EVALUATING THE CONSTRUCTION AND DEMOLITION WASTE MANAGEMENT SYSTEM IMPLEMENTED IN LOMBARDY REGION (ITALY) THROUGH LIFE CYCLE ASSESSMENT

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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
GEOGRAPHICAL CONTEXT

LOMBArdY REGION - ITALY

AREA: 23.844 km²
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

1157 PLANTS IN OPERATION IN 2016
(LANDFILLS: 39; RECYCLING PLANTS + TRANSFER STATIONS: 1118)

SOURCE: CATASTO GEOREFERENZIATO DEI RIFIUTI REGIONE LOMBARDIA
http://www.cgrweb.servizirl.it/cgrweb/ricerca.do
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)
REFERENCE YEAR: 2014

WASTE MANAGEMENT SYSTEM

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

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

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

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

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

* ≥ = because it doesn’t include the CDW quantity from those producers not obliged to fill in the yearly waste declaration.
FUNCTIONAL UNIT:
1 t OF CDW PRODUCED AND TREATED AT REGIONAL LEVEL (2014)

- 17 01 (10.9%)
- 17 03 02 (8.4%)*
- 17 08 02 (0.3%)*
- 17 09 02 (80.4%)

* NET TO THE QUANTITY OF 170302 AND 170802 SENT TO SPECIFIC TREATMENT FACILITIES (NOT MIXED)

ESTIMATION OF TRANSPORT DISTANCES FROM DELIVERING DECLARATION: 27.5 km

LCA SYSTEM

LCA OF THE CDW MANAGEMENT SYSTEM IMPLEMENTED IN LOMBARDY REGION → 6,999,986 t in 2014

- ENERGY CONSUMPTION
- AUXILIARY MATERIALS CONSUMPTION

TRANSFER STATIONS
6.0%
(R13 operation)

RECYCLING PLANTS
90.7%
(all other R operations)

LANDFILL DISPOSAL
3.2%
(D1 operation)

OTHER DISPOSAL
0.1%
(D9, D13, D14, D15)

ESTIMATION OF TRANSPORT DISTANCES FROM PLANT DECLARATIONS:
27.5 km

ESTIMATION OF TRANSPORT DISTANCES FROM PLANT MANAGING COMPANIES: 15 km

SUBSTITUTION OF NATURAL RESOURCES

AVOIDED EMISSIONS

EMISSIONS

TRANSFER STATIONS
11.6%

RECYCLING PLANTS
85.1%

LANDFILL DISPOSAL
3.0%

OTHER DISPOSAL
0.3%

EMISSIONS ESTIMATION

- ENERGY CONSUMPTION
- AUXILIARY MATERIALS CONSUMPTION

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

RECEIVED WASTE
- MIXED CDW (EWC 170904)

FIXED PLANTS (TYPE A)

MOBILE PLANTS (TYPE B)

RECYCLED AGGREGATES (RA)
- RA 25/63
- RA 63/125
- RA 0/63

SUB-BASE LAYER
DRAINAGE LAYERS
RECLAMATION/FILLINGS
FUNCTIONAL UNIT:
1 t OF MIXED CDW
- 1701 (10.9%)
- 170302 (8.4%)
- 170802 (0.3%)
- 170904 (80.4%)

STORAGE 0%

RECYCLING 96.7%

LANDFILL 3.3%

ASSUMPTIONS:
- 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

TECHNICAL VISITS DATA-SET:
- 13.9% CDW sent to facilities powered by electricity (EE) (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
### REQUIREMENTS AND SUITABILITY FOR RECYCLED AGGREGATES USE:

**CIRCULAR n. 5205/2005 + EC MARKING (UNI 13242)**

<table>
<thead>
<tr>
<th>Coarse aggregates * (25/63; 63/125)</th>
<th>24.8%</th>
<th>90%</th>
<th>10%</th>
<th>MIXED NATURAL RAW MATERIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fine aggregates (0/25)</td>
<td>21.6%</td>
<td>0%</td>
<td>100%</td>
<td>AVOIDED IMPACTS: ONLY EXTRACTION</td>
</tr>
<tr>
<td>All-in aggregates (0/60; 0/80)</td>
<td>53.5%</td>
<td>70%</td>
<td>30%</td>
<td></td>
</tr>
</tbody>
</table>

