POLITECNICO MILANO 1863

Assessment on WAste and REsources

mater
materia & energia da rifiuti
materials & energy from refuse

Effectiveness and efficiency of construction and demolition waste recycling in Lombardy: a life cycle based evaluation

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Regione Lombardia

Assessment on WAste and REsources

OBJECTIVES OF THE RESEARCH PROJECT

- Quantifying construction and demolition waste (CDW) amount and flows within the management system of Lombardy Region
- Investigating types, amount and quality of "secondary products" obtained from CDW recovery plants and their actual use (highlighting the limiting factors for their market)
- Assessing the environmental performance of the current regional management system through the application of the Life Cycle Assessment (LCA) methodology
- Identifying benefits and critical aspects of the CDW management system
- Defining possible improving actions based on the state-of-the-art recovery technology and the LCA results of the current management scenario, to be compared and evaluated from a life cycle perspective

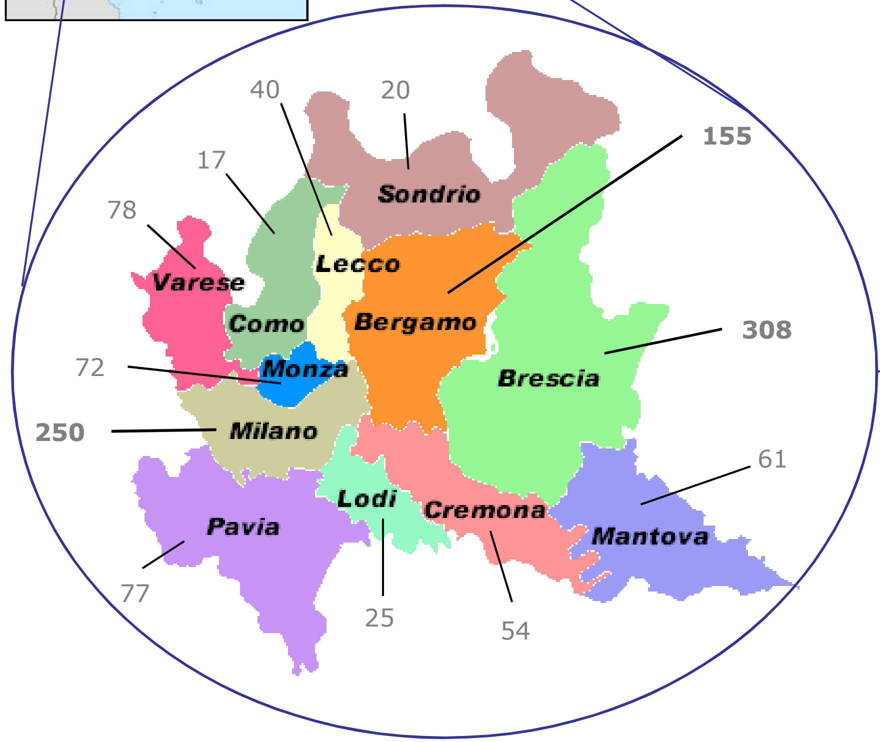
LOMBARDY REGION - ITALY

AREA: 23.844 km^2

POPULATION: 10 MILLION (1/6 ITALIAN POPULATION)

GROSS DOMESTIC PRODUCT (GDP): 22% ITALY'S GDP

ADMINISTRATIVE DIVISIONS: 12 PROVINCES, 1530 MUNICIPALITIES



Non hazardous CDW generation in Lombardy (2014): 11.9 Mt

(Italy: 50.2 Mt) (source: ISPRA2017)

CDW MANAGEMENT SYSTEM

1'157 PLANTS IN OPERATION IN 2016 (LANDFILLS: 39; RECYCLING PLANTS + TRANSFER STATIONS: 1'118)

SOURCE: CATASTO GEOREFERENZIATO DEI RIFIUTI REGIONE LOMBARDIA www.cgrweb.servizirl.it/menu.do?method=ricerca

NON-HAZARDOUS CDW INCLUDED IN THE STUDY:

EUROPEAN WASTE CODE (EWC) 17 XX XX:

- **17 01 concrete, bricks, tiles and ceramics**
  - CONCRETE (17 01 01)
  - BRICKS (17 01 02)
  - TILES AND CERAMICS (17 01 03)
  - CONCRETE, BRICKS, TILES AND CERAMICS IN MIXTURES, CONTAINING NON HAZARDOUS SUBSTANCES (17 01 07)
- **17 02 wood, glass and plastic** (17 02 01, 17 02 02, 17 02 03)
- **17 03 bituminous mixtures, coal tar and tarred products** (17 03 02)
- **17 04 metals (including their alloys)** (17 04 01, 17 04 02, 17 04 03, 17 04 04, 17 04 05, 17 04 06, 17 04 07, 17 04 11)
- **17 08 gypsum-based construction material** (17 08 02)
- **17 09 other construction and demolition waste**
  - MIXED CONSTRUCTION AND DEMOLITION WASTES (17 09 04)

RESULTS: CDW FLOWS

REFERENCE YEAR: 2014

EXPORT (plants)

EWC 17 01: 9,189 t
EWC 17 03 02: 1,665 t
EWC 17 08 02: 4,870 t
EWC 17 09 04: 38,149 t

FOCUS OF THE PRESENT RESEARCH

Imported CDW:
EWC 1701: 47,075 t;
EWC 170302: 174,389 t;
EWC 170802: 4,419 t;
EWC 170904: 382,931 t

CDW GENERATION IN LOMBARDY REGION(2014):

EWC 17 01: >= 804,625 t
EWC 17 03 02: >= 1,018,580 t
EWC 17 08 02: >= 31,405 t
EWC 17 09 04: >= 5,851,639 t

WASTE DELIVERY

WASTE MANAGEMENT SYSTEM

CDW GENERATED AND TREATED IN LOMBARDY

EWC 17 01: 763,950 t
EWC 17 03 02: 971,656 t
EWC 17 08 02: 20,988 t
EWC 17 09 04: 5,625,978 t

