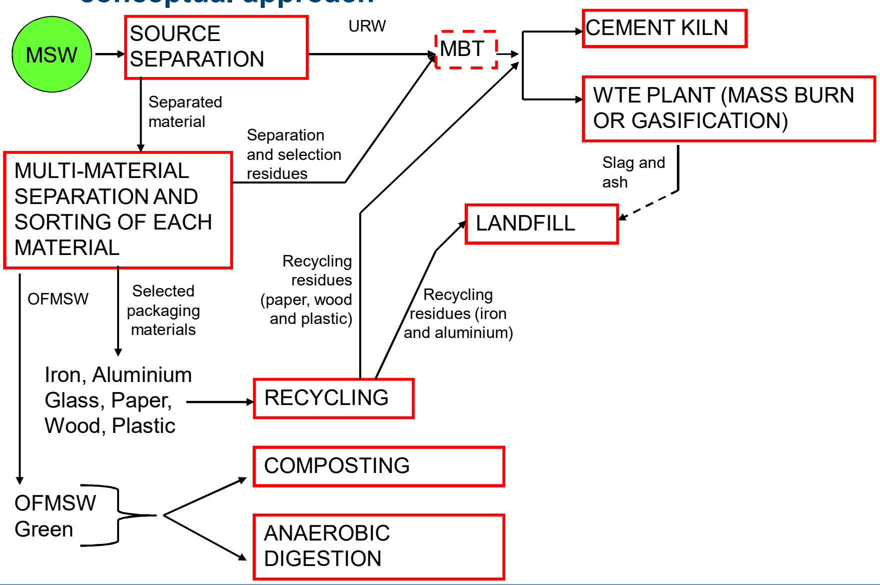
M. Grosso

POLITECNICO MILANO 1863

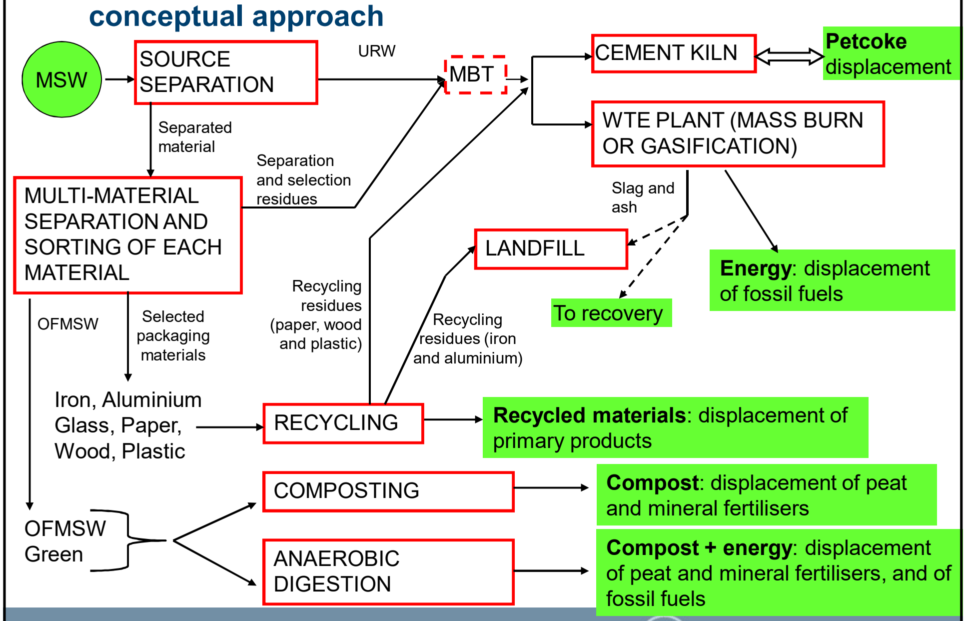
Integrated waste management scenarios: conceptual approach



Integrated waste management scenarios: conceptual approach



Integrated waste management scenarios: conceptual approach



Source separation of waste – definition

$$SS(\%) = \frac{\sum_i SS_i}{\sum_i SS_i + RW + R_{SS}} \times 100$$

Where:

