ATTI

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IX Convegno dell'Associazione Rete Italiana LCA

La sostenibilità della LCA tra sfide globali e competitività delle organizzazioni

Cortina d'Ampezzo
9-11 dicembre 2020

A cura di Erika Mancuso, Sara Corrado, Arianna Dominici Loprieno, Laura Cutaia

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Carbon footprint implications of using seawater and marine aggregates in concrete

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Abstract

The use of seawater and marine aggregates in concrete can significantly reduce the pressure on freshwater resources in areas carachterized by low local water availability. However, possible burden shiftings have not been investigated yet. The present study investigates the carbon footprint implications of using seawater and marine aggregates in concrete mixes and analyses the trade-offs between water and carbon footprints. Geo-referenced data are used to explore the influence of the distance from the coast to the concrete batching plant. The use of seawater does not seem to increase the greenhouse gas emissions of concrete production in regions near the sea. However, using marine aggregates could significantly worsen the carbon footprint of concrete if the batching plant was distant from the coast.

1. Introduction

Among construction materials, concrete is the most used and the one that has experienced the faster growth in consumption in the last 50 years (Miller at al., 2016). Global water consumption related to its production has been estimated in 16.6 Gm^3 in 2012, and it is expected to grow by more than 40% by 2050 if no action is taken (Miller et al., 2018). The production of 1 m^3 of fresh concrete in Italy was estimated to require from 1.7 m^3 to 5.5 m^3 of freshwater, when all the life cycle stages of the production process (i.e., from the extraction of raw materials to the delivery to the construction site) are included. Although aggregate production proved to be the main responsible for freshwater consumption, it was estimated that the concrete mixing process itself contributes significantly to the total consumption (Arosio et al., 2019). A solution that has been explored to reduce the pressure on freshwater resources is the substitution of freshwater with seawater in the concrete mixing process. Even though the use of seawater is currently forbidden in many countries to prevent the corrosion of the steel rebars (Redaelli et al., 2019), the use of alternative non-corrosive reinforcing materials (e.g., glass fiber-reinforced polymer, stainless steel) could pave the way to the use of salt-contaminated water and aggregates (Younis et al., 2020). A recent study showed that when seawater is used in combination with reinforcing elements resistant to corrosion, the mechanical proprieties and durability of concrete can be preserved or even improved (Nanni, 2015).

In a previous research, the water scarcity footprint (WF) implications of substituting freshwater with seawater and land-won aggregates with unwashed marine aggregates have been investigated for the Italian context. The AWARE method (Boulay et al., 2018) was used for the assessment, and the use of seawater in the mixing process proved to effectively reduce the WF of concrete in areas affected by water scarcity (e.g., up to 17 m^3 world equivalent of water per m^3 of concrete in eastern Sicily). Moreover, if land-won aggregates were also substituted with their marine counterpart, a WF reduction of more than 80% could be achieved in arid regions. However, although the study clearly showed the benefits in terms of freshwater availability of using marine resources, possible unintended consequences in other areas of interest (i.e, burden shiftings) have not been investigated. The present study aims therefore to uncover one of these potential burden shiftings due to a change in the mix design: the climate implications. The goal is to compare the life cycle greenhouse gas emissions of the innovative concrete mix designs to the ones emitted by traditional mixes. To do so, the greenhouse gas emissions linked to the extraction of marine aggregates and seawater, and their transport from the coast to the batching plants are explored. This study is intended to provide new insights to policymakers and concrete industry in order to avoid the adoption of a technology that presents more drawbacks than advantages.

2. Goal

The goal of this study is to assess the variation in the carbon footprint (CFP) of concrete production in Italy if seawater and marine aggregates were used instead of seawater and land-won aggregates.

3. Scope

The CFP of three concrete mixes are compared: 1) the reference mix, made with land-won aggregates and freshwater (LAFW); 2) a concrete mix made with land-won aggregates, but using seawater instead of freshwater for mixing (LASW); and 3) a concrete mix made with marine dredged aggregates instead of land-won ones, and seawater for mixing (MASW). The reference mix (LAFW) is modelled based on the Italian current practice, while the other scenarios (i.e., LASF and MASW) are hypothetical scenarios aimed to investigate the implications of using seawater and marine aggregates in Italy. It’s worth noting that new infrastructure would be required in Italy if the new mix desings were adopted. The development and costs of this new infrastructure are outside the scope of this study.

