Quality criteria under research

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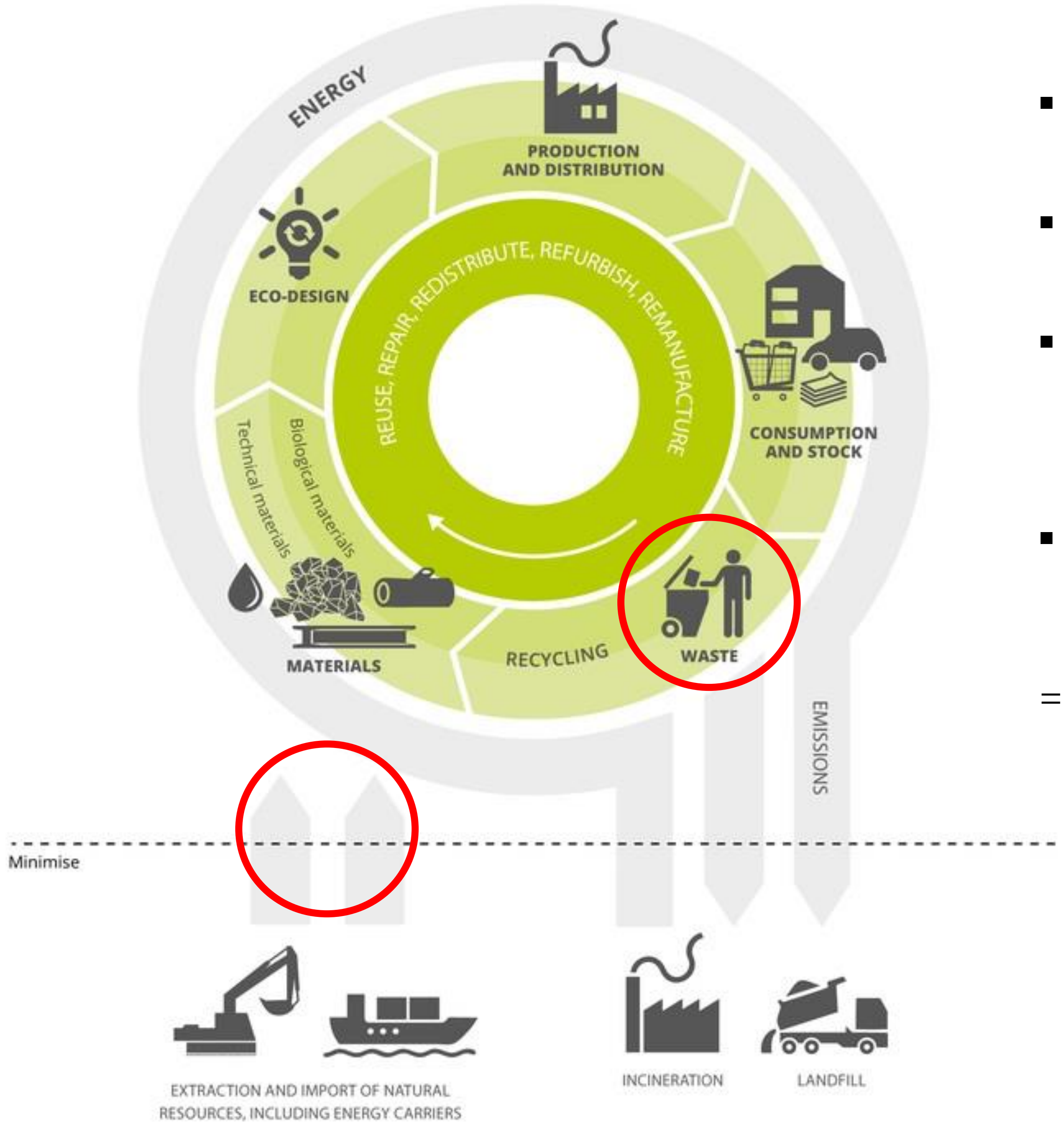


- Increasing resource consumption
- Increasing competition for resources
- Most environmental impacts are associated with resource consumption
- Resources and materials should be "kept in the loop"

= Quality of resources is critical

Source: European Environment Agency

Materials and resources in waste

1.i.1 Avoidable-processed food waste
1.i.2 Avoidable-unprocessed food waste
1.i.3 Unavoidable food waste

2.1.1 Dead animals
2.1.2 Animal excrement bags from animal excrement
2.2.1 Humid soil
2.2.2 Plant material
2.2.3 Woody plant material
2.2.4 Animal straw

3.7.1 Envelopes
3.7.2 Kraft paper
3.7.3 Other paper
3.7.4 Receipts
3.7.5 Self-adhesives
3.7.6 Tissue paper
3.7.7 Wrapping paper

4.4.1 Beverage cartons
4.4.2 Paper plates & cups
4.4.3 Cards & labels
4.4.4 Egg boxes & alike
4.4.5 Other board
4.4.6 Tubes

5.i.1 PET/PETE[a]
5.i.2 HDPE[b]
5.i.3 PVC/V[c]
5.i.4 LDPE/LLDPE[d]
5.i.5 PP[e]
5.i.6 PS[f]
5.i.7 Other plastic resins labelled with[1–19] and ABS
5.i.8 Unidentified plastic resin
5.3.1 Pure plastic film
5.3.2 Composite plastic + metal coating