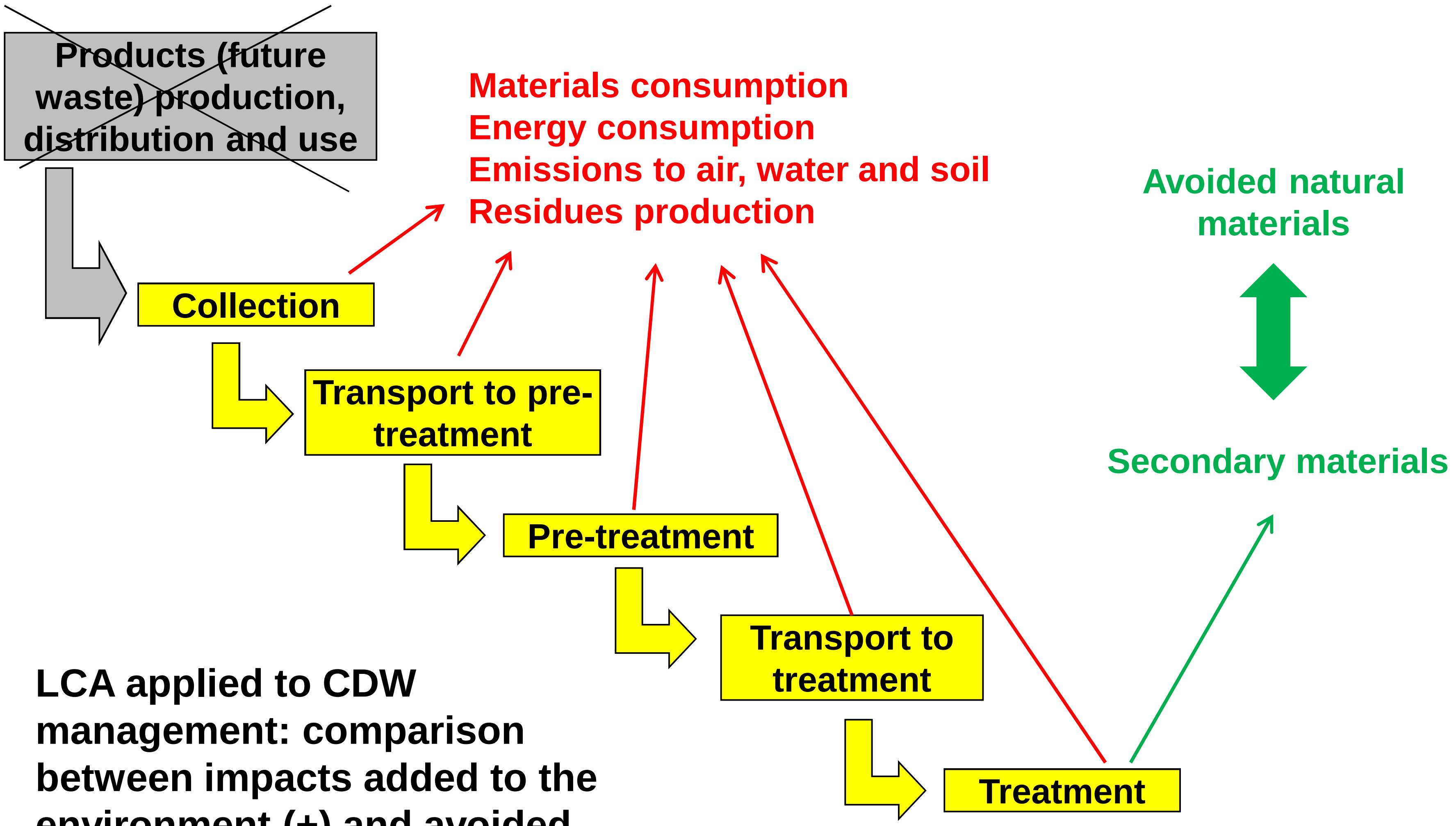
PRODUCED AND TREATED IN LOMBARDY
EWC 1701, 170302 and 170904: 95%
EWC 170802: 67%