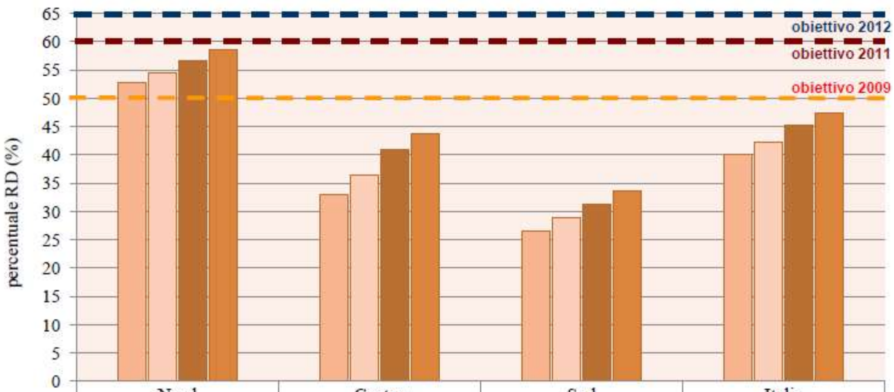
$\sum_i SS_i$ = sum of the different waste fractions that make the overall source separation, excluding the selection residues

RW = residual waste

R_{SS} = residues from SS selection operations

Source separation of waste in Italy

87



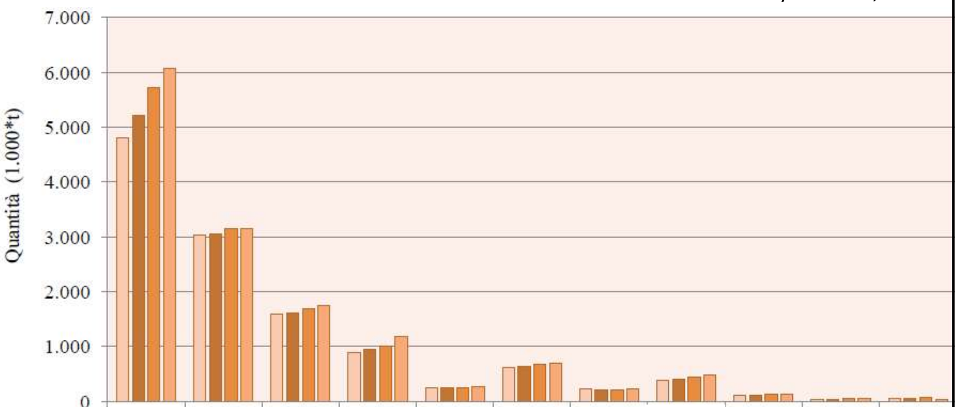
	Nord	Centro	Sud	Italia
2012	52,7	33,1	26,5	40,0
2013	54,4	36,4	28,8	42,3
2014	56,7	40,8	31,3	45,2
2015	58,6	43,8	33,6	47,5