6.i.1 Ferrous
6.i.2 Non-ferrous

7.i.1 Clear
7.i.2 Brown
7.i.3 Green

8.1.1 Diapers

8.1.2 Tampons
8.1.1 Condoms
8.2.1 Textiles
8.2.2 Leather
8.2.3 Rubber

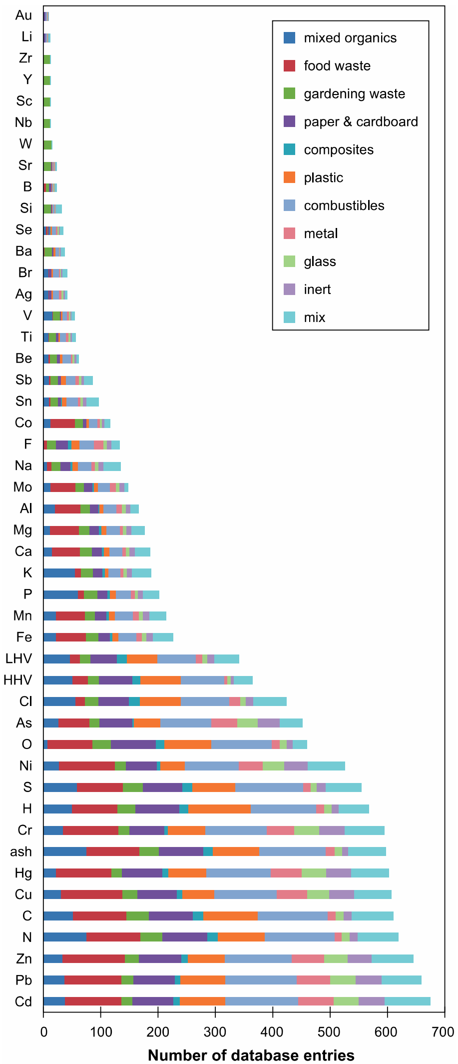
Source: Maklawe E. Edjabou and Kostyantyn Pivnenko, DTU

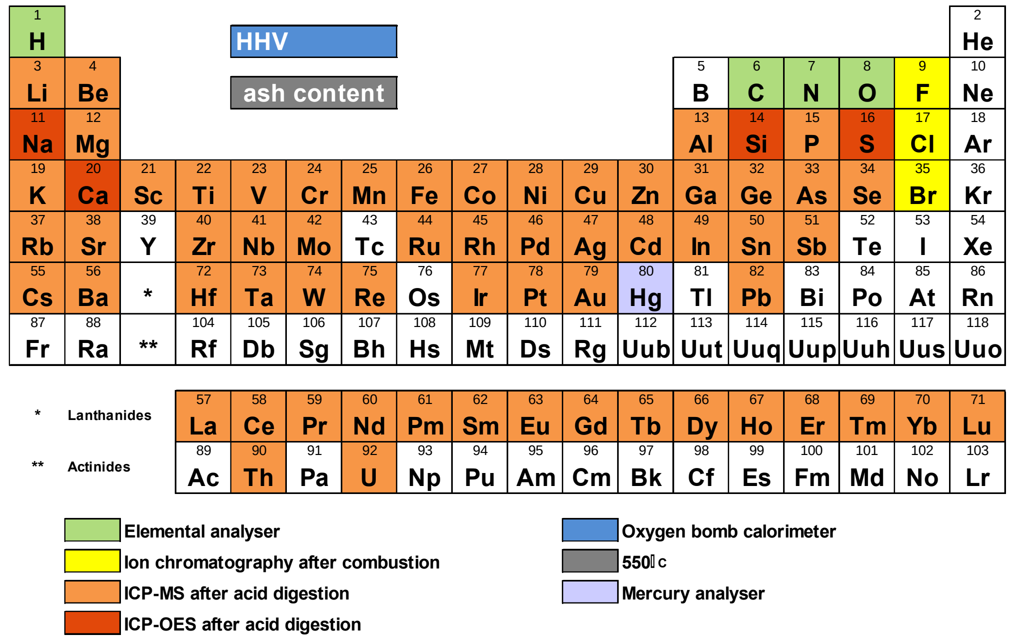
Götze, Boldrin, Scheutz, Astrup (2016). Physico-chemical characterisation of material fractions in household waste: Overview of data in literature. *Waste Management*, 36, 12-23.

Edjabou, Jensen, Götze, Pivnenko, Petersen, Scheutz, Astrup (2015). Municipal solid waste composition: Sampling methodology, statistical analyses, and case study evaluation. *Waste Management*, 36, 12-23.

Götze, Pivnenko, Boldrin, Scheutz, Astrup (2015). Physico-chemical characterization of material fractions from residual and source-segregated household waste in Denmark. *Waste Management,* 54, 13-26.