*DIRECTLY EXPORTED WASTE**

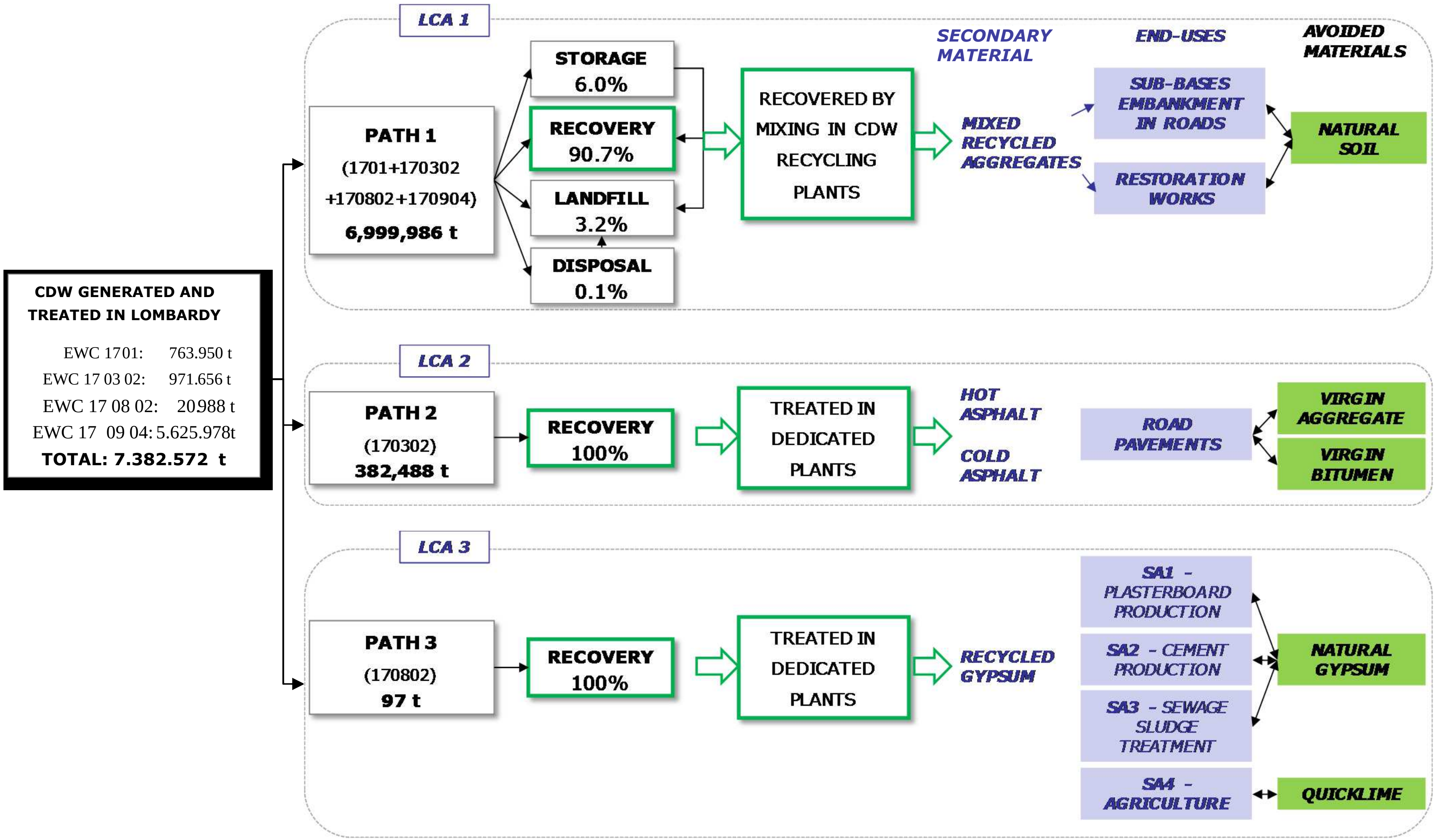
EWC 17 01: > = 31,487 t
EWC 17 03 02 > = 45,259 t
EWC 17 08 02 > = 5,547 t
EWC 17 09 04: > = 187,512 t

* >= because it doesn't include the CDW quantity from those producers not obliged to fill in the yearly waste declaration

EWC = European Waste Code



LCA applied to CDW management: comparison between impacts added to the environment (+) and avoided impacts (-) in each scenario



CDW GENERATED AND TREATED IN LOMBARDY
EWC 1701: 763.950 t
EWC 17 03 02: 971.656 t
EWC 17 08 02: 20.988 t
EWC 17 09 04: 5.625.978t
TOTAL: 7.382.572 t
LCA 1
PATH 1
(1701+170302 +170802+170904)
6,999,986 t
STORAGE 6.0%
RECOVERY 90.7%
LANDFILL 3.2%
DISPOSAL 0.1%
RECOVERED BY MIXING IN CDW RECYCLING PLANTS
SECONDARY MATERIAL
END-USES
AVOIDED MATERIALS
MIXED RECYCLED AGGREGATES
SUB-BASES EMBANKMENT IN ROADS
RESTORATION WORKS
NATURAL SOIL
LCA 2
PATH 2
(170302)
382,488 t
RECOVERY 100%
TREATED IN DEDICATED PLANTS
HOT ASPHALT
COLD ASPHALT
ROAD PAVEMENTS
VIRGIN AGGREGATE
VIRGIN BITUMEN
LCA 3
PATH 3
(170802)
97 t
RECOVERY 100%
TREATED IN DEDICATED PLANTS
RECYCLED GYPSUM
SA1 - PLASTERBOARD PRODUCTION
SA2 - CEMENT PRODUCTION
SA3 - SEWAGE SLUDGE TREATMENT
SA4 - AGRICULTURE
NATURAL GYPSUM
QUICKLIME

SETTING UP THE LCA

CDW GENERATED AND TREATED IN LOMBARDY

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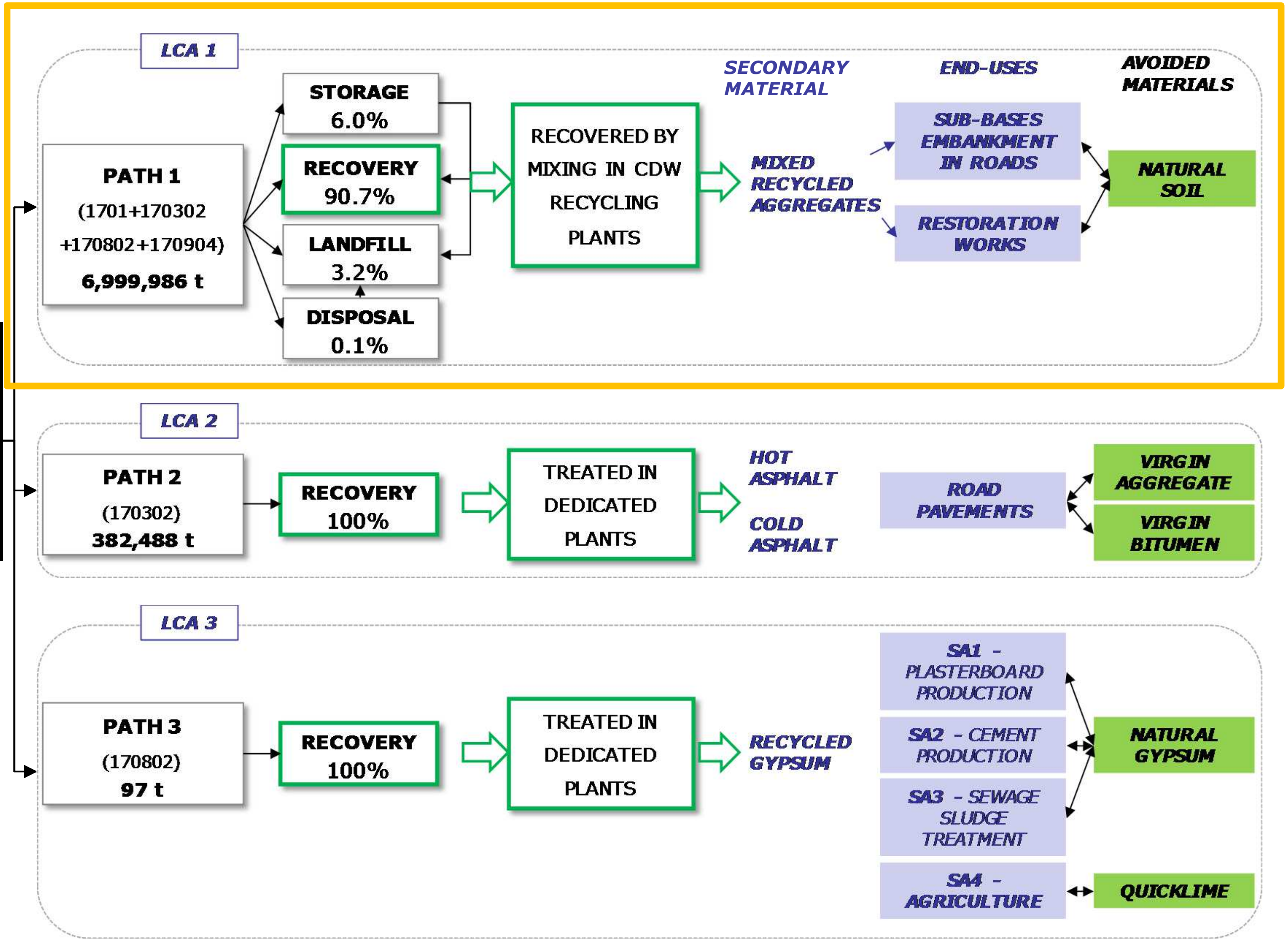


