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ENVIRONMENTAL IMPACTS OF USING DESALINATED WATER IN CONCRETE PRODUCTION IN AREAS AFFECTED BY FRESHWATER SCARCITY

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Abstract.

Up to 500 litres of water may be consumed at the batching plant per cubic meter of ready mix concrete, if water for washing mixing trucks and equipment is included. Demand for concrete is growing almost everywhere, regardless of local availability of freshwater. The use of freshwater for concrete production exacerbates stress on natural water resources. In water-stressed coastal countries such as Israel, desalinated seawater (DSW) is often used in the production of concrete. However, the environmental impacts of this practice have not yet been assessed. In this study the effect of using DSW on the water and carbon footprints of concrete was investigated using life cycle assessment. Water footprint results highlight the benefits of using DSW rather than freshwater to produce concrete in Israel. In contrast, because desalination is an energy intensive process, using DSW increases the greenhouse gas intensity of concrete. Nevertheless, this increase (0.27 kg CO_2e/m^3 concrete) is small, if compared to the life cycle greenhouse gas emissions of concrete. Our results show that using untreated seawater in the mix (transported by truck from the coast) in place of DSW, would be beneficial in terms of water and carbon footprints if the batching plant were located less than 13 km from the withdrawal point. However, use of untreated seawater increases steel reinforcement corrosion, resulting in loss of structural integrity of the reinforced concrete composite. Sustainability of replacing steel with non-corrosive materials should be explored as a way to reduce both water and carbon footprints of concrete.

Keywords: Carbon footprint, desalinated water, seawater, water footprint.

1. Introduction

Water scarcity affects two-thirds of the global population [1] and climate change, economic development and population growth might worsen this issue in the near future [2]. Industrial development plays an important role in the growing demand for water [2], with concrete being a significant contributor. The life cycle of concrete requires large amounts of water, from the production of the raw materials (i.e., cement and aggregates), through mixing, curing, and hydration, to equipment cleaning processes [3]. In 2012, the estimated global water consumption for concrete production was 16.6 km^3 and it is expected to grow with the increase in production, by more than 40% by 2050 if no action is taken [4]. Aggregate production is the main water-consuming activity in the life cycle of concrete [5], but water consumption at the batching plant is very significant. Considering ready-mix concrete, up to 500 litres of water per cubic meter of concrete may be consumed, including water for washing the mixing trucks, on-site equipment and floor [6]. Water used at the batching plant is typically sourced from a potable supply network, on-site wells, or harvested stormwater [6]. Potable water is used to avoid any adverse effects on the properties of the concrete, such as hydration, strength development and durability performance [7]. However, using available freshwater for concrete production will exacerbate the stress on natural water resources. In water-stressed coastal countries, such as Israel, desalinated seawater (DSW) is increasingly used to meet the potable water demand [8].

Although reducing the stress on freshwater resources, desalination comes with an environmental cost. In Qatar, for instance, 4.66 million tons of CO_2 were estimated to be emitted by desalination plants in 2014 [9]. One appealing option to reduce the stress on available freshwater resources, and at

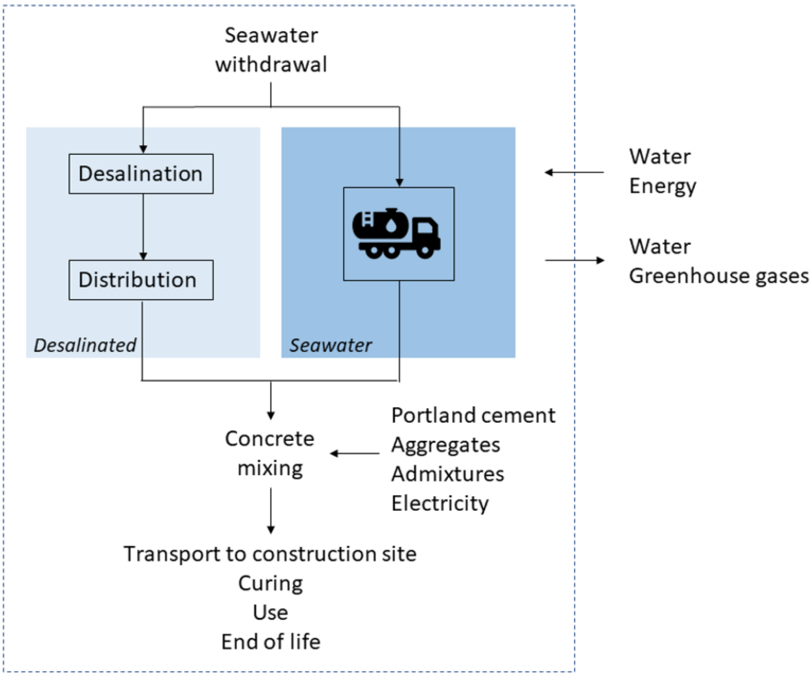

Figure 1. Flow chart for the product system analyzed. The different paths for the two scenarios are highlighted: Desalinated and seawater. The unit processes valid for both processes (e.g., seawater withdrawal, concrete mixing, etc.) are considered unaffected by the type of water used in the mix and therefore excluded from the comparative LCA.

the same time avoid the impacts associated with desalination, is to replace potable water with untreated seawater in the manufacture of concrete [10]. However, the use of seawater is currently forbidden in reinforced concrete standards because it contributes to the early corrosion of carbon steel reinforcement, which is the present common practice in construction [11]. Nevertheless, in recent studies, the use of seawater combined with non-corrosive reinforcing materials, such as glass fibre reinforced polymers, has shown promising results in terms of mechanical properties and durability [12].

