Reducing Water Footprint of building sector: concrete with seawater and marine aggregates

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Presentation outline

Introduction
- Water stress and freshwater consumption in the building sector
- SEACON project

Goal of the study

Materials and methods
- Scope of the LCA
- Life Cycle Inventory
- Life Cycle Impact Assessment

Results

Conclusions and further investigations
Introduction

- ½ of the global population live in areas potentially scarce in water at least one month per year\(^a\)
- Concrete is the building material with higher rate of growth\(^b\)

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\(^b\) Miller et al. 2016, Readily implementable techniques can cut annual CO\(_2\) emissions from the production of concrete by ove 20%. ERL, 11(7)

\(^c\) Miller et al 2018, Impacts of booming concrete production on water resources worldwide Nature Sustainability 1 69-76
Introduction

SEACON project

- Sustainable concrete using seawater, salt-contaminated aggregates
- Non-corrosive reinforcements: Glass Fiber Reinforced Polymer (GFRP), Stainless steel
Goal of the study

Assess the water footprint of concrete and investigate whether the use of seawater and marine aggregates could reduce it.

- LAFW: Land-won Aggregates (LA) • Fresh-Water (FW)
- LASW: Land-won Aggregates (LA) • Sea-Water (SW)
- MASW: Marine Aggregates (MA) • Sea-Water (SW)
Assess the water footprint of concrete and investigate whether the use of seawater and marine aggregates could reduce it.
Goal of the study

Assess the water footprint of concrete and investigate whether the use of seawater and marine aggregates could reduce it.

- LAFW
  - Land-won Aggregates (LA)
  - Fresh-Water (FW)

- LASW
  - Land-won Aggregates (LA)
  - Sea-Water (SW)

- MASW
  - Marine Aggregates (MA)
  - Sea-Water (SW)
1 cubic metre of unreinforced fresh generic concrete delivered to the construction site

a Ecoinvent, dataset “Concrete, normal (CH), unreinforced concrete production with cement CEM/IIA”
Scope
System boundaries

Cradle-to-gate analysis

Aggregates production

Concrete production (batching plant)

Cement production

Mixing water extraction
Scope
System boundaries

LAFW

Aggregates production
- Wet quarry
- Dry quarry
- Rock quarry

Cement production

Mixing water extraction
- Well water

Concrete production (batching plant)
Scope
System boundaries

LASW

Aggregates production
- Wet quarry
- Dry quarry
- Rock quarry

Cement production

Mixing water extraction
- Seawater

Concrete production
(batching plant)
Scope
System boundaries

MASW

- Aggregates production
  - Marine aggregates

- Cement production

- Mixing water extraction
  - Seawater

Concrete production (batching plant)
Scope
Geography

Legend

- Regional boundaries
- Regions investigated

- Lombardy
- Abruzzo
- Eastern Sicily
Life Cycle Inventory

1. Inventory of materials, energy and water flows
2. Geolocation of quarries, cement plants and batching plants
3. Geolocation of water intake and marine aggregates discharge facilities
4. Distance calculation
Life Cycle Inventory

Sources of data

- Wet quarry
- Dry quarry
- Rock quarry
- Batching plant
- Cement plant

Primary data
- (Producers)
- (API Google Distance matrix)

Secondary data
- (Ecoinvent, scientific literature)
Life Cycle Inventory
Geolocation of quarries, cement plants and batching plants

Sources of data:
- Official regional websites
- Italian Association of Cement manufactures
- Italian Technical Economic Association for Ready-Mixed Concrete

Legend
- Quarries
- Cement plants
- Batching plants
Life Cycle Inventory
Geolocation of seawater intake facilities and marine aggregates processing plants

Point along coast at the minimal linear distance from each batching plant

- Seawater intake facility
- Marine aggregates processing plants

Legend
- Intake facilities
- Batching plants
Life Cycle Inventory
Freshwater use

Indirect water use

Water used in preceding processes, embedded in materials and energy flows entering the process unit.