LCA 1

TECHNICAL VISITS TO SELECTED RECYCLING PLANTS:

- 2 FIXED PLANTS (MI) – **TYPE A**
- 4 MOBILE PLANTS (2 MI, 1 BS, 1 BG) – **TYPE B**
- 3 MOBILE PLANTS WITH SORTING OF PACKAGING MATERIALS FROM WORKSITES (1 MI, 1 LC, 1 MB)– **TYPE C**

RECEIVED NON-HAZARDOUS CDW (CODES 1701 + 170302 + 170904):

1.28 Mt

+ FORMS TO FILL OUT HAVE BEEN SENT TO CREATE A MORE REPRENTATIVE DATA-SET FOR THE REGIONAL CONTEXT

COLLECTED DATA:

- TOTAL RECEIVED AND TREATED NON HAZARDOUS CDW IN 2014
- TYPES AND AMOUNT OF PRODUCED RECYCLED MATERIALS
- QUALITY AND FINAL UTILIZATION OF RECYCLED MATERIALS
- AMOUNT OF SEPARATED METALS, PLASTICS, GLASS, …
- RESIDUES TO LANDFILL

OVERALL MASS BALANCE OF DIFFERENT TYPES OF RECYCLING PLANTS

- ENERGY AND FUEL FOR CDW PROCESSING (crushing, sieving,..)
- FUEL AND OIL FOR WASTE MOVING MACHINES
- WATER SUPPLY FOR DUST REMOVAL SYSTEMS
- SUPPLY OF MECHANICAL COMPONENTS SUBJECT TO WEAR AND TEAR

CONSUMPTIONS OF ENERGY AND MATERIALS FOR CDW TREATMENT

LCA 1: RECYCLING PLANTS

RECEIVED WASTE

MIXED CDW
(EWC 170904)

STATIONARY PLANTS

MOBILE PLANTS

RECYCLED AGGREGATES (RA)

RA 25/63 mm

SUB-BASE LAYERS

RA 63/125 mm

DRAINAGE LAYERS

RA 0/63 mm

RECLAMATION /FILLINGS

MODELLING THE SUBSTITUTION

Using recycled aggregates in the civil sector → **Mineral non-renewable resources avoided use (avoided impact on the environment)** → Evaluation of the substitution coefficient between recycled and natural aggregates

SAVED NATURAL RESOURCE:

Recycled aggregates final use

- Embankment body (All. C1)
- Sub-base layers (All. C2)
- Environmental reclamations (All. C4)

→ **Natural raw material**

- Base layers (All. C3)
- Anti-freeze, anti-capillary and draining layers (All. C5)
- Concrete production (UNI EN 12630/2005)

→ **Natural aggregate**

MODELLING THE SUBSTITUTION

Modelling the natural aggregates production in Lombardy region	DATA SOURCES	INFORMATION OBTAINED
	Local quarries plans	- Authorized volumes in 10 years (283,074,399 t) - Extractive activities distribution on the territory (Milano, Brescia, Bergamo) - Authorized volume for dry (40%), wet (44%) and terrace extraction (16%)
	Local authorities statistics	Quantities of extracted material every year, energy consumption and destination of natural aggregates produced
	Quarries technical visits	Characteristics associated with the various types of quarry cultivation

Dry pit quarry

Wet pit quarry

Terrace quarry

REPLACEMENT COEFFICIENT (R) BETWEEN RA AND NA CALCULATION

R= Q*M

Q = quality and performance, associated to the specific application of the RA:

$$Q = Q_1 \cdot Q_2$$

Q_1 → RA quality (i.e. soil) ⇨ *Q_1=0.97*

Q_2 →technical characteristics for the specific RA end-use ⇨ *Q_2 (C1/C2) = 1*, *Q_2 (C4) = 0.89*

M = market factor for RA:

M=1 → RA totally sold
M=0 → RA totally unsold ⇨ *M=0.67*

The recycled aggregates market in Lombardy region is unstable

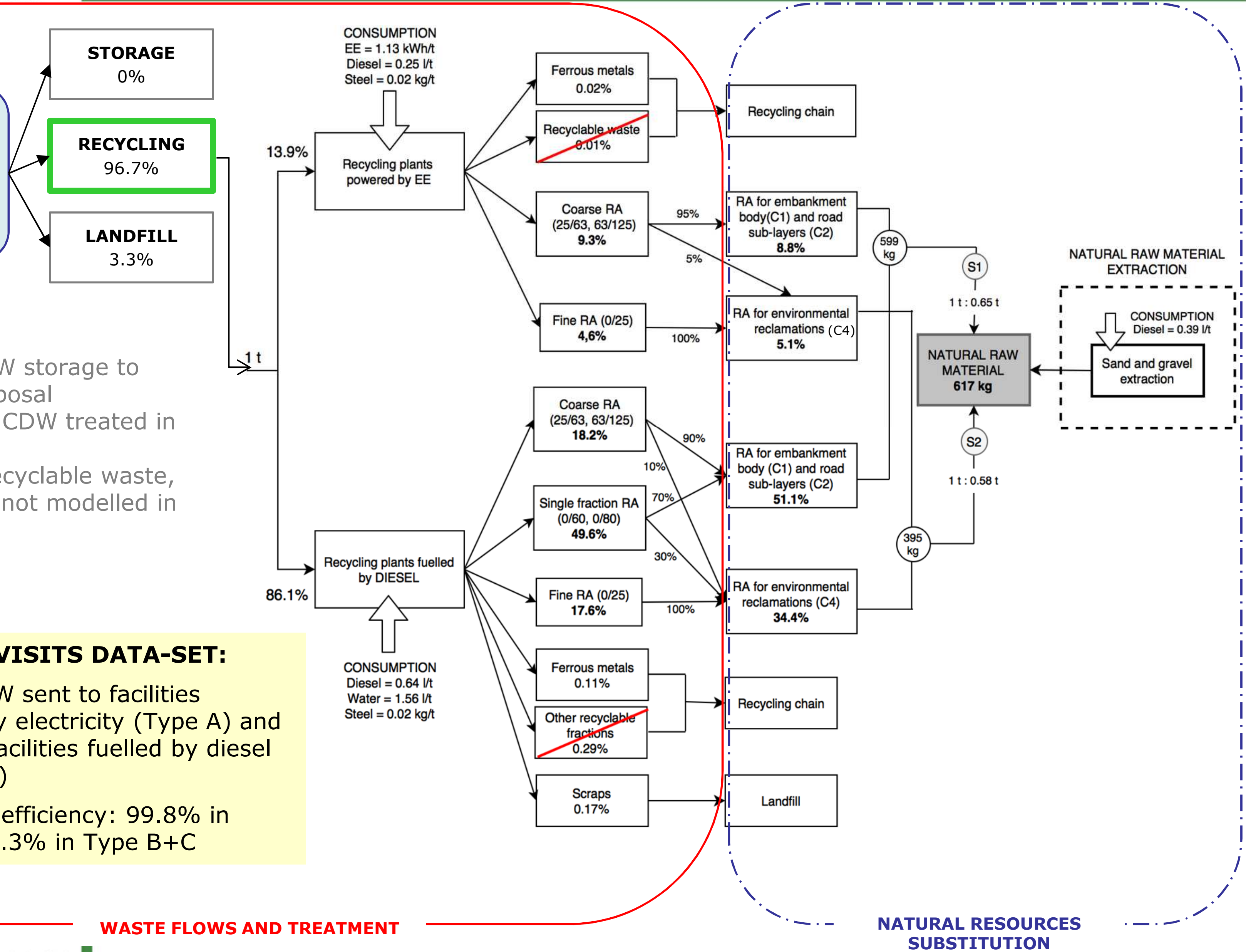
Application for mixed recycled aggregates	**R value**	*Range*
Embankment (C1) and sub-layers (C2)	**0.65**	0-0.97
Environmental reclamations (C4)	**0.58**	0-0.86

RA = recycled aggregates
NA = natural aggregates

LCA RECYCLING SYSTEM

FUNCTIONAL UNIT:
1 TON OF MIXED CDW

- 1701 (10.9%)
- 170302 (8.4%)
- 170802 (0.3%)
- 170904 (80.4%)



HYPOTHESES:
-Allocation of CDW storage to recycling and disposal
-Landfill includes CDW treated in "other disposal"
-Destination of recyclable waste, wood and plastic not modelled in the LCA analysis

FIELD VISITS DATA-SET:

- 13.9% CDW sent to facilities powered by electricity (Type A) and 86.1% in facilities fuelled by diesel (Type B+C)
- Treatment efficiency: 99.8% in Type A; 99.3% in Type B+C

LCA OF BASELINE SCENARIO, IN COMPARISON WITH A LANDFILL SCENARIO FOR 1 t OF MIXED CDW

Impact category	Unit of measure	BASELINE SCENARIO	LANDFILL SCENARIO
ILCD impact categories:			
Climate change	kg CO_2 eq	3.40	11.44
Ozone depletion	kg CFC-11 eq	9.27E-07	3.09E-06
Human toxicity (non-cancer effects)	CTUh	7.32E-06	1.86E-04
Human toxicity (cancer effect)	CTUh	5.00E-06	3.43E-06
Particulate matter	kg PM2.5 eq	2.93E-03	9.21E-03
Photochemical ozone formation	kg NMVOC eq	0.03	0.08
Acidification	mol H+ eq	0.02	0.08
Terrestrial eutrophication	mol N eq	0.10	0.27
Freshwater eutrophication	kg P eq	-1.38E-03	3.06E-03
Marine eutrophication	kg N eq	0.01	2.45E-02
Freshwater ecotoxicity	CTUe	226.1	4031.7
Water resource depletion	m^3 water eq	0.02	0.04
Mineral, fossil & renewable resource depletion	kg Sb eq	2.81E-04	5.81E-04
Cumulative Energy Demand (CED)	MJ	65.0	304.5
Natural resource consumption (sand and gravel)	kg sand&gravel	-611.4	175.3
Saved volume of landfill	m^3	0.69	-

The actual CDW management system implemented in Lombardy region

- has better environmental performances than the landfill disposal
- but the induced environmental impacts are higher than the benefits arising from CDW recycling. The biggest environmental burdens come from waste transportation and are not balanced by the small avoided impacts associated with the use of recycled aggregates in the actual applications (i.e. low grade applications)