Resource quality of waste





70+ material fractions in waste from single and multi family houses

30+ paper and cardboard materials

30+ plastic materials

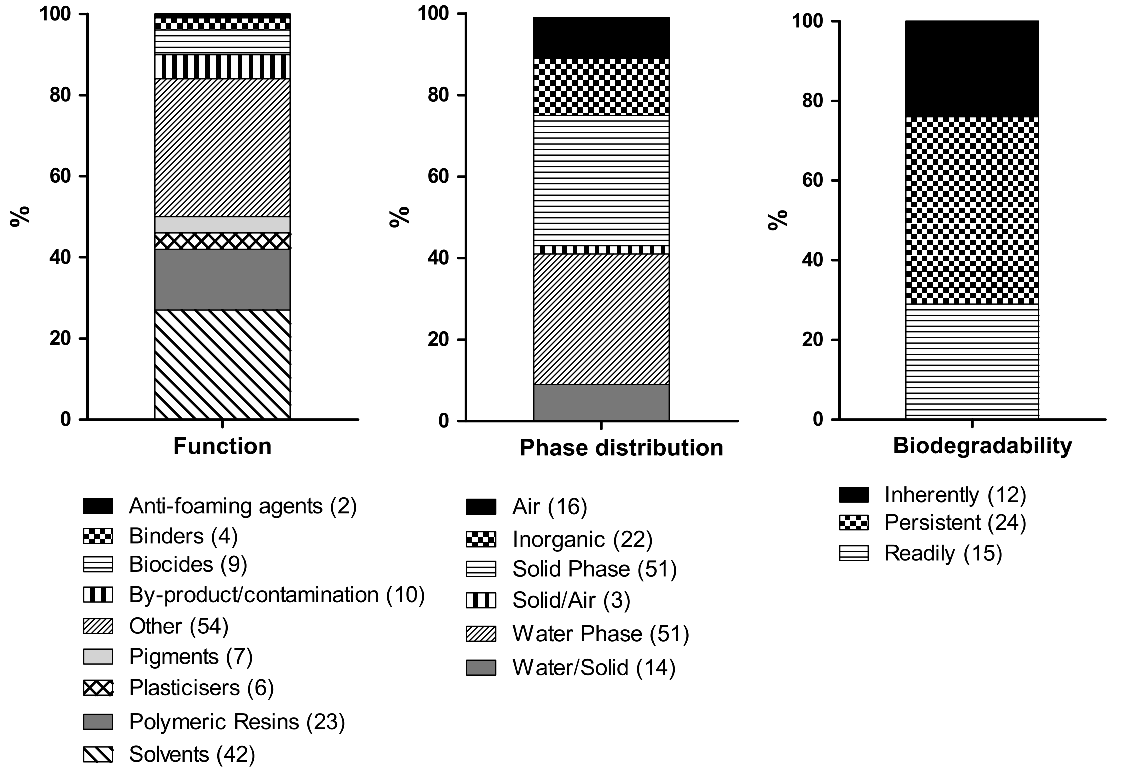
30+ wood waste materials

…

Götze, Boldrin, Scheutz, Astrup (2016). Physico-chemical characterisation of material fractions in household waste: Overview of data in literature. *Waste Management*, 36, 12-23.

Götze, Pivnenko, Boldrin, Scheutz, Astrup (2015). Physico-chemical characterization of material fractions from residual and source-segregated household waste in Denmark. *Waste Management*, 54, 13-26.

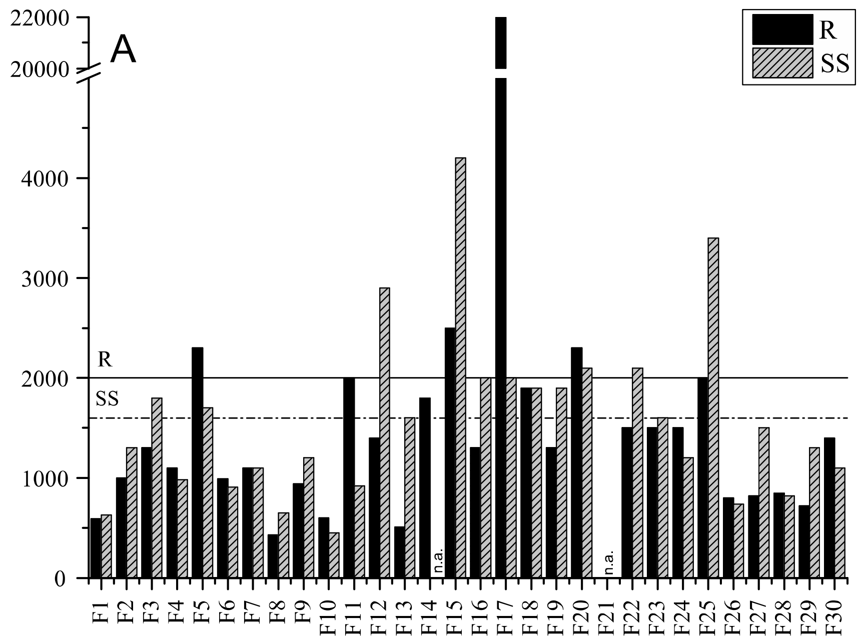
Resource quality and recycling: paper and cardboard



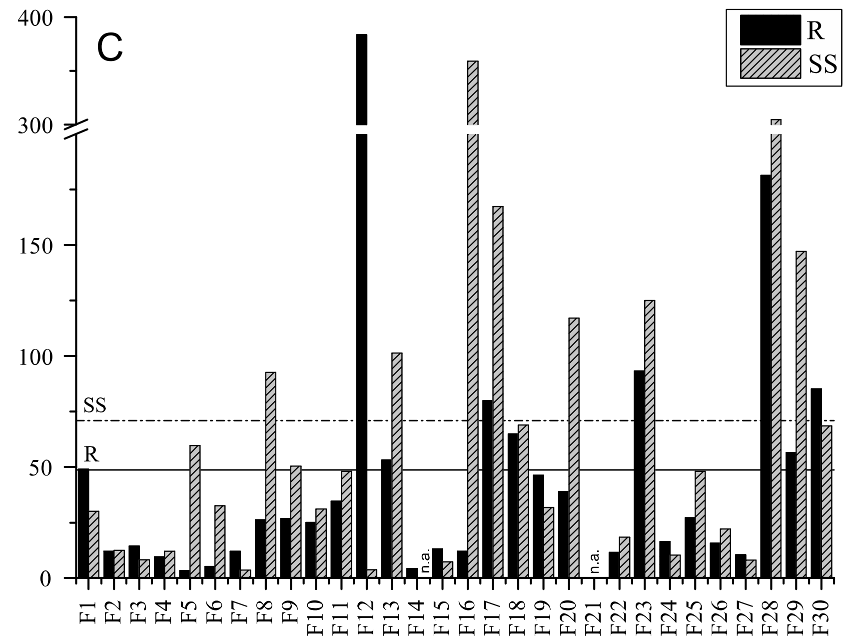
10,000 potential chemical substances ⇨ 157 identified substances ⇨ 51 potentially critical substances ⇨ 24 persistent substances

Pivnenko, Eriksson, Astrup (2015). Waste paper for recycling: Overview and identification of potentially critical substances. *Waste Management*, 45, 134-142.