SOURCE: Waste Report 2016, ISPRA

Source separation of waste in Italy

88

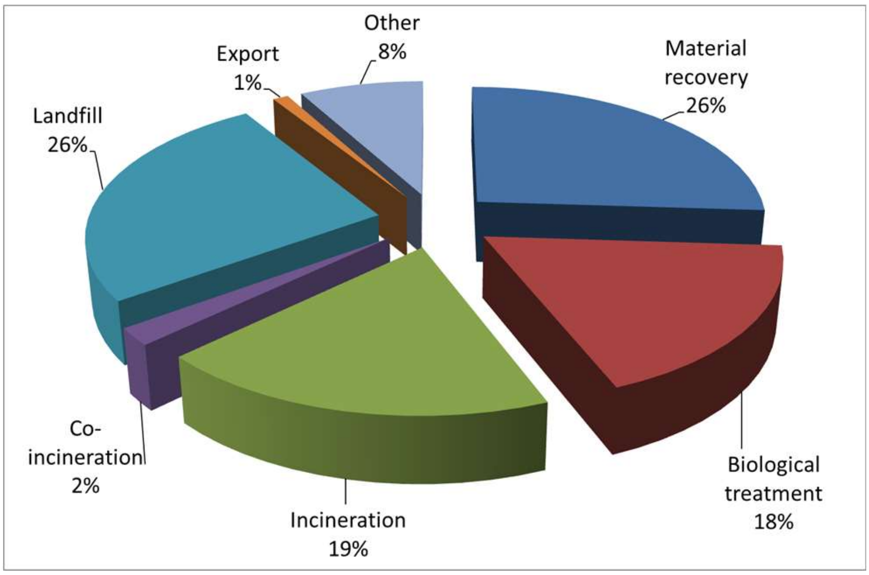
SOURCE: Waste Report 2016, ISPRA



	Organic fraction	Paper	Glass	Plastic	Metals	Wood	WEEE	Bulky waste	Textile	Selective	Other
2012	4.813,4	3.037,6	1.598,1	889,8	248,9	614,1	219,7	377,3	101,1	38,6	53,7
2013	5.216,9	3.051,4	1.608,1	945,2	241,0	635,2	209,2	398,5	110,9	39,9	52,2
2014	5.720,0	3.153,9	1.691,3	1.012,5	249,6	676,0	213,7	447,3	124,4	40,6	72,2
2015	6.071,5	3.149,9	1.747,8	1.178,0	261,1	695,3	222,9	484,3	129,0	42,4	38,6

Waste management in Italy (year 2015)

91

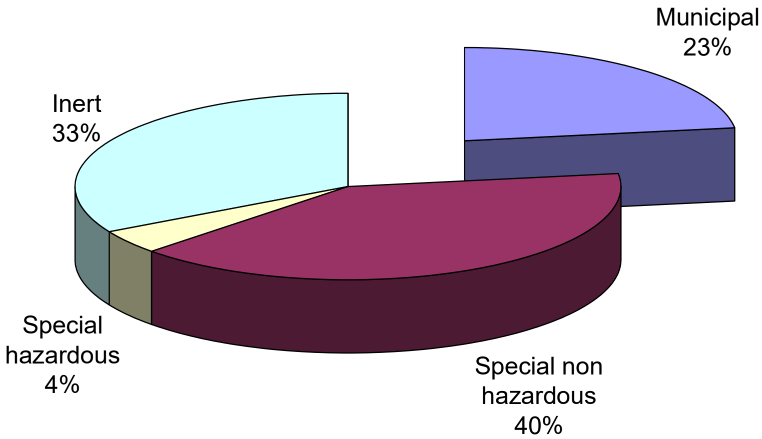


M. Grosso

POLITECNICO MILANO 1863

Municipal waste vs. total waste generation in Italy (year 2005)

94

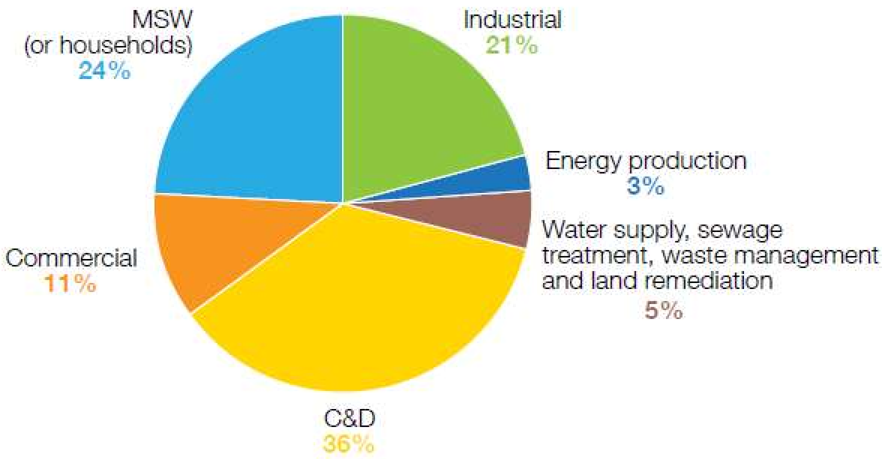


M. Grosso

POLITECNICO MILANO 1863

Breakdown of the different waste streams (OECD countries)