* COARSE AGGREGATES CAN BE USED ALSO IN THE CONSTRUCTION OF DRAINAGE LAYERS (C5) IN SUBSTITUTION OF ROUND/CRUSHED GRAVEL. IN THE ACTUAL LCA SCENARIO THIS APPLICATION HAS BEEN NEGLECTED.

**Use of recycled aggregates**

<table>
<thead>
<tr>
<th>Embankment body/sub-base layer (C1/C2)</th>
<th>Environmental reclamations (C4)</th>
<th>Replaced natural resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>% on total recycled aggregates</td>
<td></td>
<td></td>
</tr>
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<td>30%</td>
</tr>
</tbody>
</table>

**AVOIDED IMPACTS:**

- ONLY EXTRACTION
Modelling the natural aggregates production in Lombardy region

DATA SOURCES

- Local quarries plans
- Local authorities statistics
- Quarries technical visits

INFORMATION OBTAINED

- 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%)

Quantities of extracted material every year, energy consumption and destination of natural aggregates produced

Characteristics associated with the various types of quarry cultivation

Dry pit quarry
Wet pit quarry
Terrace quarry
THE MARKET FOR RECYCLED AGGREGATES

- The recycled aggregates market in Lombardy region is unstable and strictly connected to the realization of great works (e.g. EXPO 2015, high speed rail lines, ..)

- The low cost (4-5 €/t) of natural aggregates and their wide availability (low taxes associated to the extraction activity and lack of restrictions in Lombardy) represent the main factors that limit the development of the recycled aggregates market, making them less competitive than natural virgin materials

- Lack of knowledge in designers and diffidence by end-users in the technical characteristics of recycled aggregates (because of their "waste origin")

- Not updated technical instruments to the European standards (in call of tenders no equivalence between recycled and natural aggregates)

- Lack of specific “end of waste” criteria for CDW, that limits the recycled aggregates use in the construction sector

LCA SHOULD CONSIDER NOT ONLY THE TECHNICAL CHARACTERISTICS OF RECYCLED AGGREGATES, BUT ALSO THE AVAILABILITY OF A MARKET
METHOD 1:

\[ R = Q \times M \]

- **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)
  - \( Q_2 \) → technical characteristics for the specific RA end-use

- **M** = market factor for RA:
  - \( M = 1 \) → RA totally sold
  - \( M = 0 \) → RA totally unsold

**METHOD 2:**

\[ R = \frac{\text{Price (RA)}}{\text{Price (NA)}} \]

- Price (RA) = average selling price for recycled aggregates: 0-4.2 €/t
- Price (NA) = average selling price for natural aggregates in Lombardy region: 4.0-9.2 €/t

**SENSITIVITY ANALYSES**

<table>
<thead>
<tr>
<th>Application for mixed recycled aggregates</th>
<th>R value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embankment (C1) and sub-layers (C2)</td>
<td>0.65</td>
<td>0-0.97</td>
</tr>
<tr>
<td>Environmental reclamations (C4)</td>
<td>0.58</td>
<td>0-0.86</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application for mixed recycled aggregates</th>
<th>R value</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Embankment (C1), sub-layers (C2) and Environmental reclamations (C4)</td>
<td>0.37</td>
<td>0-0.8</td>
</tr>
</tbody>
</table>

RA = recycled aggregates
NA = natural aggregates
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