→ **The system can be improved** so that the environmental benefits associated with the use of recycled aggregates compensate the impacts due to the waste management system itself

LCA 1: RECOMMENDATIONS

PROMOTE THE MARKET OF THE RECYCLED AGGREGATES

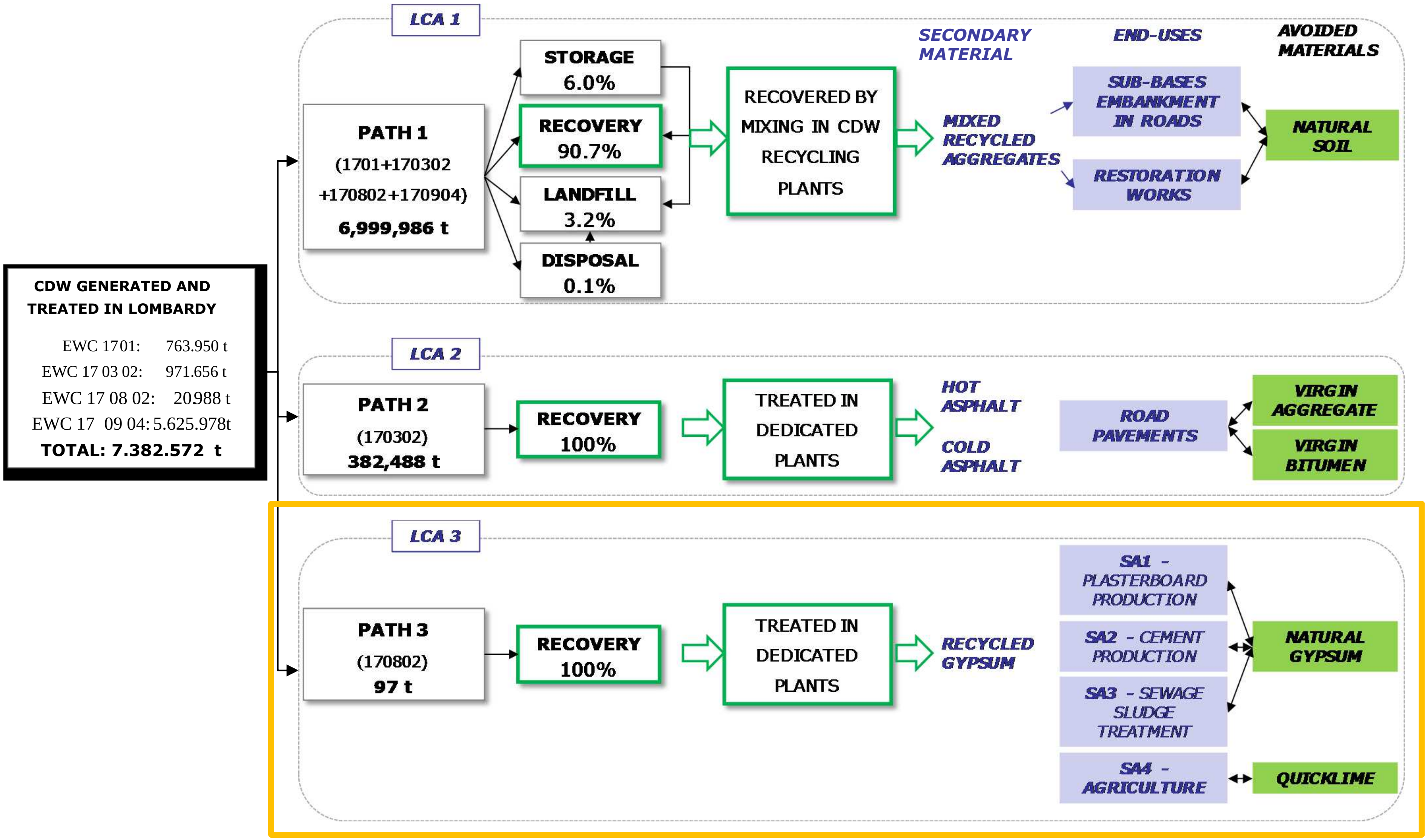
Regulatory tools aimed at promoting the use of recycled aggregates	Green Public Procurement
Mining sector planning aimed at having a more sustainable use of natural resources	• Higher taxes for the extraction activities • More rational permission system, that considers recycled aggregates availability on the territory
Adapt the technical tools to the European standards	Special tender dossier, price list of construction works

IMPROVE THE QUALITY OF RECYCLED AGGREGATES

Selective demolition on site to improve the CDW quality entering the recycling facilities	• Separation of undesired materials • Market creation for those materials that are now mixed together before the recycling treatment
Improve the plant technologies	• Encourage and promote the authorization of recycling facilities powered by electricity • Improve selection efficiencies; implement more advanced plant technologies

