Water scarcity footprint for cement production

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1. General aspects

This study evaluates the production of cement in Lafarge-Holcim factory located in Nobsa, Colombia, corresponding to the 2013 water footprint evaluation. The study was elaborated within the frame of SuizAgua Colombia project, an Initiative of the Global Programme Water Initiatives of the Swiss Agency for Development and Cooperation that aims to improve corporate water stewardship with the use of innovative approaches including the water footprint concept.

1.1 Water Scarcity Footprint methodologies

The water scarcity footprint following ISO 14046 refers to the extent to which demand for water compares to the replenishment of water in an area, without taking into account the water quality. For evaluating it, the usual procedure is:

$$Water\ Scarcity\ Footprint = Water\ Consumption * Characterisation\ Factor$$

In Life Cycle Assessment, there are several characterization methods, developed for obtaining characterization factors, which meet this definition (Boulay et al., 2015). Because this reason, the Life Cycle Initiative group project for Water (WULCA) following the request of the UNEP-SETAC Life Cycle Initiative has been working towards a consensus method following analysis of existing ones (Boulay et al., 2015). At the end of two year activity, three methods emerged as more appropriated to be chosen. These are (Boulay et al., 2015):

DTA: It is defined as the relation between demand and availability, but includes a filter for arid regions. Arid regions would be those where potential evapotranspiration (PET) is greater than five times the precipitation (P).

$$DTA = \frac{Demand}{Availability} \qquad for\ PET < 5P$$

$$DTA = Max = 1 \qquad for\ PET > 5P$$

DTA$_X$: It is based on two parameters, the relative availability (DTA) and the absolute availability per unit of surface. Absolute availability is applied an exponent of 0.34 to make its contribution equal to relative availability. This exponent was found by adjusting the exponent in order to obtain equal correlation of both parameters with the final result over all (sub) watersheds.

$$DTA_X = \left(\frac{Demand}{Availability}\right) \times \left(\frac{Area}{Availability}\right)^{0.34}$$

AWARE100: Represents the Available Water Remaining per unit of surface in a given watershed relative to the world average, after human and aquatic ecosystem demands have been met. It is based on 1/AMD, the inverse of the difference between availability and demand. When the value of the demand is equal to or larger than the availability (negative AMD), the factor is set to be maximal. For a given watershed area:

$$\frac{1}{AMD} = \frac{Area}{Availability - Demand} \quad for\ Demand < Availability$$

$$\frac{1}{AMD} = Max \qquad for\ Demand \geq Availability$$

AWARE100 is defined as:

$$\mathrm{AWARE100} = \frac{AMD_{world\ average}}{AMD}$$

$\text{AMD}_{\text{world average}}$ is 0.0136 m^3/m^2/month

(Annual proxy used was 0.0136x12 = 0.1632 m^3/m^2/month)

AWARE100 or **AWARE** is limited to a range from 0.1 to 100.
AWARE10 is limited to a range from 0.1 to 10.
AWARE1000 is limited to a range from 0.1 to 1000.

For the all these methods:

Availability = Total river discharge, sum of surface runoff and groundwater recharge
Demand = water consumed by domestic, industrial, agricultural and livestock uses, termo energy production plus Freshwater Ecosystems Demand.

AWARE100_EWR+50%, uses a higher value for the Environmental Water Requirement (Ecosystem demand), by taking 150% of the original value.

1.2 Water Availability Footprint

A water availability footprint assesses contribution of the product to potential environmental impacts related to pressure on water availability, or the extent to which humans and ecosystems have sufficient water resources for their needs (ISO 14046). For comparison purposes, in this analysis the Water Impact Index (WIIX) will be included as an indicator of pressure due to affectation on water quantity and quality.

Water Impact Index: It is a value expressed in equivalent cubic meters (m^3_{eqWIIX}) that can be as big as the positive value of water withdrawal and as low as the negative value of the release. Its formula is [4]:

$$WIIX = \sum_i [W_i \cdot Q_{W_i} \cdot WSI_i] - \sum_j \left[R_j \cdot Q_{R_j} \cdot WSI_j\right]$$

Where:

W_i and R_j are respectively, water withdrawal from source i, and water release returned to source j.