TECHNICAL 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
<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit of measure</th>
<th>BASELINE SCENARIO</th>
<th>LANDFILL SCENARIO</th>
</tr>
</thead>
<tbody>
<tr>
<td>ILCD impact categories:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Climate change</td>
<td>kg CO₂ eq</td>
<td>3.40</td>
<td>11.44</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>kg CFC-11 eq</td>
<td>9.27E-07</td>
<td>3.09E-06</td>
</tr>
<tr>
<td>Human toxicity (non-cancer effects)</td>
<td>CTUh</td>
<td>7.32E-06</td>
<td>1.86E-04</td>
</tr>
<tr>
<td>Human toxicity (cancer effect)</td>
<td>CTUh</td>
<td>5.00E-06</td>
<td>3.43E-06</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>kg PM2.5 eq</td>
<td>2.93E-03</td>
<td>9.21E-03</td>
</tr>
<tr>
<td>Photochemical ozone formation</td>
<td>kg NMVOC eq</td>
<td>0.03</td>
<td>0.08</td>
</tr>
<tr>
<td>Acidification</td>
<td>mol H+ eq</td>
<td>0.02</td>
<td>0.08</td>
</tr>
<tr>
<td>Terrestrial eutrophication</td>
<td>mol N eq</td>
<td>0.10</td>
<td>0.27</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg P eq</td>
<td>-1.38E-03</td>
<td>3.06E-03</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg N eq</td>
<td>0.01</td>
<td>2.45E-02</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>CTUe</td>
<td>226.1</td>
<td>4031.7</td>
</tr>
<tr>
<td>Water resource depletion</td>
<td>m³ water eq</td>
<td>0.02</td>
<td>0.04</td>
</tr>
<tr>
<td>Mineral, fossil &amp; renewable resource depletion</td>
<td>kg Sb eq</td>
<td>2.81E-04</td>
<td>5.81E-04</td>
</tr>
<tr>
<td>Cumulative Energy Demand (CED)</td>
<td>MJ</td>
<td>65.0</td>
<td>304.5</td>
</tr>
<tr>
<td>Natural resource consumption (sand and gravel)</td>
<td>kg sand&amp;gravel</td>
<td>-611.4</td>
<td>175.3</td>
</tr>
<tr>
<td>Saved volume of landfill</td>
<td>m³</td>
<td>0.69</td>
<td>-</td>
</tr>
</tbody>
</table>
LCA: ALTERNATIVE SCENARIOS

Analysed alternative scenarios

Calculation methodology
- R \(\rightarrow\) Method 2 (R=0.37)

Management
- SG1 \(\rightarrow\) No storage operations
  - SG2 \(\rightarrow\) CDW totally landfilled

Recycling
- SR1 \(\rightarrow\) CDW totally sent to recycling plants powered by EE (96.7% of the total CDW managed)
  - SR2 \(\rightarrow\) CDW totally sent to recycling plants fuelled by diesel (96.7% of the total CDW managed)

Transport
- ST1 \(\rightarrow\) CDW transport distances variation
  - ST1_A=20 km
  - ST1_B=35 km
- ST2 \(\rightarrow\) RA selling distances variation (10-30 km)
  - ST2_A=10 km
  - ST2_B=30 km
- ST3 \(\rightarrow\) NA selling distances variation (30-60 km)
  - ST3_A=30 km
  - ST3_B=60 km

Replacement coefficient
- SF1 \(\rightarrow\) Market factor (M) variation (0-1)
  - SF1_A \(\rightarrow\) M=0
  - SF1_B \(\rightarrow\) M=1
- SF2 \(\rightarrow\) Method 2 replacement coefficient variation (0-0.8)
  - SF2_A \(\rightarrow\) R=0
  - SF2_B \(\rightarrow\) R=0.8

Alternative uses for recycled aggregates
- SA \(\rightarrow\) Production of 100% high-quality RA (replacement coefficient between RA and sand and gravel aggregates 1:1 )

Actual scenario (baseline):
- R: 0.65 or 0.58
- Storage: 11.6%
- Landfill: 3.3% and Recycling: 96.7%
- Electricity plants: 13.9%; diesel plants: 86.1%
- CDW transport distance: 27.5 km
- Recycled aggregates selling distance: 15 km
- Natural aggregates selling distance: 40 km
- Market factor: 0.67
- High-quality recycled aggregates production: 0%