The functional unit adopted for the assessment is 1 m^3 (2370 kg) of unreinforced generic fresh concrete supplied to the building site. All mixes are assumed to require the same proportion of aggregates, water, and cement (i.e., 1280 kg of gravel, 720 kg of sand, 170 litres of water, and 200 kg of Portland cement per m^3 of concrete). The recipe for the mix is taken from the ecoinvent database (Wernet et al., 2016), and it represents the composition of a general unreinforced concrete. The mechanical properties and the service life of concrete are assumed to be unaffected by the type of aggregates and water used, and therefore they are considered the same for the three mix designs.

Three Italian regions differing in water availability and distance from the sea are used as case studies: Abruzzo, eastern Sicily and Lombardy.

4. Product system scenarios

The system boundaries of the assessment include all processes from raw material extraction through to the delivery of fresh concrete to the construction site, as illustrated in Figure 1.

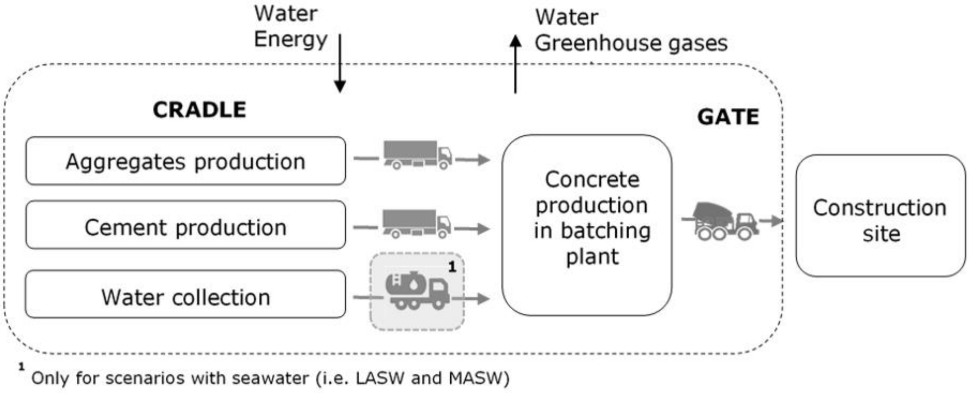

Figure 1: flow chart of the product system analysed. The gate of the analysis is the delivery of concrete to the construction site. Depending on the scenario, water for mixing the concrete is collected from a well located at the batching plant or from the sea, water transport by tanker is needed only in the latter case

In LAFW and LASW, land-won aggregates are considered as supplied from the most common types of quarries available in Italy: dry quarries, wet quarries, and rock quarries. Quarrying operations in dry quarries occur above the water table. Conversely, sand and gravel are dredged from below the water level in wet quarries, causing the formation of a lake. Aggregates from rock quarries are obtained by blasting and crushing stones from hard rock formations. In MASW, marine aggregates are assumed to be dredged from the seabed close to the Italian coastline, and then transported by ship to the shore to be processed. This is a hypothetical scenario since mining of marine aggregates is not currently practiced in Italy. Data for modelling marine aggregates dredging, transport and processing rely on information available in the UK and the Netherlands, where marine dredging is a common practice (Kemp, 2008). In LASW, freshwater for mixing concrete in the reference mix is considered as collected from a well located at the batching plant; hence, there is no transportation of mixing water. In the other scenarios, water for mixing is assumed to be withdrawn from the sea by an open intake facility situated 500 meters from the coast (Shahabi et al., 2015) and then transported by tanker to the batching plants.