Q_{W_i} and Q_{R_j} are water quality indexes from sources i and j.

WSI_i and WSI_j are respectively, Water Stress Index for water sources i and j; as defined by Pfister et. al. 2009

Water quality indexes are evaluated with:

$$Q_{W_i} = min_P\left(1; \frac{Cref_p}{C_{W_{i,p}}}\right) \text{ y } Q_{R_i} = min_P\left(1; \frac{Cref_p}{C_{R_{i,p}}}\right)$$

Where

$Cref_p$ is reference concentration for pollutant p, that should not be exceeded in order to protect the environment. (Hoekstra et al. 2011, cited by Bayart et. Al 2014).

$C_{W_{i,p}}$ and $C_{R_{i,p}}$ are, respectively, effective concentration of pollutant p in withdrawal water source i or release water source j.

2. Goal of the study

This study is carried out in order to identify hotspots of cement production and compare the results of different indexes for water scarcity footprint. The targeted audience is the WULCA, or anyone interested in the water scarcity footprint of cement. The study is a stand–alone assessment, doesn't consider other impact categories like climate change, land use or air pollution. This study doesn't intend comparative assertion with other products.

3. Scope

3.1 Functional unit

The declared unit is 1000 kg (1 ton) of cement. The plant produces different types of cement, but mainly Portland cement.

3.2 System boundaries

Geographical and temporal dimensions

The year evaluated is 2013, but estimation of captured rain water required multi-annual precipitation data, as specified in Table 2. Location of cement plant is Magdalena-Cauca basin in Colombia (watershed ID: 49500).

Omissions of life cycle stages

Results include upstream activities, packaging and administration; from cradle to gate. Transport of supplies is included with exception of transport of imported raw material within the external country (Spain, from the mine to the port) but it is considered negligible given this material is less than 5% of total input of mineral supplies. Other activities downstream are omitted in this analysis.

Quantification of energy and material input and outputs

Figure 1 presents the type of processes involved in cement production. Supply chain including limestone, gypsum and iron ore is transported to the cement plant, where they are milled and then are treated with high temperatures in a kiln to obtain a pre-product (clinker) that is milled again with gypsum to obtain cement. Water for industrial use is mainly from a river, and used for cooling. Plant recycles and reuses industrial water, also collects rain water for industrial purposes. Tap water is used for domestic purposes; this water is treated before its release to a surface water source. Direct water use's calculations employs specific data, available from water meters and water quality analysis. Indirect water use utilizes data of Ecoinvent and Quantis datasets as described in Table 3.

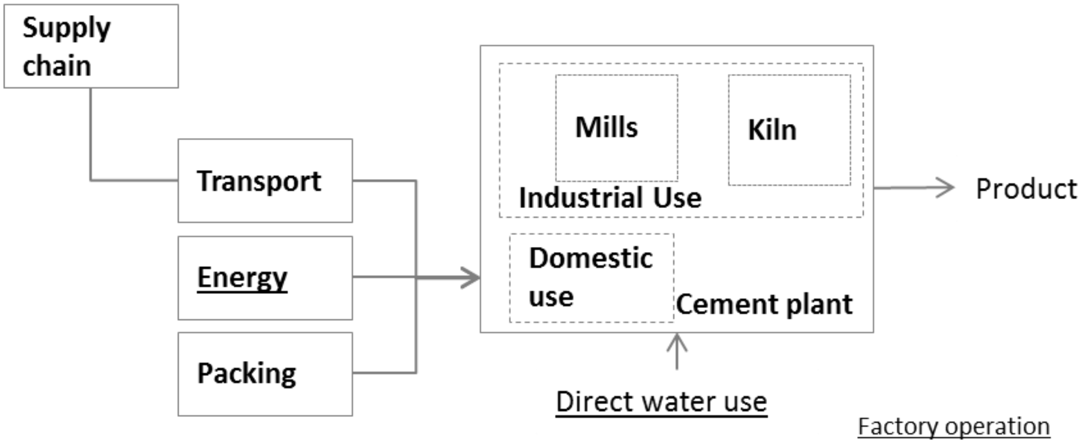


Figure 1. System Boundaries

Table 1 presents energy and material inputs and outputs for 1 ton of cement in this plant, with scope as described previously. Supply chain production includes limestone, gypsum, iron scrap and ore, and pozzolan.