RA = recycled aggregates
NA = natural aggregates

ST1_A = 20 km, ST1_B = 35 km
ST2_A = 10 km, ST2_B = 30 km
ST3_A = 30 km, ST3_B = 60 km
SF1_A = M=0, SF1_B = M=1
SF2_A = R=0, SF2_B = R=0.8
**ASSUMPTIONS:**
- No CDW storage
- No CDW sent to landfill
- 100% electricity plants
- Minimum distance for CDW delivery
- Minimum distance for recycled aggregates selling
- Unchanged distance for natural aggregates selling
- Market factor = 1
- 90% high-quality recycled aggregates (10% low-quality used for environmental reclamation (fine fraction))

*Considering 6,999,986 t: 23,800 t CO₂ eq → -12,500 t CO₂ eq*

<table>
<thead>
<tr>
<th>Impact category</th>
<th>Unit of measure</th>
<th>BEST-CASE SCENARIO</th>
</tr>
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<tr>
<td><strong>ILCD impact categories:</strong></td>
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<td></td>
</tr>
<tr>
<td>Climate change</td>
<td>kg CO₂eq/t</td>
<td>-1.78*</td>
</tr>
<tr>
<td>Ozone depletion</td>
<td>kgCFC-11eq/t</td>
<td>-5.1E-08</td>
</tr>
<tr>
<td>Human toxicity (non-cancer effects)</td>
<td>CTUh/t</td>
<td>1.0E-07</td>
</tr>
<tr>
<td>Human toxicity (cancer effect)</td>
<td>CTUh/t</td>
<td>4.6E-06</td>
</tr>
<tr>
<td>Particulate matter</td>
<td>kgPM2.5eq/t</td>
<td>-0.0013</td>
</tr>
<tr>
<td>Photochemical ozone formation</td>
<td>kgNMVOCeq/t</td>
<td>-0.010</td>
</tr>
<tr>
<td>Acidification</td>
<td>mol H+eq/t</td>
<td>-0.0104</td>
</tr>
<tr>
<td>Terrestrial eutrophication</td>
<td>mol Neq/t</td>
<td>-0.03</td>
</tr>
<tr>
<td>Freshwater eutrophication</td>
<td>kg Peeq/t</td>
<td>-0.0018</td>
</tr>
<tr>
<td>Marine eutrophication</td>
<td>kg Neq/t</td>
<td>-0.0031</td>
</tr>
<tr>
<td>Freshwater ecotoxicity</td>
<td>CTUe/t</td>
<td>65.5</td>
</tr>
<tr>
<td>Water resource depletion</td>
<td>m³water eq/t</td>
<td>0.013</td>
</tr>
<tr>
<td>Mineral, fossil &amp; renewable resource depletion</td>
<td>kg Sbeq/t</td>
<td>9.1E-05</td>
</tr>
<tr>
<td>Cumulative Energy Demand (CED)</td>
<td>MJ/t</td>
<td>-24.1</td>
</tr>
<tr>
<td>Natural resource consumption (sand and gravel)</td>
<td>kg/t</td>
<td>-1025.4</td>
</tr>
</tbody>
</table>
The actual (2014) CDW management system implemented in Lombardy region
- has better environmental performances than the landfill disposal
- can be improved so that the environmental benefits associated with the use of recycled aggregates in the civil sector are higher than the impacts induced by the waste management
## Promote the Market of the Recycled Aggregates

<table>
<thead>
<tr>
<th>Regulatory tools aimed at promoting the use of recycled aggregates</th>
<th>Green Public Procurement</th>
</tr>
</thead>
</table>
| 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 |

## Produce Better-Quality 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 |

## Optimize 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 |
ACKNOWLEDGMENTS

This research project was financially supported by the Lombardy region government. We thank ARPA Lombardia, ANPAR and ANCE for the technical support; local officers for having supplied quarries statistic data; all CDW plants and quarries managers for having supplied primary data for the LCA study and road companies for the information about recycled aggregates final use.

THANK YOU FOR YOUR ATTENTION

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