Resource quality and recycling: paper and cardboard



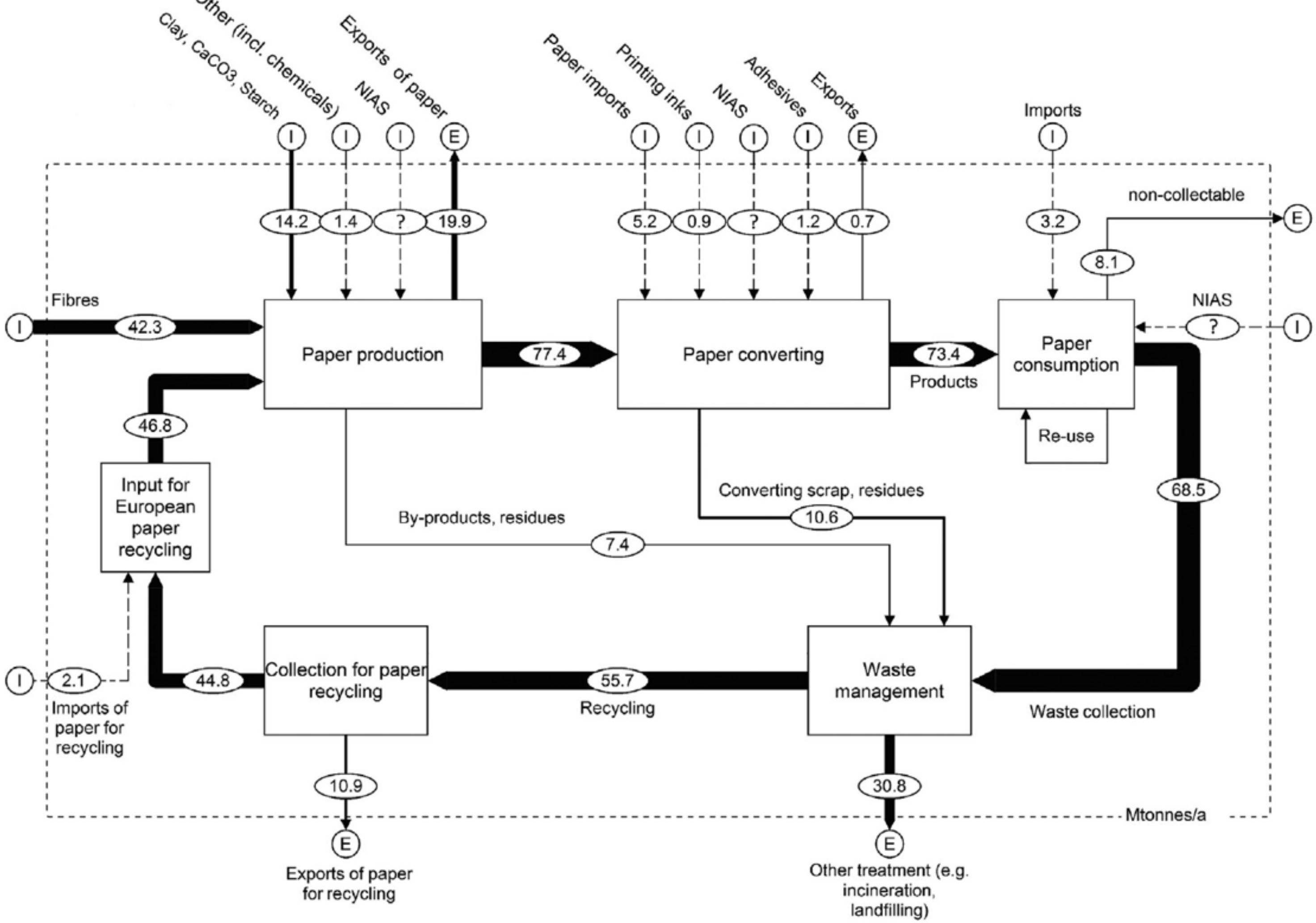
Mineral oil hydrocarbons (mg/kg)



Phthalates (mg/kg)

Pivnenko, Olsson, Götze, Eriksson, Astrup (2016). Quantification of chemical contaminants in the paper and board fractions of municipal solid waste. Waste Management, 51, 43-54