Table 1. Cement production inventory data

		Amount	Unit
Direct water use	Rain water captured	19.2	L
	superficial water input	86.2	L
	tap water input	10.1	L
	treated domestic waste water release	9.1	L
Energy consumption	Electricity, Med Volt	84.8	kWh
	Carbón	82.9	kg
	Diesel 8% biodiesel	0.5	gal
	AFR (alternative fuel residues)	0.0	Ton
Supply chain production		1'446.3	kg
supply chain transport	transport, transoceanic freight ship	1.7	tkm
	transport, lorry >32t, EURO4	0.3	tkm
	transport, lorry 16-32t, EURO4	36.6	tkm
Packing	Bags (2 paper kraft layers)	2.2	kg
	Bags (2 paper kraft + 1 PE layers)	0.0	kg

Energy quantification and assumptions

Electricity: A processes for Colombia's electricity production matrix was elaborated as described in Table 3. At the cement plant, the main electricity consumption occurs in mills operation. Administrative areas consume only a small part of total electricity consumption.

Fuels: calorific values used were: diesel 8% biodiesel: 145.71 MJ/gal; Coal: 33.97 MJ/kg.

Cut-off criteria

No cut-off criteria was applied, all supply chain for industrial process was included.

4. Inventory

4.1 Data collection procedures

Information was collected through an Excel datasheet, given that the company previously listed its consumptions of energy and supplies. Direct and indirect inputs were analyzed in technical sessions. Datasheet information was divided into: i) production, ii) indirect water uses (inputs and outputs), iv) energy consumption, v) supplies consumption (including packing and transport) v) water quality data for water releases. An internal analysis was necessary in order to calculate bags input in kg, using data about cement production per type of packing.

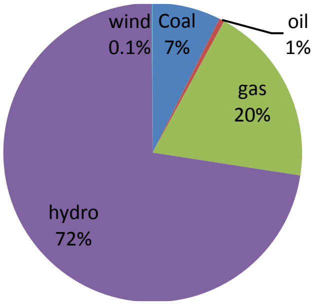
4.2 Sources of data and data quality assessment

Direct water uses in cement plant are described in Table 2, and indirect water uses, including origin and the generic dataset chosen for its modelling are included in Table 3.

Table 2. Direct water use and qualitative precision analysis

Tipo	Flow	Description and calculation methodology	Precision
Inputs	Tap water	Water meter	High
	Superficial water input	Water meters	High
	Captured rain water	Multi-annual precipitation data multiplied by capture area	Medium-low
Water consumption	Spraying of roads	Water for dust control. Based on the amount of water trucks sent for spraying.	Medium
	Water evaporated in Kilns area	Equipment cooling and water evaporated within the production process. A small part is related to trucks cleaning (0.1%)	Medium
	Water evaporated in mills area	For raw materials and equipment cooling. Data based on water meters history.	High
	Natural evaporation from water pools	Multi-annual evaporation data multiplied by pools area	Medium-low
	Water evaporated in new equipment	Equipment without water meters history; therefore amounts were estimated by water balance. 24% of total input.	Medium-low
	Waste water treatment	Technical assumption: 10.16% of water input is evaporated in domestic waste water treatment.	Medium-low
Release	Treated domestic waste water	Tap water (only for domestic use) minus water evaporated in the waste water treatment	Medium-low