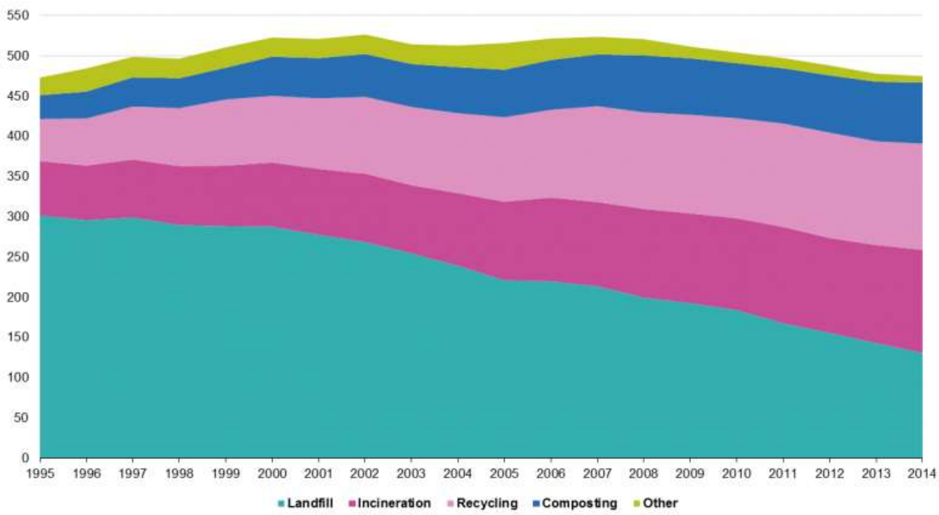
95



Source: Global Waste Management Outlook (ISWA, 2015)

The situation in Europe

102



Source: Eurostat

Waste-to-energy options

From residual waste

- → Mass burn combustion (incineration)
- → Pre-treatment (MBT) to obtain SRF
  - → Co-combustion
  - → Gasification
  - → Fluidised bed combustion

From selected waste streams

- → Anaerobic digestion
- → Sorting and recycling residues
  - → Mass burn combustion
  - → Co-combustion

Some references on Waste-to-energy

CEWEP – Confederation of European Waste-to-Energy plants

- ✓ Technical data on European WTE plants
- ✓ Energy efficiency report

European Environmental Agency – EEA

- ✓ Waste statistics at the EU level

OECD

Eurostat

mater
materia & energia da rifiuti
materials & energy from refuse

WTERT Waste-to-Energy Research and Technology Council
Advancing Sustainable Waste Management

Waste characteristics

- ➢ Waste composition
- ➢ Proximate analysis
- ➢ Elemental analysis
- ➢ Calorific value
- ➢ Biogenic and biodegradable fractions

Waste composition

Characterisation of waste

Major limitation → **representativeness** of the sample:

- intrinsic heterogeneity
- geographical variability
- seasonal variability
- daily variability (ex. rainy days)

❍ Methodologies for assessing waste composition:

- CNR method (National Research Council)
- IPLA method
- CITEC guidelines
- other international methods

Waste composition

Waste composition (8 major fractions)

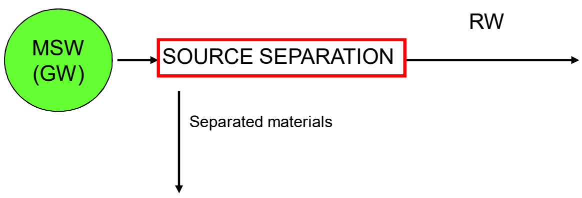
- *Cellulosic materials*
  - paper, cardboard
- *Textile and wood*
  - textiles (garments, fabric, etc.)
  - wood
- *Plastic and rubber*
  - rigid (PET, HDPE, PVC)
  - film (LDPE, PP)
  - rubber and thermosetting plastic
- *Metals*
  - ferrous (steel, cast iron, iron scraps)
  - non ferrous (aluminium, copper, stainless steel, others)
- *Glass and inert*
  - glass
  - other inert (ceramics, stones, rubble)
- *Organic material*
  - kitchen waste
  - garden waste ("green")
- *Hazardous municipal waste*
  - batteries
  - drugs,....
- *Fines*
  - Everything smaller than 20 mm (mainly organic material and inert)

Waste composition

Focus is on the composition of:

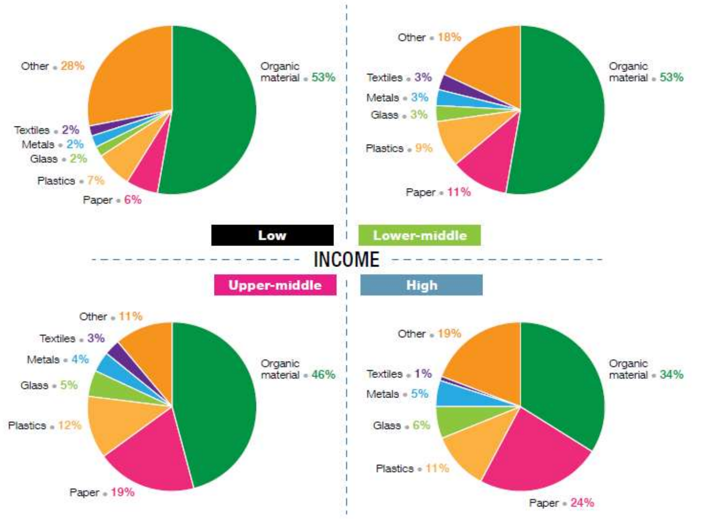
• residual waste (RW) → direct analysis at the gate of the recovery/disposal plants (incinerators, MBT, landfills)

• gross waste (GW) → to be calculated (estimated) according to the existing type and level of source separation (SS)



Waste composition

Variation in MSW composition grouped by country income levels



Source: Global Waste Management Outlook (ISWA, 2015)

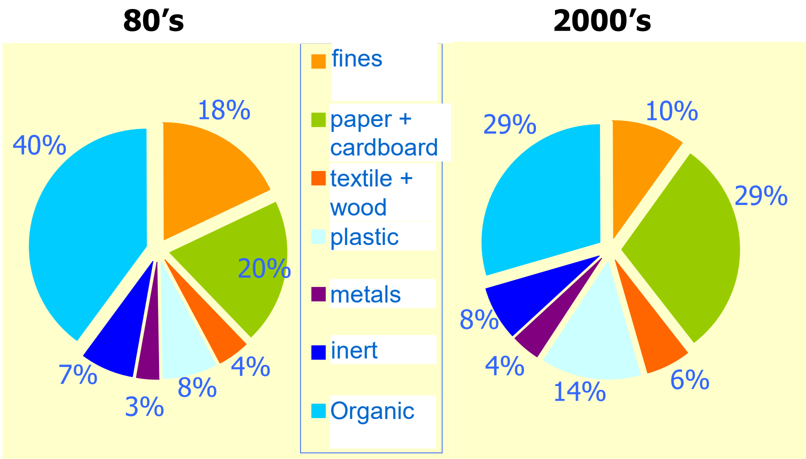
Waste composition

Gross waste in the EU

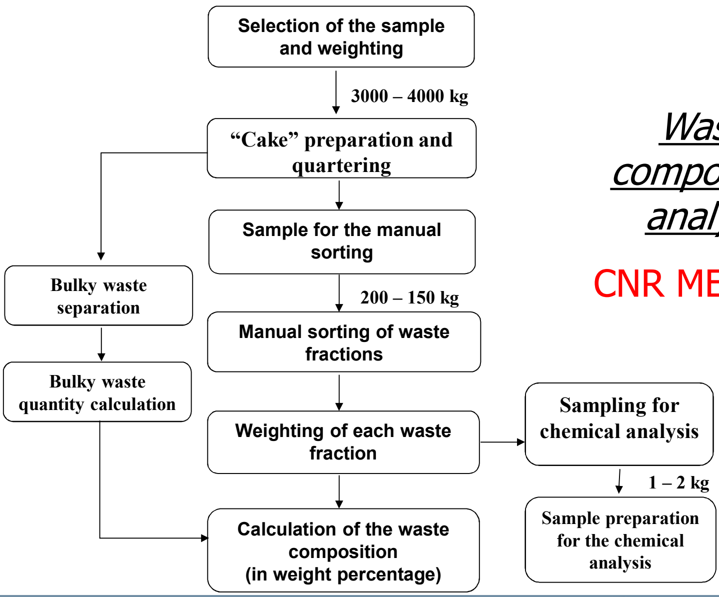
% ww	Western central Europe	Southern Europe	Eastern Europe
Kitchen waste	22	35	33
Garden waste	10	6	2
Paper	16	14	13
Cardboard	8	7	6
Plastic	10	11	10
Glass	9	7	10
Ferrous metal	2.25	2.25	2.25
Aluminum	0.75	0.75	0.75
Textile	2	2	3
Wood	5	5	5
Diapers	5	4	4
Battery	0.2	0.2	0.2
Fines (< 20 mm)	9.8	5.8	10.8