Resource quality and recycling: chemical substances



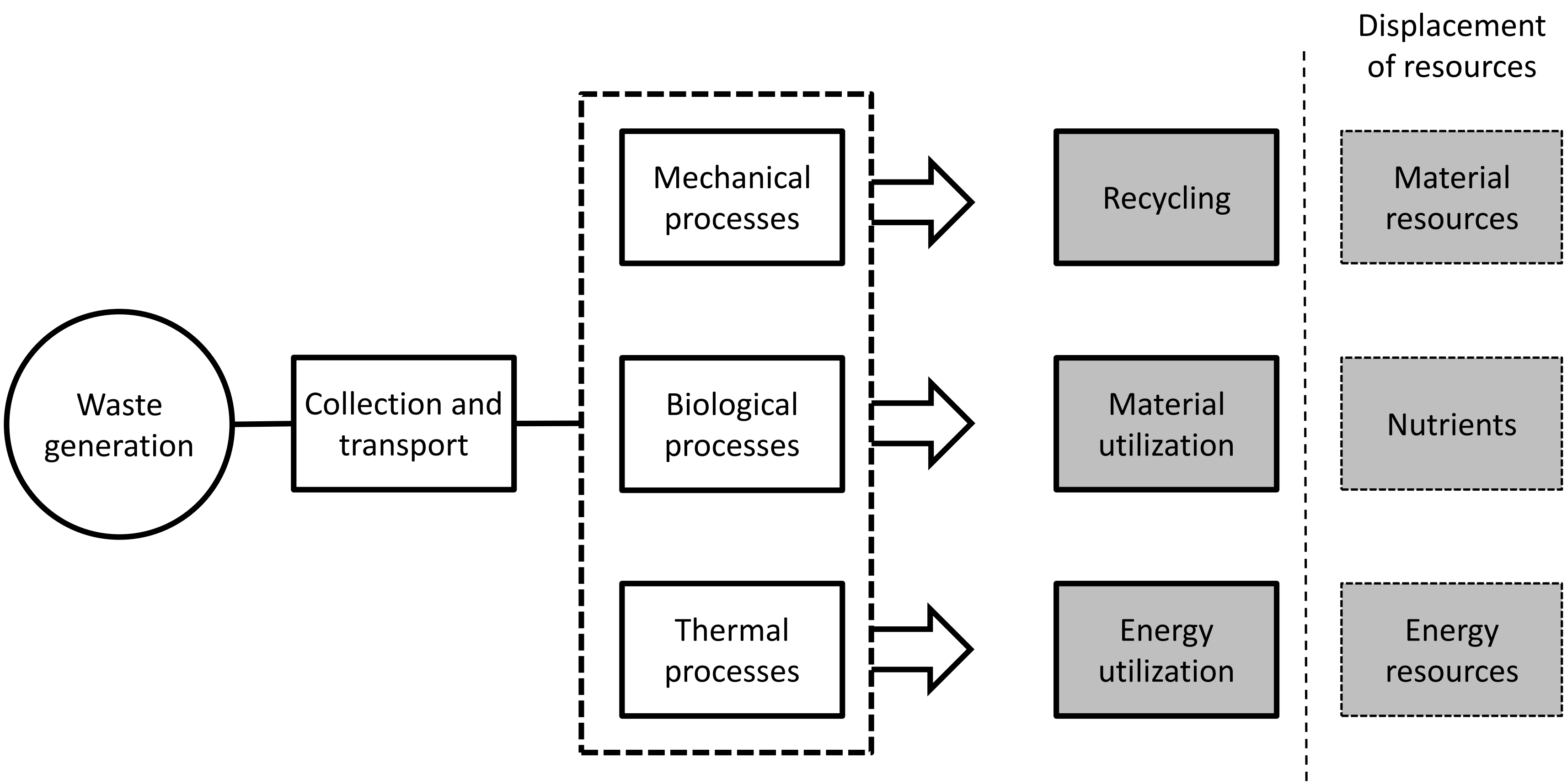
Pivnenko, Eriksson, Astrup (2015). Waste paper for recycling: Overview and identification of potentially critical substances. *Waste Management*, 45, 134-142.

Resource quality and recycling: Plastic

- Food packaging
- Toys
- Pharmaceuticals
- Electrical and electronic devices
- Building and construction
- Non-food packaging
- Automotive
- Other