Table 3. Stages, Origin, datasets processes assigned to indirect water uses

	Stage			Origin	Quantis/Ecoinvent database process assigned
Factory operation	**Direct water use**			Basin ID 49500 Nobsa	-
	indirect water use	**Energy consumption**	**Electricity, Med Volt**	Colombia Av	electricity, medium voltage, production CO, at grid/CO; made from averages for Colombia's type of electricity in 2009: Coal 7% : electricity, hard coal, at power plant/UCTE U Oil 1% : electricity, oil, at power plant/UCTE U Gas 20% : electricity, natural gas, at power plant/UCTE U Hydro 72% : electricity, hydropower, at reservoir power plant, non alpine regions/RER U 
			Coal	Colombia Av	hard coal mix, at regional storage/UCTE U
			Diesel 8% biodiesel	Colombia Av	diesel 8% biodiesel /CO; made from 92% diesel, burned in diesel-electric generating set/GLO U 8% palm methyl ester, at esterification plant/MY U
			AFR (alternative fuel residues)	Colombia Av	This fuel is a mixture of residues with high calorific value, that otherwise would be disposed as dangerous residues, i.e.: waste oils. A water impact of zero is assumed.
Supply chain (upstream activities)		**Supply chain production**	**Limestone**	Basin ID 49500 Cities: Nobsa and Tibasosa	limestone, at mine/CH U
			Gypsum	Spain Av	gypsum, mineral, at mine/CH U
			Gypsum	Basin ID 49500 Villanueva	gypsum, mineral, at mine/CH U
			Iron scrap	Basin ID 49500 Paz del río	iron scrap, at plant/RER U
			Iron ore	Basin ID 49500 Paz del río	iron ore, 65% Fe, at beneficiation/GLO U
			Iron ore fines	Basin ID 49500 Sibaté	
			Pozzolan	Basin ID 49500 Iza	basalt, at mine/RER U
		supply chain transport	**transport, transoceanic freight ship**	Global Av	transport, transoceanic freight ship/OCE U
			transport, lorry >32t, EURO4	Colombia Av	transport, lorry >32t, EURO4/RER U
			transport, lorry 16-32t, EURO4	Colombia Av	transport, lorry 16-32t, EURO4/RER U
		Packing	**Bags (2 paper kraft layers)**	Basin ID 49500 Palmira	Bags (2 paper kraft layers)/RER; made from: use, printer, laser jet, colour, per kg printed paper/RER U kraft paper, unbleached, at plant/RER U
			Bags (2 paper kraft + 1 PE layers)	Basin ID 49500 Palmira	Bags (2 paper kraft + 1 PE layers); made from: use, printer, laser jet, colour, per kg printed paper/RER U kraft paper, unbleached, at plant/RER U packaging film, LDPE, at plant/RER U

*only 0,03% of the supply chain is imported

4.3 Validation of data

Table 4 presents data quality evaluation of collected information. It includes **geographical coverage** of indirect water uses (given by databases for indirect water uses), **integrity**, or amount measured of material or energy inputs/outputs divided by total amount measured or estimated; and a qualitative measurement of **precision** and **representativeness**; the first refers to variability of data compared to real amounts and the second to the degree to which the data set reflects the true population of interest.

Table 4. Data quality

	Tipo	Geographical coverage	Integrity	DU: Precision E and SC: Representativeness
Cement	UD: Inputs, Outputs, water quality	Nobsa (Boyaca)	51%	High
	E: Coal Diesel (80% biodiesel), Electricity	Europe Colombia	100%	Medium
	CS: Limestone, Gypsum Iron ore, Iron scrap, Puzol, Pozzolan, Bags of Kraft paper and PE	Switzerland Europe Global Average	100%	Medium

DU: Direct Use. E: Energy. CS: Supply chain BD: Database

All supplies input data is evaluated as of high precision. **Allocation** was not necessary given that cement is the only product.