OPTIMISE THE MANAGEMENT SYSTEM

Minimize transport distances and temporary management phases	• Optimal facilities distribution • Updating recycling plants regional lists and maps • Promote the opening of facilities where it is needed
Reduce landfill disposal	• Increase disposal taxes • Ban on disposal for those fraction that can be recycled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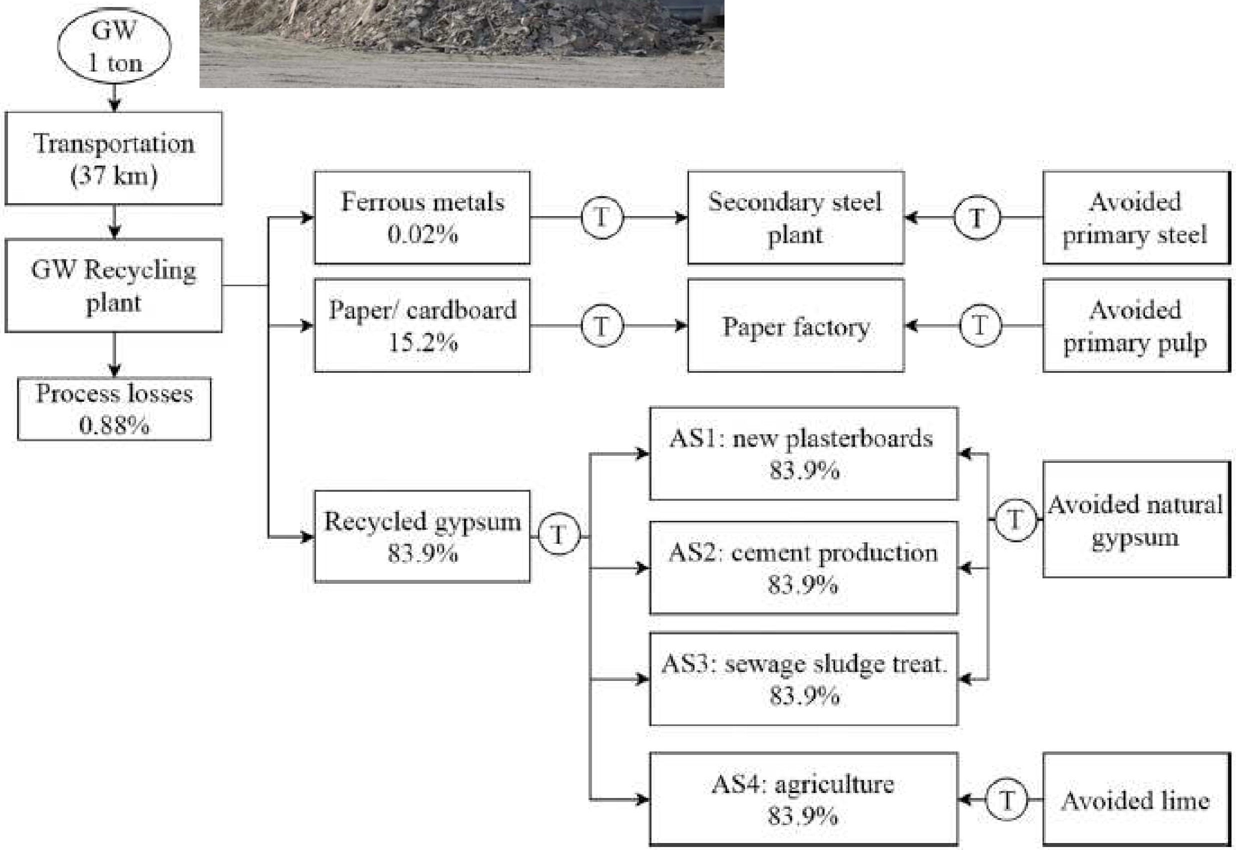


Fig. 1. Gypsum waste (GW) management in the alternative scenarios (AS). T = transportation.

LCA 3: MODELLING THE SUBSTITUTION

Alternative scenario	End-uses	Avoided primary product	Adopted RC	RC computational method	Note
SA1	Plasterboards production	Natural Gypsum	0.882	$\frac{Purity\ of\ GR}{Purity\ of\ GN}$	In terms of calcium sulphate content (CaSO4 *2H2O) - measured
SA2	Cement production	Natural Gypsum	0.991	$\frac{Purity\ of\ GR}{Purity\ of\ GN}$	Absence of residual liner paper (= 1 – TOC). Purity of natural gypsum assumed equal to 1
SA3	Sewage sludge treatment	Natural Gypsum	0.9	$\frac{Dosage\ of\ GN}{Dosage\ of\ GR}$	Primary data from a sewage sludge treatment plant
SA4	Agriculture (pH raising agent)	Quicklime	0.4	$\frac{Alkaline\ power\ of\ GR}{Alkaline\ power\ of\ quicklime}$	Stoichiometric estimation - same solubility

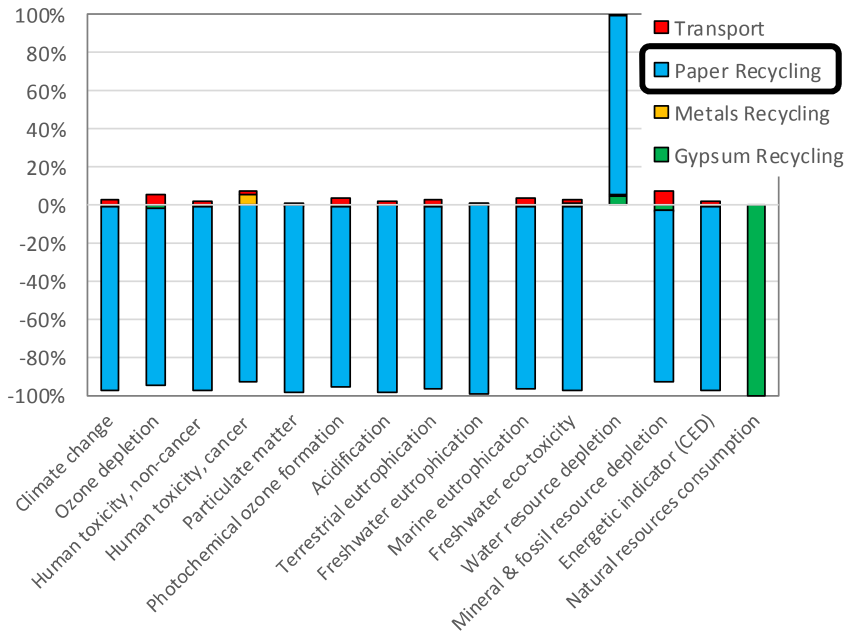
RC: replacement coefficient between secondary and primary materials
GR: recycled gypsum; GN: natural gypsum