The focus of this study is to estimate the consequences of using seawater for concrete production in Israel, using a consequential life cycle assessment (LCA) methodology. The results are intended to pave the way for further investigation of the feasibility and sustainability of using seawater and marine aggregates for concrete production.

2. Goal

The objective of this analysis is to assess the potential water and carbon footprint savings for Israel if seawater was used in place of municipal grid water in concrete production. The study is aimed to set the stage for further analyses of the feasibility and sustainability of using alternative concrete designs with the ultimate goal of reducing the environmental impacts of the most prevalent construction material in the Israeli construction sector.

3. Scope and methods

The functional unit of the study is the production of 1 m^3 of generic non-reinforced concrete (100% ordinary Portland cement, 0.85 water-to-cement ratio) in Israel. Two alternatives differing in the type of water used in the mix are compared in the analysis: municipal grid water (current practice) and untreated seawater. The market demand for concrete is assumed to be constant (18 Mm^3 per year [13]) and its mix design (i.e., the amounts and types of binders, aggregates and admixtures) and mechanical properties are assumed to be identical in both cases. The production process at the batching plant in this study is the only life cycle phase that differs between the compared scenarios.

We use a consequential approach in this LCA. Unlike attributional LCA, which aims to capture all environmental flows associated with the life cycle of the activity, a consequential assessment accounts only for the flows affected by a certain change in the system [14]. According to the principles of consequential LCA, we consider the marginal water supply, which is the one that is most likely to react to a change in market demand. In the case of the Israeli water market this is the supply of DSW, coming from five major desalination plants along the Mediterranean coast. In the case of electricity, the marginal supplier in Israel is under most circumstances one of several natural gas power plants [15]. We consider only the variations in impacts resulting from avoiding the desalination

Scenario	Unit process	Water footprint (L-eq./m^3 concrete)	Carbon footprint (kg CO_2-eq./m^3 concrete)
Desalinated	Desalination	18	0.27
	Distribution	4.8	0.071
	Mixing[a]	0.0	Excluded
	Total	23	0.34
Seawater	Transportation	$1.8 \cdot x$	$0.016 \cdot x$
	Mixing[a]	0.0	Excluded
	Total	$1.8 \cdot x$	$0.016 \cdot x$

[a] The energy intensity of the mixing process, and therefore the greenhouse gas emissions and water footprint associated with the process, is assumed to be independent from the water used (DSW or SW) and therefore excluded from the analysis. Since the water used for mixing was originally seawater in both scenarios, its water footprint is zero.

TABLE 1. Water and carbon footprint results for the activities considered in the two scenarios (i.e., activities affected by the change in the system). Variable x represents the distance (km) travelled by the truck from the desalination plant to the batching plant.

process by replacing DSW with untreated seawater throughout the life cycle of concrete. The ecoinvent consequential database was used for modelling background processes in the system. The LCA is limited to two environmental impact categories: climate change and water consumption. Inputs and outputs to the system are considered from cradle to grave.

4. Product system

Two scenarios of concrete production in batching plants in Israel are modelled. In the base case scenario, representing current practice, water for mixing concrete is sourced from the Israeli water grid. DSW is the marginal source of water in Israel [16], meaning that a change in potable water demand will affect the extent of its production [17]. Therefore, in the base case scenario (named desalinated scenario from now on) seawater is drawn from the sea, desalinated and distributed to the concrete batching plants via the national supply grid. In the alternative (seawater) scenario, once drawn, seawater is transported via trucks to the batching plants. If using untreated seawater proves to be a viable and sustainable solution, pipelines could be installed to deliver seawater to the batching plants. Existing desalination plants inlets are assumed to be used as a means for pumping water from the sea into the trucks.

The product system analysed is illustrated in Figure 1. The mixing process, the delivery of concrete to the construction site, and the properties of the concrete are assumed to be unaffected by the type of water used. In future work the effects on concrete properties and on the service life of the mixing trucks (which might be reduced due to potential corrosivity of the seawater mix) will be included.

5. Life cycle inventory

Both primary and secondary data are used for the analysis: primary data for the inputs and outputs of the Israeli desalination plants and the distribution process [18]; secondary data from the ecoinvent 3.6 database [19] for the average amount of water used in the concrete mix (i.e., 170 L/m^3), and for the emissions and indirect water consumption of electricity production and road transportation (e.g., water consumed in fuel production).