5. Water scarcity footprint results

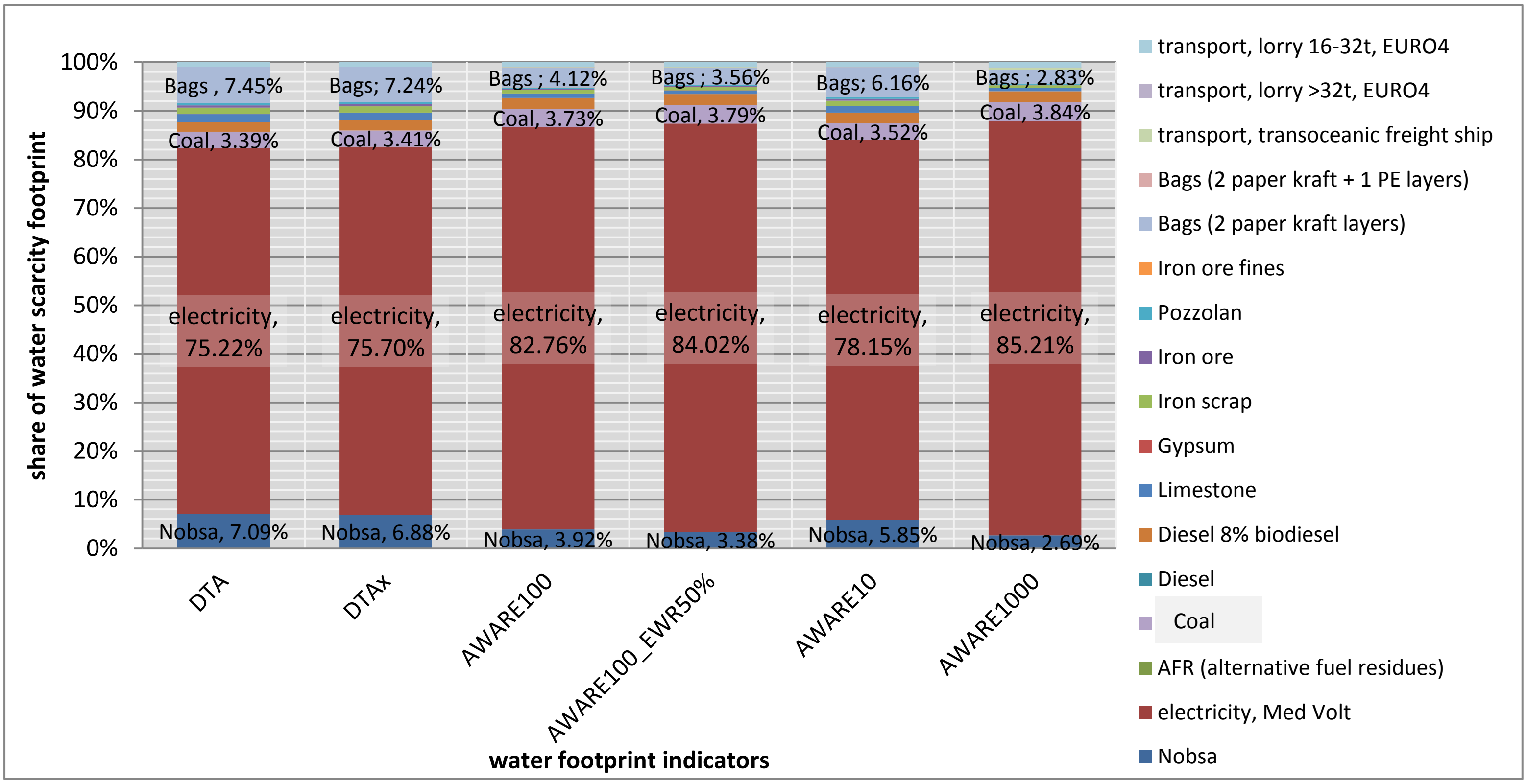


Figure 2. Water scarcity footprint comparing different indicators in percentages

Figure 2 presents results for 6 different indicators for water scarcity footprint: DTA, DTAx, AWARE100, AWARE100_EWR+50%, AWARE10 and AWARE1000. For all of them, hotspot is indirect water footprint related to electricity consumption; the largest is given by AWARE1000 (85.21%), followed by AWARE100_EWR+50% (84.02%) and AWARE100 (82.76%). After electricity, main share of water footprint is on Nobsa cement plant (whose share varies between 2.69% and 7.09% for the different indicators), Bags (varies between 2.83% and 7.45%) and coal (between 3.39% and 3.79%); however none of them goes beyond 10%.

In summary, all evaluated indicators shown similar results about water scarcity footprint hotspots. This is because high indirect water consumption due to high electricity consumption per ton of cement produced, and because there is a large water consumption associated to dams of hydroelectric plants.

Figure 3 shows comparison of absolute values for the six water scarcity indicators.