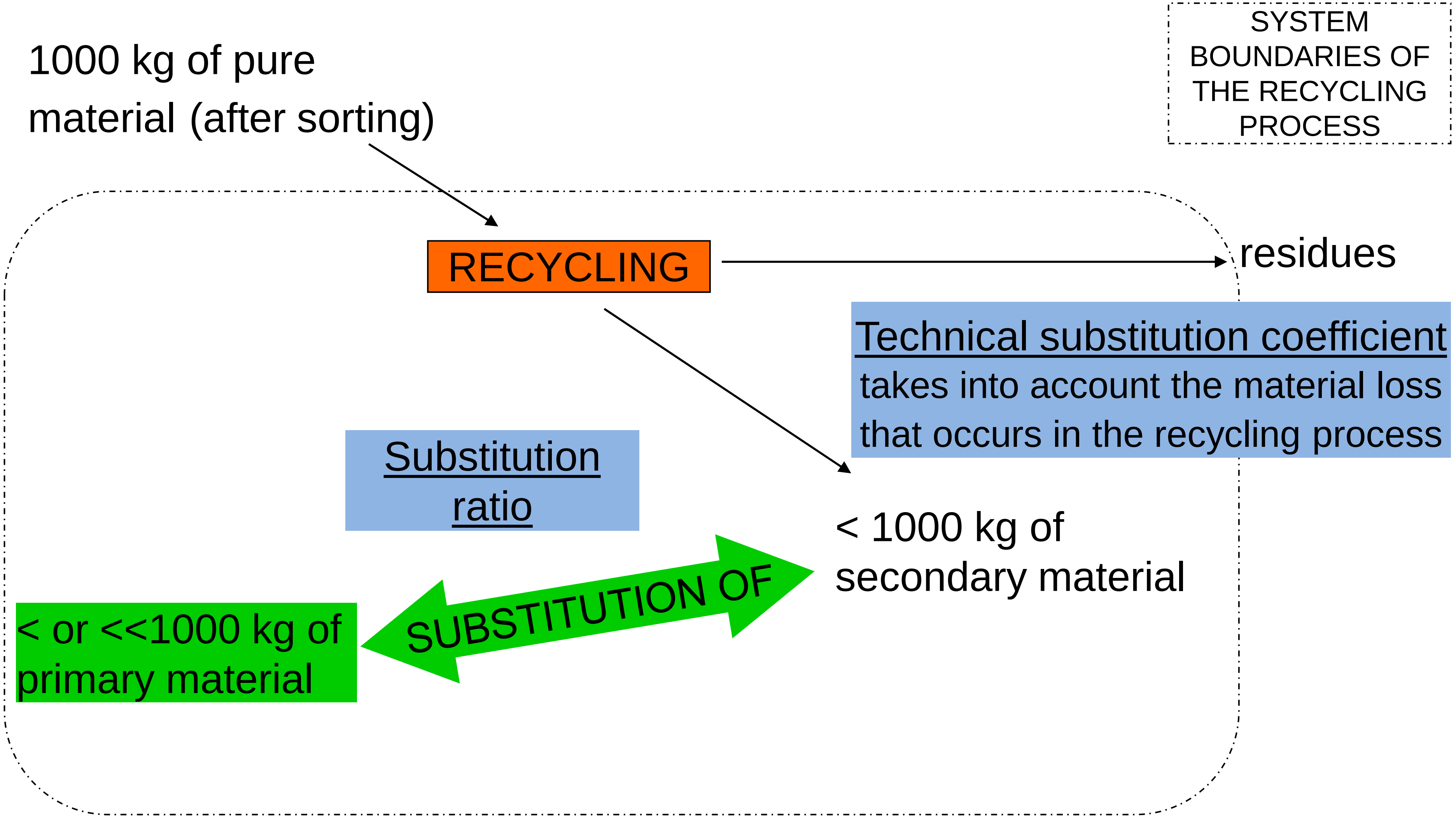
Source: Marie K. Eriksen, DTU

Potential substitution of virgin production



$$\text{Substitution ratio} = \frac{\textit{amount of displaced resource or virgin production}}{\textit{amount of waste material}}$$

How to model this in LCA of waste management?



Substitution ratios and downcycling

For paper: substitution ratio calculated from the estimated maximum number of recycling cycles which a single paper fibre can undergo

For plastic: calculated based on the ratio between the market value of the primary and of the secondary polymers

For wood: based on the different physical and mechanical properties (modulus of elasticity and longitudinal bending strength) of secondary particle board compared to virgin plywood

Rigamonti et al., 2010

Technical substitution and substitution ratio

	Technical substitution coefficient		Substitution ratio	
	value	source	value	source
Steel/iron	88.1%	Elaboration from IPPC, 2009	100%	Rigamonti et al., 2010
Aluminium	83.5%	Rigamonti et al., 2010	100%	
Glass	100%		100%	
Paper	89%		**83%**	Rigamonti et al., 2009
Plastic	PET: 75.5%		**81%**	
	HDPE: 90%		**81%**	
	Mix*: 60%		-	-
Wood	95%		**60%**	Rigamonti et al., 2010

* 50% wood and 50% nothing (Rigamonti & Grosso, 2009)

Discussion on substitution ratios

Steel and iron

- During scraps smelting, some of the **impurities and alloying elements** will remain in the metallic phase (especially **copper** and **tin**)
- When the contaminants occurring in secondary materials exceed the maximum content allowed for the target product, **additional high purity materials must be added to "dilute" the contaminant to an acceptable level** *(Nakamura et al., 2012)*
- A **45% increase of electricity consumption** in the EAF for low-quality scrap (i.e. from WTE bottom ash) than for high-quality scrap was observed by *Haupt et al. (2016)*

Discussion on substitution ratios

Aluminium

- The quality of secondary aluminium is affected by its **oxidation level** (estimated between 11% and 23% for Al from WTE bottom ash above 0.8 mm, *Biganzoli and Grosso, 2013*)
- The potential use of secondary aluminium is also affected by the content of **alloying elements** (*Nakajima et al., 2010*)
- **Mixing with primary aluminium** or with high quality secondary aluminium might be required, according to the application
- **Substitution ratios** can be calculated based on **market price ratio between secondary and primary aluminium,** as proposed by EAA and by *Koffler and Florin (2013)*

A case study

Assessment of the effect of varying:

- ✓ the substitution ratios
- ✓ the amount of virgin material in the substituted mix

→ Applied to the integrated WMS of Lombardia Region (Italy)

Assessing the environmental credit of recycling

Environmental credit = x * REC + (1-x) * Q * VIR

Where:

x	is the proportion of recycled material in the average market mix
(1-x)	is the proportion of virgin material in the average market mix
Q	is the quality factor of recycled material vs. virgin material (Q≤1)
REC	is the environmental load of the recycling process (1 t of recycled material in output)
VIR	is the environmental load of the production process of the virgin material (1 t in output)

Gala et al., 2015

Quality factor = substitution ratio

Amount of virgin material in the substituted mix

Average European market mixes for different materials *(Gala et al., 2015)*

Material	% Virgin	% Recycled	Source
Aluminium*	63	37	Calculated from EAA 2011
Steel	50	50	EUROFER 2014
Glass	55	45	Roldán and Pino 2012
Cardboard	16	84	Calculated from CEPI 2010
Paper	71	29	Calculated from CEPI 2010
Beverage cardboard	57	43	Calculated from CEPI 2010
Plastics**	**	**	–

*For the packaging sector, these percentages move to 25 % of virgin and 75 % of recycled