5. Life Cycle Inventory

Both primary and secondary data are used for the assessment. Primary data are collected in a wet quarry and in a batching plant. When primary data are not available, secondary data from scientific literature, reports and ecoinvent 3.3 database (Wernet et al., 2016) are used. The Italian electricity mix is applied to model the electricity consumed in quarries, cement factories and batching plants. The energy consumption and the source of data for aggregates production, water collection and batching plant operations are listed in Table 1. Cement production is modelled based on the information reported for portland cement in ecoinvent 3.3.

Regarding plant locations and distances, geodata related to active quarries are collected from the official websites of the analysed regions. Location of cement factories and batching plants are sourced, respectively, from the Italian Association of Cement manufacturers (AITEC, 2019) and the Italian Technical Economic Association for Ready-Mixed Concrete (ATECAP, 2019). It is assumed that each batching plant acquires aggregates in equal amount from the closest four quarries, and cement from the closer cement factory. The closer facilities are identified via ArcGIS. For simplicity, seawater intake facilities and wharves for marine aggregates discharging are assumed to be located along the coastline, at the minimal straight-line distance from the batching plant that is supplied. Road distances between the batching plants and the selected suppliers were calculated by Distance Matrix API of Google. An average distance of 10 km is assumed for the transport of concrete to the construction site (ANCE, 2012).

Table 1: energy consumption for production of aggregates, water collection and activities occurring in the batching plant, referred to the functional unit (i.e. 1 m^3 of fresh concrete produced with 1280 kg of gravel, 720 kg of sand, 170 litres of water, and 200 kg of cement)

Process unit	Consumption	UM[a]	Qty	Source (Reference)
Aggregates production (Rock quarry)	Electricity	kWh	6.66	Primary data
	Diesel	MJ	13.16[b]	Primary data
Aggregates production (Dry quarry)	Electricity	kWh	2.70	(Rigamonti, et al. 2017)
	Diesel	MJ	24.20[b]	(Rigamonti, et al. 2017)
Aggregates production (Wet quarry)	Electricity	kWh	4.00	(Regione Piemonte, 2014)
	Diesel	MJ	43.60[b]	(Regione Piemonte, 2014)
Aggregates production	Electricity	kWh	3.00	(Kemp,2008)

Process unit	Consumption	UM[a]	Qty	Source (Reference)
(Off-shore)	Diesel	MJ	43.60	(Kemp,2008)
Water collection (well)	Electricity	kWh	0.0678	Ecoinvent 3.3
Water collection (sea)	Electricity	kWh	0.0085	(Shababi, et al., 2015)
Concrete production in batching plant	Electricity	kWh	3.85	Primary data
	Diesel	MJ	0.20	Primary data
	Thermal Energy	MJ	5.00	Ecoinvent 3.3

[a] All quantities are referred to 1 m3 of fresh concrete

[b] Calculated considering density of fuel oil equal to 0.82 kg/l and calorific value equal to 42.7 MJ/kg.

6. Life Cycle Impact Assessment

The CFP assessment is standardized by ISO 14067 (ISO, 2018): “Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification”. CFP aims to quantify the greenhouse gas emissions of a product or activity throught their life cycles. The IPCC 2013 method available in Simapro 8.5 (i.e., GWP100) is used for assessing the CFP. The method uses IPCC carachterization factors to quantify the relative global warming impacts of various gases in terms of kg CO_2-equivalents per kg of greenhouse gas, and it does not account for indirect effects (Intergovernmental Panel on Climate Change, 2013).

7. Results and discussion

The resulting CFP for each of the three concrete mixes in each of the regions analysed are presented in Figure 2. An average of 145 kg of CO_2 eq. are estimated to be emitted to produce 1 m^3 of the reference mix in Abruzzo and Lombardy, while the CFP of concrete in eastern Sicily results to be slightly higher (i.e., 158 kg of CO_2 eq. per m^3) due to the longer distances covered to transport the land-won aggregates. Nevertheless, most of the emissions (i.e., around 80%) are caused by cement production.

To allow a more complete comparison between different scenarios, the WF of each scenario for each region are reported in Figure 3. The WF results were calculated in previous study (Arosio et al., 2019) and are here updated, consistently with the hypothesis on raw materials suppliers described in the inventory phase.