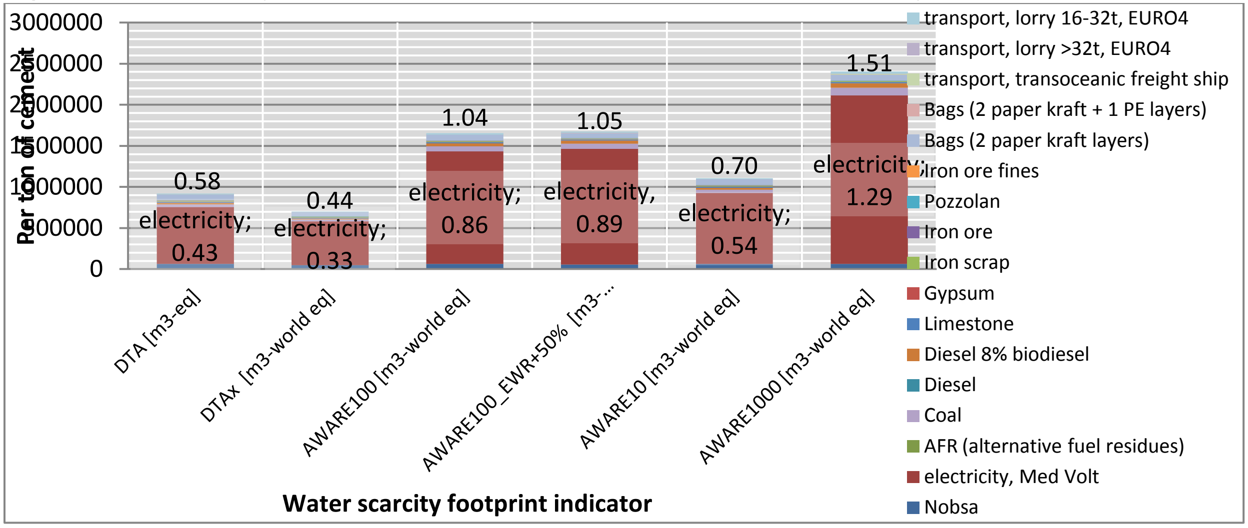


Figure 3. Water scarcity footprint comparing different indicators in absolute values

As expected, the largest absolute value is associated with *AWARE1000* method, 1.51 m$^3_{\text{world-eq.}}$, associated to an increased water scarcity of energy inputs (electricity, coal) of Colombian origin, because AWARE1000/AWARE100 for Colombia relation is 1.5. The difference should be associated to dry months on Caribe basin, which increases average value of scarcity for Colombia. Relationship between *AWARE10* result, 0.7 m$^3_{\text{world-eq,}}$ and AWARE100 result, 1.04 m$^3_{\text{world-eq}}$ is also explained by this reason. In this case study, AWARE increases when taking 150% of original value for Environmental Water Requirement doesn't significantly increase Water Scarcity Footprint, the increase is from 1.04 to 1.05 m$^3_{\text{world-eq}}$ per ton cement. DTAx and DTA imply a smaller absolute value by definition, and results for DTA and DTAx are close (0.58 m$^3_{\text{eq}}$ and 0.44 m$^3_{\text{world eq}}$).