Waste composition

Historical evolution in Italy (gross waste)



Waste composition

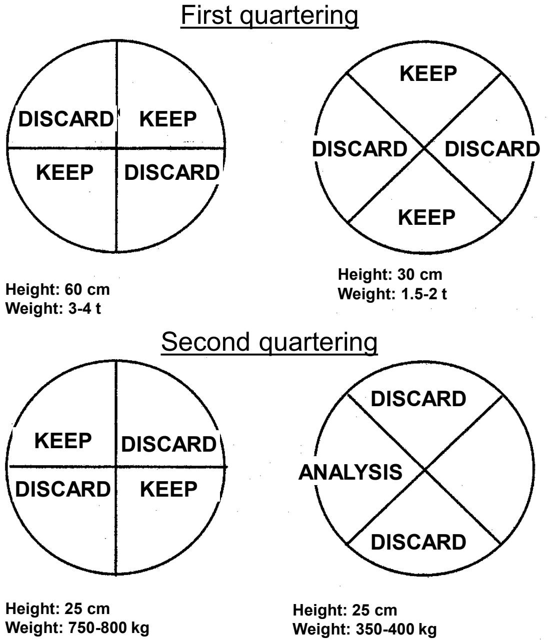


<u>Waste composition analysis</u>

CNR METHOD

Waste composition

First quartering



Waste composition analysis

CNR METHOD

Quartering method

Waste composition

Waste composition analysis

CNR METHOD

Waste composition

CITEC guidelines

A size distribution analysis must be performed as the first step:

- Φ < 20 mm
- 20 mm < Φ < 50 mm
- Φ > 50 mm
- bulky waste

Waste composition

CITEC guidelines

On each size fraction:

- Φ < 20 mm → total solids and moisture; volatile solids; leaching test (Pb, Zn, Cr, Cu, Cd, As)
- 20 mm < Φ < 50 mm → Basic waste composition analysis *(cellulosic materials, metals, kitchen waste, plastic, inert)*; LHV, moisture
- Φ > 50 mm → Full waste composition analysis; Moisture of each fraction
- bulky waste → Number and types of items; Evaluation of recovery options

Waste characteristics

Specific weight (SW)

$$SW\ (kg\ \mathrm{m}^{-3}) = \frac{\text{Weight (kg)}}{\text{Occupied volume } (\mathrm{m}^3)}$$

Depends on waste compaction

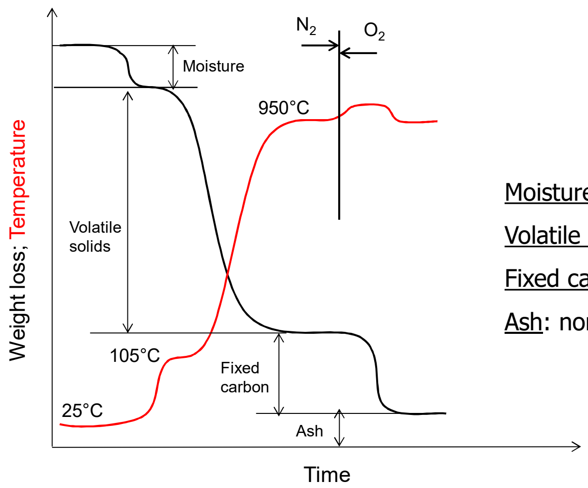
"fresh" waste – plastic bags: 150 -200 kg m^{-3}

Compacted waste in landfill: 600 -800 kg m^{-3}

Relevant for:

* waste collection and transfer
* waste storage

Waste characteristics – proximate analysis



Moisture (H_2O content): 105°C, 24 h

Volatile solids: 950°C, 7 min

Fixed carbon: combustible residue

Ash: non combustible residue

Waste characteristics – elemental analysis

128

% weight	Residual waste (RW)	RDF/SRF
C	28	42
H	3.8	5.9
S	0.2	0.1
O	21	20
Moisture	24	20
Ash	23	12
TOTAL	**100**	**100**

Waste characteristics – elemental analysis

129

Fraction	C % dm	H % dm	O % dm	N % dm	S % dm	Ash % dm	H_2O %	LHV kJ kg^{-1}
Paper	44.80	6.00	43.30	0.24	0.16	5.50	15.00	12100
Cardboard	43.85	6.00	45.00	0.25	0.20	4.70	12.50	13100
Textile	52.00	6.30	35.83	3.20	0.17	2.50	20.00	14200
Wood	50.00	6.00	42.32	0.20	0.08	1.40	22.00	13800
Plastic	61.60	8.50	17.40	2.30	0.20	10.00	6.00	28300
Rubber	81.20	9.00	0.00	0.90	0.90	8.00	2.00	20800
Glass and inert	3.00	0.40	0.40	0.15	0.05	96.00	2.50	0
Metals	4.50	0.60	4.28	0.07	0.05	90.50	4.00	0
Kitchen waste from household	48.00	6.00	34.00	2.18	0.32	9.50	70.00	2100
"Green" waste	47.00	6.20	37.72	2.85	0.23	6.00	50.00	6000
Kitchen waste from large users	48.00	6.17	34.10	2.40	0.33	9.00	70.00	2100
Fines	26.35	5.50	30.50	2.50	0.15	35.00	30.00	5400

Waste characteristics – calorific value

Amount of heat (kcal or kJ) released by the complete stoichiometric oxidation of one mass unit (kg), carried out at well defined temperature (T) and pressure (p).
Normal conditions: T=0°C ; p=1 atm

HHV = LHV + <u>heat of evaporation of water in the flue gas</u>

<u>HHV > LHV</u> **always!**

Water (steam) in the flue gas:

- waste moisture U (% weight)
- combustion water → hydrogen (H) oxidation

$$H_2 + 1/2\ O_2 \longrightarrow H_2O$$

$$2\ \text{kg H} \longrightarrow 18\ \text{kg}\ H_2O$$

Combustion water = 9 kg/kg H

- latent heat → 2500 kJ/kg H_2O @ 25°C and 1 atm

LHV = HHV – 2500 * (U + 9H)

Waste characteristics – calorific value

Calorific value

→ Mahler bomb calorimeter

Waste characteristics – calorific value

Mahler bomb calorimeter:

- 3-4 g of dry sample
- size < 1 mm
- at least 5 repetitions for each sample

$\}$ HHV on a dry basis (DHHV)

$$HHV = DHHV * (1 - M)$$

$$DLHV = DHHV - 2500*9H*(1 - M)^{-1}$$

$$LHV = DLHV * (1 - M) - 2500 * M$$

$$LHV = DHHV * (1 - M) - 2500 * (M + 9H)$$

$$\mathbf{LHV = HHV - 2500 * (M + 9H)}$$

M = *moisture* of waste
H = *hydrogen* content of waste

Waste characteristics – calorific value

Summary of calorific values

	Acr.	U. M.	Water in flue gas	Notes
Dry higher heating value	DHHV	kJ kg_{dm}^{-1}	Liquid phase (combustion H_2O)	Measured with the Mahler bomb
Higher heating value	HHV	kJ kg^{-1}	Liquid phase (combustion H_2O + moisture in waste)	-
Dry lower heating value	DLHV	kJ kg_{dm}^{-1}	Vapour phase (combustion H_2O)	-
Lower heating value	LHV	kJ kg^{-1}	Vapour phase (combustion H_2O + moisture in waste)	Utilised when designing combustion plants

Waste characteristics – calorific value

Calorific value of waste fractions

Fraction	LHV_{dry}	
	kcal kg^{-1}_{dm}	**MJ kg^{-1}_{dm}**
Plastic and rubber	7500	31
Textiles – wood	4000	17
Paper and cardboard	3700	15
Green waste	3000	12
Kitchen waste	1500	6.2
Fines	1400	5.8
Metals	0	0
Glass and inerts	0	0