Although replacing freshwater with seawater would cause an average reduction of the WF of 7% in Abruzzo and eastern Sicily, it would slightly increase in the

CFP (by 2% and less than 0.6% in the two regions, respectively). In Lombardy, the increase of CFP is higher (from 2% to 5%) due to the grater distances covered by the tankers to transport seawater, while the WF savings were lower than the other ragions (less than 2%). Therefore, the freshwater replacement is certaintly convienent in terms of WF, while the result of CFP is not conclusive in view of low percentage improvements/worsenings.

Introducing marine aggregates results in significant increase of the CFP in almost all the cases considered. The CFP for marine aggregates production, in fact, results to be higher than the CFP related to land-won ones for all the type of quarries. The CFP of marine aggregates is estimated to be 10.8 kg CO_2 eq. per ton of aggregates produced; while the CFP of land-won aggregates is estimated to be 1.8 kg CO_2 eq. per ton produced in dry quarries, 3.0 kg CO_2 eq. per ton in rock quarries, and 2.2 kg CO_2 eq. per ton in wet quarries. The impact of transporting the aggregates to the batching plant results particularly significant in Lombardy and Abruzzo, due to the long distance from the coast. Four batching plants in Sicily showed an opposite trend: being situated near the coast, the emissions to extract, process, and transport marine aggregates result to be lower than transporting aggregates from farther land quarries. At the same time, the impacts on freshwater resources in Abruzzo and Eastern Sicily would significantly reduce (from 45% to 80%). In Lombardy, the WF decreases (up to 36%) only if marine aggregates are used in place of land-won aggregates from wet quarries; otherwise, WF would increase compared to the reference mix due to the long distance from the coast.

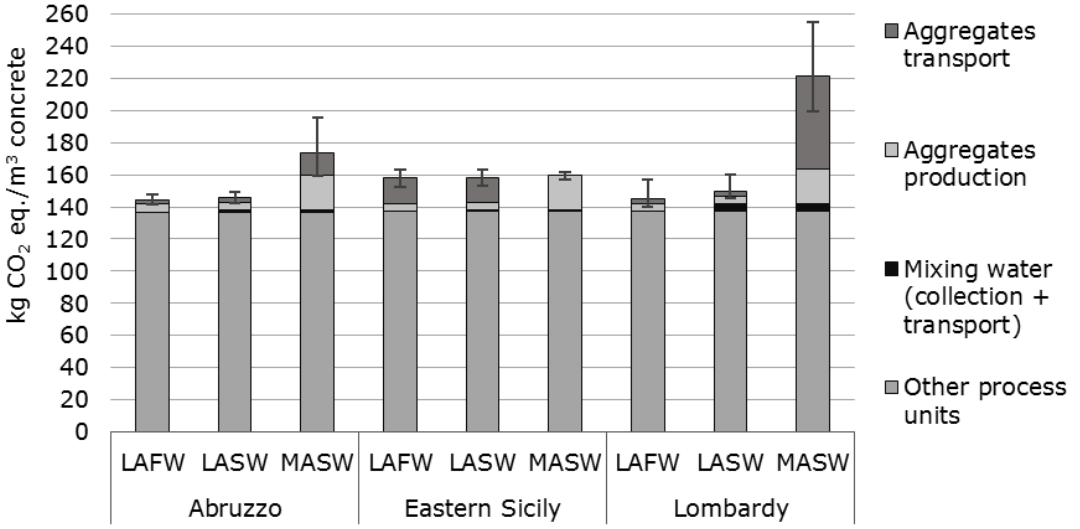

Figure 2: CFP of 1 m^3 of fresh concrete delivered to the construction site in the three scenarios for each of the three regions. The histogram bars indicate the calculated regional average, while the error bars show the minimum and the maximum CFP in the region. Aggregate production phase includes extraction (of land-won aggregates) or dredging and shipping (of marine aggregates), and processing of aggregates