6. Sensitivity analysis

6.1 Comparison of Water Scarcity vs Water Availability Footprint

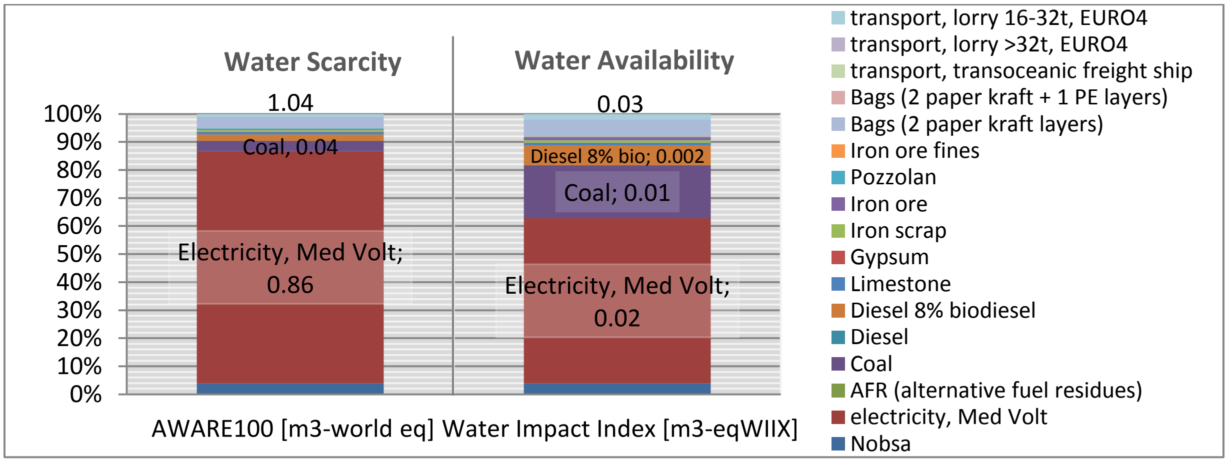


Figure 4. Comparison of AWARE100 and Water Impact Index

From Figure 4, it is observed that the Water Impact Index identifies coal as responsible of 19% (0.01 m^3_{eqWIIX}) of water availability footprint; this percentage is partly explained by pollution generated in coal mining. Electricity consumption is still the most relevant hotspot for bouth indicators. Water Scarcity is 1.04 $m^3_{world\ eq}$ compared to a WIIX of 0.03 $m^3_{wIIX\ eq}$; therefore communicated as single score of impact, AWARE100 albeit only accounts for scarcity gives a pretty larger amount than the WIIX that is a water availability footprint indicator.

6.2 Sum of Monthly vs. annual Water Scarcity Footprint

For this case study, inventory data was available per month. Therefore, a monthly water scarcity footprint was calculated, then it was summed to compare with the annual result previously calculated. Comparison is presented in Figure 5.

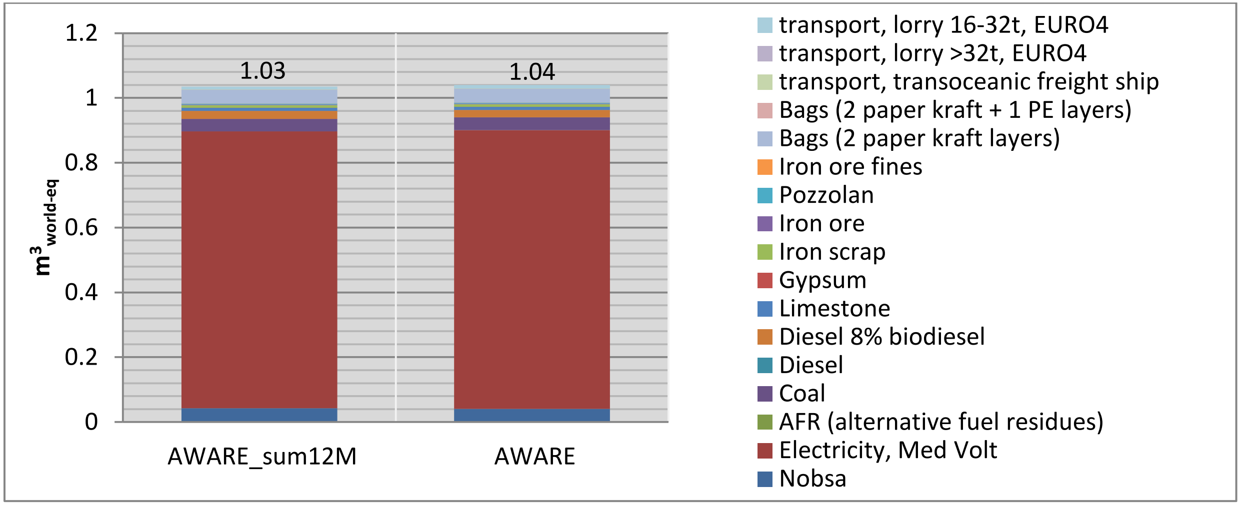


Figure 5. Comparison of sum of monthly AWARE vs annual AWARE

Variation of annual AWARE when using monthly indicator is small, of -0.5%. However, it should be noted that indirect water consumption due to electricity is calculated using database (m3/kwh) and therefore variation of water consumption between months for electricity production is not considered.