**The percentage of recycled plastic is difficult to quantify

Application to the Lombardia Region

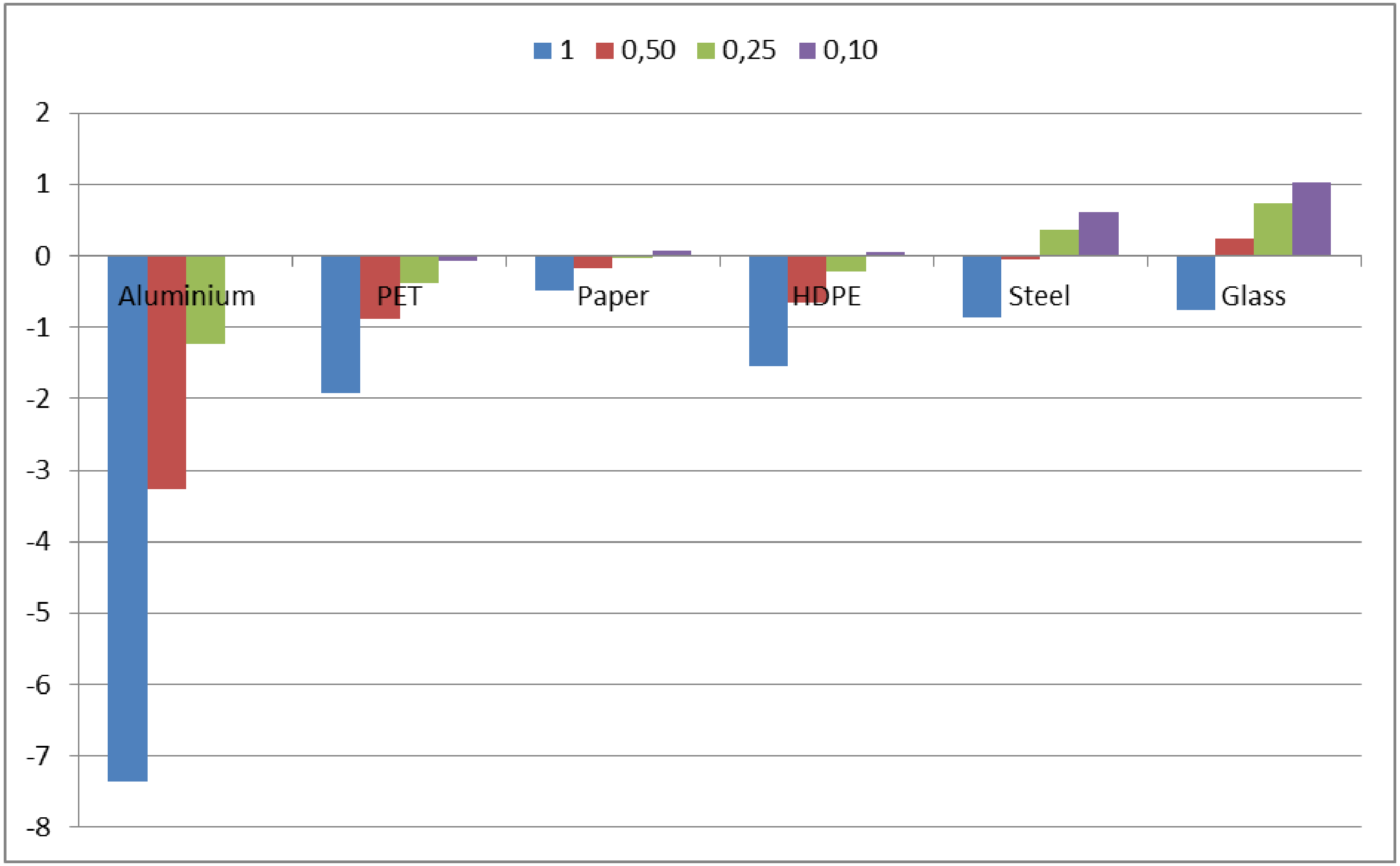
<u>Scenario BAU, year 2020</u>

Key facts:

- ✓ 10 million inhabitants
- ✓ About 5 million tonnes of yearly MSW generation
- ✓ 66% source separation
- ✓ 75% of RW to WTE plants (with Fe and non-Fe recovery from BA)
- ✓ 25% of RW to MBT followed by WTE or cement kiln co-combustion
- ✓ Marginal energy: NGCC for power, natural gas for heat