Waste characteristics – calorific value

Comparison with conventional fuels

	MJ kg^{-1}
Coal	25.1
Natural gas (methane)	48.1
Fuel oil	39.7
Diesel fuel	42.6
Wood	12.5
Waste	
Municipal residual waste (RW)	**10-12.5**
Dry fraction	**11.5-15**
SRF	**15-20**

Waste characteristics – biogenic and biodegradable fractions

"Biodegradability" and "renewability"

Biodegradable material: the one that undergoes aerobic or anaerobic biologic decomposition in natural conditions

→ this affects its **treatment** (suitable for biological treatments)

Biogenic material: that produced from living organisms in natural processes, but not deriving from fossilisation

→ this affects the **"global warming" issue** (CO_2- neutral when degraded under aerobic conditions)

Biomass: material of "recent" biogenic origin, thus excluding that stored in geological formation or fossilised

BORDERLINE SITUATIONS

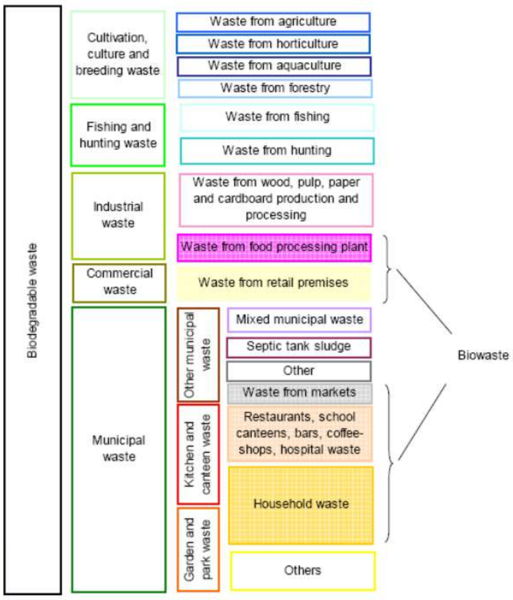
- wood rich in lignin is a biomass but has a slow biodegradability
- biodegradable plastic is quickly biodegradable despite not being a biomass

Waste characteristics – biogenic and biodegradable fractions

Assessment of the biogenic fraction of waste
(Ref.: prEN 15440:2008)

1. Selective dissolution method: acid attack (H_2SO_4) in an wet oxidising environment. It is assumed that only the biogenic fraction is converted to CO_2 (with some exceptions!)
2. Manual selection method: waste composition analysis (14 fractions), each of them associated to a specific category: biogenic, fossil, inert
3. Mass and energy balance method: numerical solution of a system with 5 mass balance and 1 energy balance equations, with 4 unknowns (over-determined system): inert mass fraction (mI), biogenic mass fraction (mB), fossil mass fraction (mF) and water mass fraction (mW)
4. Radiocarbon method (^{14}C): sample combustion, followed by the analysis of C isotopes in the flue gas; ^{14}C to ^{12}C ratio is related to the "age" of material (method used for dating)

Waste characteristics – biodegradable waste vs. “bio-waste”



BIODEGRADABLE WASTE: <u>any waste</u> that can undergo aerobic or anaerobic decomposition, such as kitchen waste, green waste, cellulosic material

BIOWASTE: biodegradable waste from gardens and parks, kitchen waste from household, canteens, street markets, as well as similar waste from food processing plants

Source: JRC, "Supporting Environmentally Sound Decisions for Bio-waste Management" (2010)

Waste characteristics – summary

Summary of the characteristics of each waste fraction

	Material recovery	Combustibility	Biodegradability	Renewability (biogenic)	Hazardous ness
Plastic and rubber	Yes (partially)	Yes	No	No	No
Textile – wood	Yes	Yes	Poor	Yes	No
Paper and cardboard	Yes	Yes	Yes	Yes	No
Organic	Yes	No	Yes	Yes	No (*)
Fines	No	No	Partial	Partial	Partial
Metals	Yes	No	No	-	Yes
Glass	Yes	No	No	-	No
Haz.	No	No	No	-	Yes

(*) but easily contaminated