Direct water use

Water used directly in the process analyzed.
# Life Cycle Inventory

## Direct freshwater use

<table>
<thead>
<tr>
<th>Aggregates production</th>
<th>Dry quarry</th>
<th>Wet quarry</th>
<th>Rock quarry</th>
</tr>
</thead>
<tbody>
<tr>
<td>❑ Wash the machinery</td>
<td>❑ Wash the machinery</td>
<td>❑ Wash the machinery</td>
<td>❑ Wash the machinery</td>
</tr>
<tr>
<td>❑ Wash the aggregates</td>
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<td>❑ Wash the aggregates</td>
<td>❑ Dust control</td>
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<tr>
<td></td>
<td></td>
<td>❑ Evaporation from quarry lake</td>
<td></td>
</tr>
<tr>
<td>Aggregates production</td>
<td>Dry quarry</td>
<td>Wet quarry</td>
<td>Rock quarry</td>
</tr>
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</tr>
</tbody>
</table>

**Water consumption:**
- ❑ Evaporated water
- ❑ Water incorporated in the final product
Life Cycle Inventory
Direct freshwater use

Cement plant
- Wash the machinery and the yards
- Cooling activities
- Gas conditioning

Batching plant
- Mixing the concrete
- Wash the trucks
- Wash the yards

Water consumption:
- Evaporated water
- Water incorporated in the final product
Water Footprint = water consumption \times \text{characterization factor}

AWARE characterization factors

- Account for the Available WAter Remaining in a watershed after the demand of humans and aquatic ecosystems is met.

- Unit of measure: \( \frac{m^3_{\text{water world-eq}}}{m^3_{\text{consumed water}}} \)

<table>
<thead>
<tr>
<th>Direct water consumption</th>
<th>Basin scale factors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indirect water consumption</td>
<td>National scale factors</td>
</tr>
</tbody>
</table>
Results
Outline

Freshwater consumption in the base case scenario

Water footprint - base case scenario
- Abruzzo
- Eastern Sicily
- Lombardy
- Contribution of each unit process

Water footprint – Alternatives comparison
- LAFW → LASW
- LAFW → MASW
Results
Freshwater consumption (base case scenario)

Legend
- Direct water consumption
- Indirect water consumption

\[
\frac{m^3_{\text{water}}}{m^3_{\text{concrete}}} = 1.7 - 5.5
\]
Results
Freshwater consumption (base case scenario)

High value due to evaporation from quarry lake

Concrete batching plant

Legend
- Direct water consumption
- Indirect water consumption
Results
Water Footprint base case scenario (LAFW)

WF of 1 m³ of concrete (D.U.) in Abruzzo

126

39

Batching plants

0 20 40 60 80 100 120 140 160 180 200

world-equivalents m³ of water

Concrete transport
Cement transport
Aggregates transport
Mixing water
Batching plant
Cement plant
Aggregates production
Results
Water Footprint base case scenario (LAFW)

WF of 1 m$^3$ of concrete (D.U.) in Eastern Sicily

- Concrete transport
- Cement transport
- Aggregates transport
- Mixing water
- Batching plant
- Cement plant
- Aggregates production

Batching plants

<table>
<thead>
<tr>
<th>Batching plants</th>
<th>Concrete transport</th>
<th>Cement transport</th>
<th>Aggregates transport</th>
<th>Mixing water</th>
<th>Batching plant</th>
<th>Cement plant</th>
<th>Aggregates production</th>
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<tr>
<td>1</td>
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<tr>
<td>8</td>
<td>200</td>
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<td>160</td>
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</tr>
</tbody>
</table>

Map showing distribution with FC AWARE: 0.1 - 1, 1 - 3, 3 - 7, 7 - 10, 10 - 30, 30 - 70, 70 - 100
Results
Water Footprint base case scenario (LAFW)

WF of 1 m$^3$ of concrete (D.U.) in Lombardy

- Concrete transport
- Cement transport
- Aggregates transport
- Mixing water
- Batching plant
- Cement plant
- Aggregates production

Batching plants

<table>
<thead>
<tr>
<th>Batching plants</th>
<th>World-equivalents m$^3$ of water</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>2</td>
<td>26</td>
</tr>
</tbody>
</table>

FC AWARE:
- 0.1 - 1
- 1 - 3
- 3 - 7
- 7 - 10
- 10 - 30
- 30 - 70
- 70 - 100
Results

Water Footprint base case scenario (LAFW)

Mean WF and share of each unit process in the regions investigated

- Cement factory
- Mixing water
- Transport
- Aggregates production
- Batching plant
**Results**

**Alternatives comparison**

Mean, minimum and maximum WF in the different alternatives in the regions investigated

WF variation from basecase scenario (LAFW) to alternative mixes (LASW and MASW)