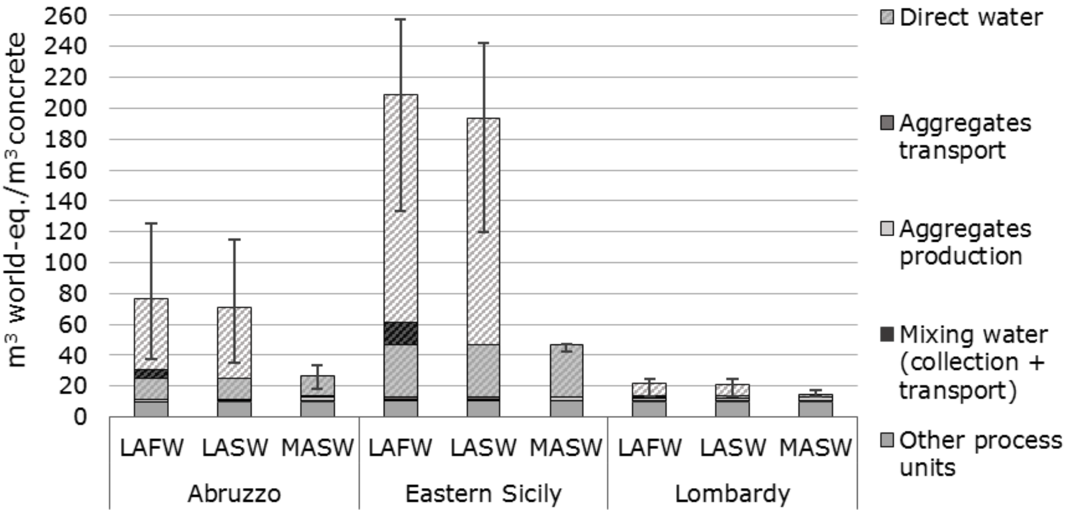

Figure 3: WF of 1 m^3 of fresh concrete delivered to the construction site in the three scenarios for each of the three regions. The histogram bars indicate the calculated regional average, while the error bars show the minimum and the maximum WF in the region. The diagonal lines highlight direct WF, the solid fill rapresents indirect WF

8. Conclusions

The greenhouse gas consequences of using seawater to mix concrete instead of freshwater and of substituting land-won aggregates with marine ones have been assessed for three Italian regions. The results have been compared to the water footprint implications assessed in a previous study.

The carbon footprint implications of using seawater are strongly correlated to the geographical position. In the case of batching plants located near the coast, the use of seawater would have an almost negligible effect on the carbon footprint of concrete (e.g., always lower than a 0.6% increase for plants located in eastern Sicily). At the same time, using seawater in the concrete mix would significantly reduce its water footprint in water stressed regions such as eastern Sicily. Conversely, when the batching plants are situated inland, the carbon foorptint implications of using seawater increase significantly (i.e., up to a 5% increase in the CFP of concrete produced in Lombardy). At the same time, Lombardy (i.e., the inland region investigated in the paper) has a larger freshwater availability and, therefore, the water footprint benefits of using seawater in the concrete mix are strongly reduced.

The use of unwashed marine aggregates (and seawater for mixing) could significantly reduce the water footprint of concrete in Abruzzo and some batching plants of Lombardy (i.e., up to 35%), and in eastern Sicily (i.e., up to 80%). Where batching plants are close to the coast (i.e., eastern Sicily), introducing marine aggregates results in a small positive or negative variation of carbon footprint. Conversely, in Abruzzo and Lombardy the carbon footprint would strongly increase due to the distance from the coast; hence in these regions the choice of the type of aggregates imply a trade-off. Finally, where aggregates need to be transported over long distances and the watershed has a large availability of freshwater, using marine aggregates might be disadvantageous for both the water footprint and the carbon footprint.

9. Further investigations

This analysis in intended to pave the way to further investigations about the environmental implications of using seawater and marine aggregates together with non-corrosive reinforcements in concrete structures. In order to extend the analysis to the complete life cycle of the structure, the durability of the new mix designs and the burdens associated to the manufacturing of the reinforcing elements should be explored. Additional sensitivity analysis considering different concrete types, transportation modes for water and fresh concrete need to be investigated further too. Finally, a life cycle cost analysis would provide useful information regarding the economic feasibility of using seawater and marine aggregates in concrete.

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