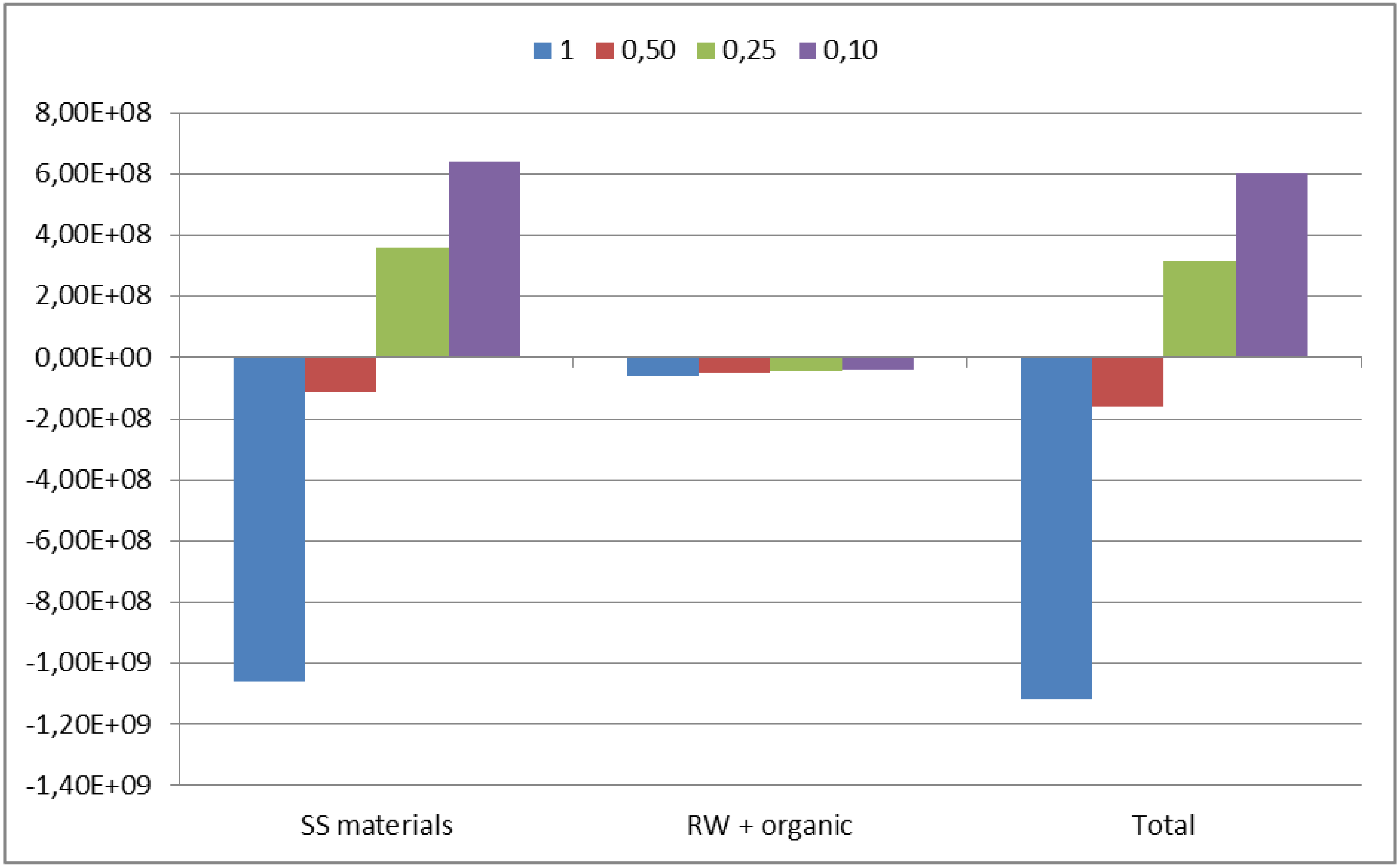
Application to the Lombardia Region

Effect of the substitution ratio on the six packaging materials
($kgCO_2eq$ per kg <u>sent to recycling</u>)



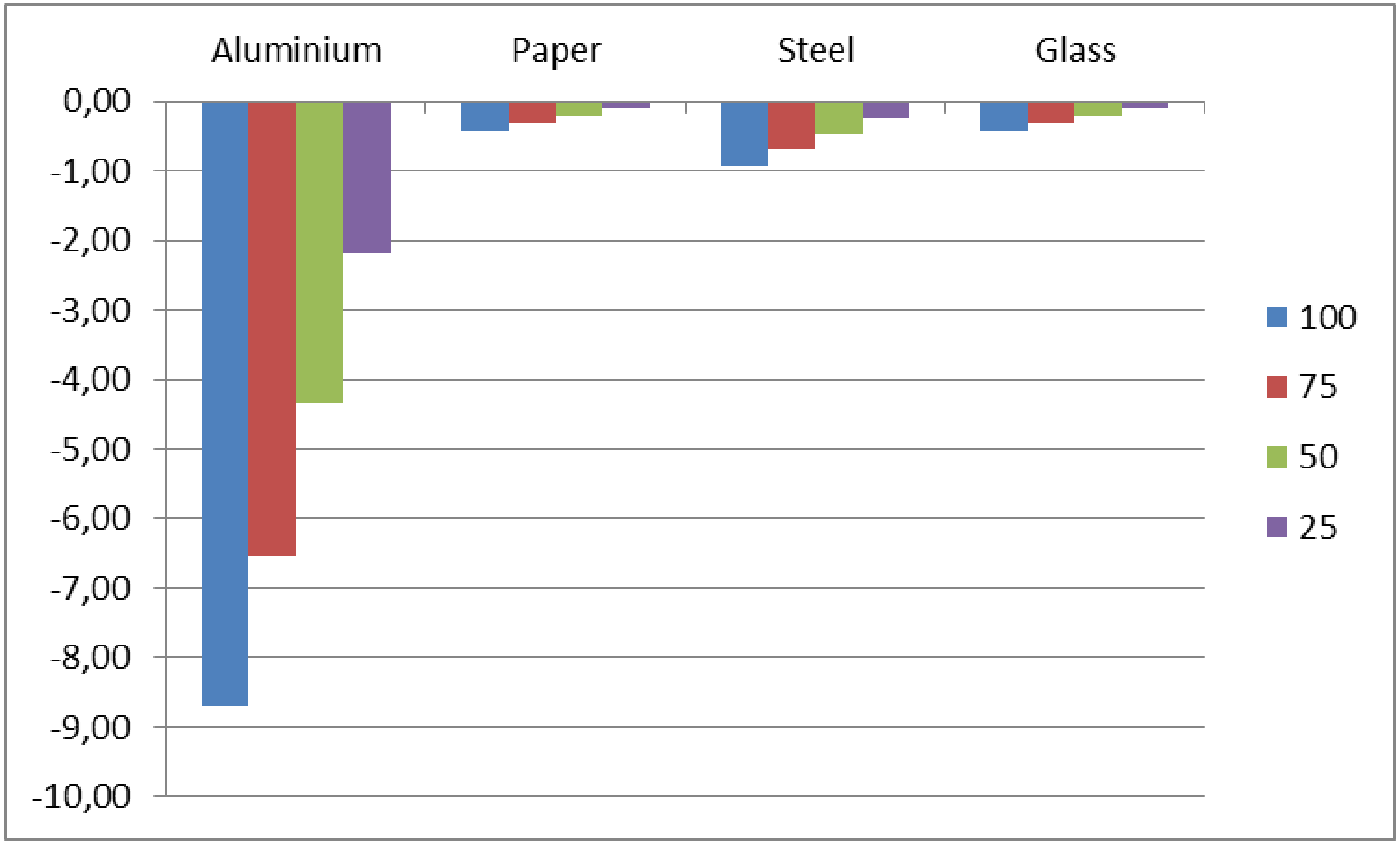
Application to the Lombardia Region

Effect of the substitution ratios on the whole management scheme (kgCO_2eq per year)



Application to the Lombardia Region

Effect of the % of virgin material in the substituted mix for four packaging materials (kgCO_2eq per kg of recycled material)



Conclusions and perspectives

- ✓ Substitution ratio strongly affects the performances of material recycling
- ✓ % of virgin material in the substituted mix also plays a role
- ✓ With a 0.4 substitution ratio for all packaging materials, the GWP performances of the Lombardia Region WM system are neutralised
- ✓ This effect should be compared with recent and perspective trends of WTE:
  - A systematic increase in energy recovery performances
  - Decrease in heat and increase in cold demand
  - A cleaner substituted energy mix
  - A possible renaissance of MBT/MRF for producing storable fuel from waste?

THANK YOU!

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