Water for washing the trucks is assumed to be reused in the concrete mix itself, as is the current common practice [13]; therefore, no additional benefits are considered for substituting municipal grid water with seawater for this purpose. Moreover, additional water required at the batching plant for washing the site and for personnel needs is assumed to be municipal grid water, in both scenarios, and is therefore excluded. A threshold is calculated for the maximum distance from the seawater extraction site for which using seawater shipped by truck to the batching plant would still be beneficial in terms of carbon and water footprint. Energy consumed by the desalination plants is supplied through the electricity grid, which uses natural gas combined cycle power plants (60% efficiency) [15].

6. Results and discussion

Table 1 presents the water and carbon footprints of the activities affected by the change in the system. Results are expressed per cubic meter of fresh concrete produced at the batching plant. In the seawater scenario, impacts depend on the distance travelled by the trucks (represented by x in Table 1) to transport seawater to the batching plant. For instance, the transport of 170 L of seawater by truck for the production of 1 m^3 of concrete is responsible for the consumption of 1.8 L-eq. of water per km.

The key observations from the results are:

- From a consequential perspective, the water footprint of concrete mixing in Israel, taking into account direct water use at the batching plant only, is considerably lower than those reported for other regions (e.g., up to 16,000 L-eq./m^3 concrete in Sicily, Italy [6], or 185 L-eq./m^3 concrete in Sweden [20]). The reason is that the marginal water supply in Israel is DSW, which has a water footprint characterization factor of zero since it does not negatively affect the availability of freshwater in the watersheds [21]. Therefore, the only freshwater consumed in the process is the water consumed indirectly for electricity generation and fuel production. This applies to both scenarios.
- The carbon footprint of desalinating seawater and distributing it to the batching plant is trivial compared with the life cycle greenhouse gas emissions of concrete production. A global average cubic meter of non-reinforced concrete is responsible for approximately 200 kg of CO_2-eq. [19]. This may be over 400 kg of CO_2-eq. for high-performance concrete (e.g., 50 MPa [19]). Either way, the impact of desalination and water distribution for the concrete mix would be far less than 1% of the total impact.
- Greenhouse gas emissions for desalination are 1.5 kg CO_2-eq/m^3 desalinated water. This is lower than the values reported for other geographical contexts. In Qatar, for instance, 9.5 kg of CO_2-eq is estimated to be emitted per m^3 of desalinated water [9]. There are two potential reasons: (i) only impacts associated with the electricity consumption of the desalination plant (3.5 kWh/m^3 DSW) are considered in this study and, (ii) the lower greenhouse gas intensity of electricity used in Israeli desalination plants.
- The thresholds for reducing water and carbon footprints by using untreated seawater in the mix in place of municipal grid water are 13 and 22 km, respectively. If a batching plant is located less than 13 km away from the desalination plant ($x < 13$), transporting seawater by truck instead of desalinating it and pumping it through the national pipeline network would reduce both the water and carbon footprints of concrete. If the distance is between 13 and 22 km, desalinating and distributing water would have a lower water footprint but would generate higher greenhouse gas emissions. Finally, if the batching plant is located more than 22 km away from the desalination plant, transporting seawater by truck would lead to higher impacts for both water and carbon.

7. Conclusions

The water and carbon footprint consequences of using seawater instead of municipal grid water for concrete mixing in Israeli batching plants are estimated. A net benefit for both impacts would emerge only if the batching plant is located less than 13 km from a desalination plant. However, even in this case, the benefits appear to be negligible compared with the average life cycle impacts of concrete. Negligible savings are observed since the marginal water supply in Israel is desalinated seawater, which has a water footprint of zero and a low carbon footprint compared to other constituents of concrete, such as cement. Nevertheless, if batching plants are located near the coast, given the large amount of concrete produced in Israel each year, significant greenhouse gas savings could still be achieved: for every km less than the 22-km threshold, 20 g of CO_2-eq. could be spared for every m^3 of concrete produced. If, theoretically, all Israeli concrete was produced in plants that are less than 10 km away from desalination plants, over 3,000 tons of CO_2-eq. could be saved every year. Moreover, by using untreated seawater in the mix, other environmental impacts (e.g., marine ecotoxicity, biodiversity) associated with the desalination process, which are not included in the present assessment, could be avoided. Approximately 1.5 m^3 of brine are produced for every m^3 of desalinated water and concerns are growing over the rising toxic levels from its discharge back into the sea [8].

To confirm the results, a sensitivity analysis on the assumptions and data should be performed. For instance, results might differ if pipes were used instead of trucks to deliver the seawater or if seawater was to replace potable water used for washing the quarried aggregates as well. Moreover, even though negligible savings (or larger impacts, when distances from the coast are above the threshold) are observed in Israel, contrary conclusions may result in countries where the marginal supply of municipal grid water comes from natural freshwater resources.

The impact of seawater on the service life of the machinery used for concrete production and of the concrete structure itself should be further investigated to avoid burden shifting. Finally, a comparison of the life cycle costs of the two scenarios would provide valuable information to the concrete industry and the government to evaluate the practicality and economic viability of shifting the concrete industry towards the use of seawater. In a future analysis the challenges of a design practice not yet widespread and the market cost of GFRP should be included.

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