LCA 3: RESULTS

BASELINE (LCA1) vs ALTERNATIVE SCENARIO (SA3): IMPACTS PER TONNE OF GYPSUM WASTE

	Unit	Baseline scenario	SA3
Environmental impact categories (ILCD)			
Climate change	kg CO2 eq/t	3.1	-158
Ozone depletion	kg CFC-11 eq/t	8.36E-07	-1.4E-05
Human toxicity, non-cancer	CTUh/t	1.23E-06	-5.0E-05
Human toxicity, cancer	CTUh/t	4.84E-06	-1.0E-05
Particulate matter	kg PM2.5 eq/t	2.65E-03	-2.1E-01
Photochemical ozone formation	kg NMVOC eq/t	0.02	-0.73
Acidification	mol H+ eq/t	0.03	-1.42
Terrestrial eutrophication	mol N eq/t	0.07	-2.73
Freshwater eutrophication	kg P eq/t	2.93E-02	-1.2E-01
Marine eutrophication	kg N eq/t	4.09E-03	-2.8E-01
Freshwater eco-toxicity	CTUe/t	93.82	-1,328
Water resource depletion	m^3water eq/t	1.95E-02	2.3E-01
Mineral & fossil resource depletion	kg Sb eq/t	2.68E-04	-4.3E-03
Energetic indicator (CED)	MJ eq/t	56.3	-3,855
Natural resources consumption:			
Sand and gravel indicator	kg/t	-617	-
Natural gypsum indicator	kg/t	-	-755

PERCENTAGE CONTRIBUTION TO THE TOTAL IMPACT (SA3)



- ❑ RECYCLING GW IN DEDICATED PLANTS IS MUCH MORE BENEFICIAL THAN ITS RECYCLING BY MIXING WITH OTHER CDW
- ❑ AVOIDING THE MIXING OF GW WITH INERT CDW ALLOWS TO ENHANCE THE TECHNICAL PROPERTIES OF RECYCLED AGGREGATES FROM CDW AND THEIR MARKET DEMAND
- ❑ LARGEST ENVIRONMENTAL BENEFITS COME FROM THE RECOVERY OF PAPER/CARDBOARD SEPARATED FROM GW TREATMENT

LCA 3: RESULTS

Results of all alternative scenarios (SA1-SA4) are expressed per tonne of gypsum waste and do not include benefits from paper recovery

	Unit	Baseline scenario	WORST PERFORMANCE SA1	SA2	SA3	BEST PERFORMANCE SA4
Environmental impact categories (ILCD)						
Climate change	kg CO2 eq/t	3.1	**2.7**	-1.5	-1.28	**-10.7**
Ozone depletion	kg CFC-11 eq/t	8.36E-07	**3.2E-07**	-5.8E-07	-3.7E-07	**-2.1E-07**
Human toxicity, non-cancer	CTUh/t	1.23E-06	**2.1E-07**	-8.8E-07	-5.7E-07	**-3.8E-06**
Human toxicity, cancer	CTUh/t	4.84E-06	**7.1E-08**	-3.7E-08	-3.2E-08	**-6.1E-07**
Particulate matter	kg PM2.5 eq/t	2.65E-03	**1.5E-03**	-1.3E-03	-6.2E-04	**-1.5E-02**
Photochemical ozone formation	kg NMVOC eq/t	0.02	**0.01**	-0.02	-0.01	**-0.03**
Acidification	mol H+ eq/t	0.03	**0.02**	-0.01	-4.6E-03	**-0.08**
Terrestrial eutrophication	mol N eq/t	0.07	**0.04**	-0.06	-0.03	**-0.12**
Freshwater eutrophication	kg P eq/t	2.93E-02	**5.8E-04**	4.3E-04	1.1E-04	**-4.2E-03**
Marine eutrophication	kg N eq/t	4.09E-03	**3.7E-03**	-5.4E-03	-2.3E-03	**-1.4E-02**
Freshwater eco-toxicity	CTUe/t	93.82	**9.71**	-18	-13.19	**-68.34**
Water resource depletion	m^3water eq/t	1.95E-02	**0.02**	0.03	0.01	**-0.01**
Mineral & fossil resource depletion	kg Sb eq/t	2.68E-04	**1.9E-07**	-2.3E-04	-1.4E-04	**-4.4E-04**
Energetic indicator (CED)	MJ eq/t	56.3	**45**	-30	-24	**-224**
Natural resources consumption:						
Sand and gravel indicator	kg/t	-617	-	-	-	-
Natural gypsum indicator	kg/t	-	**-740**	-831	-755	0

LCA 3: CONCLUSIONS AND RECOMMENDATIONS

- There is only one GW recycling plant in the region and GW is mostly (99.5%) recycled in CDW facilities → deficiency of the regional GW management system → **at least, two more plants are needed to cover current GW generation**

- Better environmental performance of dedicated GW recycling, compared to that of mixing GW with CDW → **GW recycling in dedicated plants should be promoted** (→ enhanced technical properties of mixed recycled aggregates and potentially increase their market demand)

- Recycling GW in dedicated facilities leads to significant savings, mainly ascribed to the recovery of paper → **the adoption of adequate technologies able to achieve high-quality recycled gypsum and to separate cardboard/paper sufficiently pure to be destined to paper factories should be fostered**

- Comparison among alternative end-uses of the recycled gypsum (excluding the benefits from paper recycling): the plasterboards production is the least viable option due to the nonexistence of manufacturing plants in the regional territory (→ long transport distances); the best environmental and energetic profile is associated to the use of the recycled gypsum in the agricultural sector → **promotion of the use of recycled gypsum in the different technically feasible applications (cement production, sludge treatment, agriculture)**

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Life cycle assessment of non-hazardous Construction and Demolition Waste (CDW) management in Lombardy Region (Italy)

Giulia Borghi [a, *], Sara Pantini [a, b], Lucia Rigamonti [a, b]

Waste Management 80 (2018) 423–434

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Towards resource-efficient management of asphalt waste in Lombardy region (Italy): Identification of effective strategies based on the LCA methodology

S. Pantini [a,b,*], G. Borghi [a], L. Rigamonti [a,b]

Resources, Conservation & Recycling 147 (2019) 157–168

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Full length article

A LCA study to investigate resource-efficient strategies for managing post-consumer gypsum waste in Lombardy region (Italy)

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THANK YOU FOR YOUR ATTENTION

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