<table>
<thead>
<tr>
<th>Region</th>
<th>LAFW</th>
<th>LASW</th>
<th>MASW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abruzzo</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
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<td></td>
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<td></td>
<td></td>
<td></td>
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<table>
<thead>
<tr>
<th>Region</th>
<th>Max ↓ (Min↑)</th>
<th>Max ↓ (Min↑)</th>
<th>Max ↑ (Min↑)</th>
<th>Max ↑ (Min↑)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abruzzo</td>
<td>-10%</td>
<td>-7%</td>
<td>-12%</td>
<td>-8%</td>
</tr>
<tr>
<td>Eastern Sicily</td>
<td>-12%</td>
<td>-8%</td>
<td>-2%</td>
<td>0%</td>
</tr>
<tr>
<td>Lombardy</td>
<td>-78%</td>
<td>-50%</td>
<td>-84%</td>
<td>-75%</td>
</tr>
</tbody>
</table>

Note: % variation from basecase scenario (LAFW) to alternative mixes (LASW and MASW)
Results
Alternatives comparison

Mean, minimum and maximum WF in the different alternatives in the regions investigated

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<tr>
<td>Eastern Sicily</td>
<td>−12%</td>
<td>−8%</td>
<td>−12%</td>
<td>−8%</td>
<td>−44%</td>
<td>20%</td>
</tr>
<tr>
<td>Lombardy</td>
<td>−2%</td>
<td>0%</td>
<td>−2%</td>
<td>0%</td>
<td>−44%</td>
<td>20%</td>
</tr>
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</table>
Results
Alternatives comparison

Water Footprint of the transport of 1 ton of marine aggregates from the coast to the batching plant

- Abruzzo: 0.4 m³ of water
- Eastern Sicily: 0.1 m³ of water
- Lombardy: 1.8 m³ of water

WF variation from basecase scenario (LAFW) to alternative mixes (LASW and MASW)

- Abruzzo: Max ↓ (Min ↑), % change: -10%
- Eastern Sicily: Max ↓ (Min ↑), % change: -12%
- Lombardy: Max ↓ (Min ↑), % change: -2%

LAFW ⇒ LASW:
- Abruzzo: -10%
- Eastern Sicily: -12%
- Lombardy: -2%

LAFW ⇒ MASW:
- Abruzzo: -78%
- Eastern Sicily: -84%
- Lombardy: -44%
Conclusions

- Aggregates production → determining parameter on the final overall freshwater consumption

- Freshwater evaporating from quarry lakes → considerably increase the amount of water consumed in case aggregates from wet quarries were used (i.e. up to 77% of the total consumption)

- Mixing water → only a fraction of all the freshwater consumed along the production chain (i.e. from a minimum of less than 2% to a maximum of 12%)

- Seawater as mixing water → reduction of the WF of concrete up to 12% in Eastern Sicily, negligible effect on the WF in Lombardy

- Marine aggregates instead of land-won aggregates → considerable reduction of the pressure of concrete on freshwater availability in areas affected by water stress, leaving freshwater available for human consumption (i.e. in up to 80% in Eastern Sicily); if aggregates need to be transported for a long distance and the area has a large availability of freshwater, using marine aggregates might be detrimental for the WF
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Aggregates production $\rightarrow$ determining parameter on the final overall freshwater consumption

Freshwater evaporating from quarry lakes $\rightarrow$ considerably increase the amount of water consumed in case aggregates from wet quarries were used (i.e. up to 77% of the total consumption)

Mixing water $\rightarrow$ only a fraction of all the freshwater consumed along the production chain (i.e. from a minimum of less than 2% to a maximum of 12%)

Seawater as mixing water $\rightarrow$ reduction of the WF of concrete up to 12% in Eastern Sicily, negligible effect on the WF in Lombardy

Marine aggregates instead of land-won aggregates

$\rightarrow$ in areas affected by water stress $\rightarrow$ considerable reduction of WF (i.e. in up to 80% in Eastern Sicily);

$\rightarrow$ if aggregates need to be transported for a long distance $\rightarrow$ possible increase of WF
Further investigations

Burden shiftings

- Global warming potential
- Impacts on aquatic ecosystems

Reinforcement elements

- Carbon steel
- GFRP
- Stainless steel

- Durability
- Whole life cycle
- LCC

Global warming potential

Impacts on aquatic ecosystems
### Further investigations

#### Water evaporating from the quarry lake

- **Area**
- **Temperature**
- **Productivity**

#### Different provenience of freshwater for mixing

- Desalinated water
- Municipal water network

#### Sensitivity analysis

- Different strengths and water-to-binder ratios for concrete
THANK YOU FOR THE ATTENTION!