6.3 Downscaling influence

For the following analysis, the following considerations and limitations should be noted:

- The geographical unit of analysis is hydrographic subzone – SZH; can be defined as a third level drainage sub basin but some SZH group several small watersheds. There are 316 hydrographic subzones in Colombia.
- The data available per sub water basin comes from the National Water Study of Colombia 2014 (IDEAM, 2015). Water consumption data is for 2012, per sub basin. It includes irrigation, animals' water use, domestic use, industrial use, water for mining, water evaporated from dams and water transfers.
- There was not available data per month for water availability, therefore the year AWARE and other methods results are not a result of an average of the 12 months, but based on annual data.

Downscaled indicators are presented in Annex I. Used Water Scarcity Indexes. Figure 6 presents comparison of water scarcity footprint results excluding Electricity using water basin AWARE vs results obtained with sub water basin (downscaled) AWARE. Electricity is not included because its origin is Colombia average, therefore its AWARE doesn't changes when downscaling, and because it is the main hotspot, so it hinders implications of other indirect and direct water footprints.

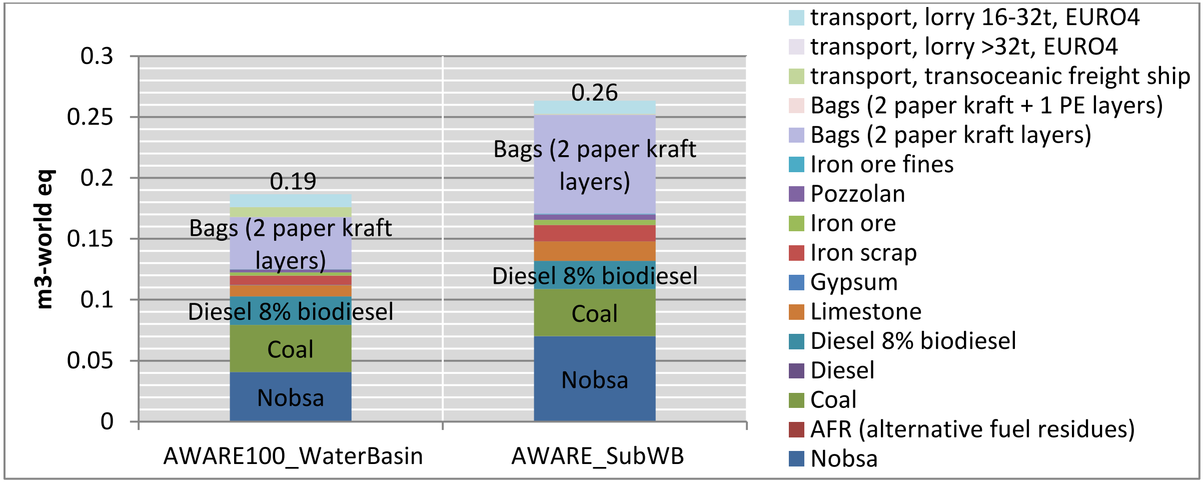


Figure 6. AWARE results excluding electricity consumption, using actual versus downscaled indexes

When including all processes, the water scarcity footprint changes from 1.05 $m^3_{world\ eq}$ /ton to 1.12 $m^3_{world\ eq}$ /ton (increases 7%). Excluding electricity consumption, water scarcity footprint changed from 0.19 $m^3_{world\ eq}$ /ton to 0.26 $m^3_{world\ eq}$ /ton (increases 41%). AWARE method with lower resolution increases water scarcity footprint and increase relevance as hotspot of packing produced in Palmira and direct water uses of the cement plant in Nobsa.

6.4 Downscaling influence considering a dry year scenario

For the following analysis, dry year water availability was used for evaluating hydrographic subzones AWARE indicator. The National Water Study evaluates a dry year water availability based on statistics, interpolation and runoff curves from the hydrologic stations; therefore it is not related to any specific period (IDEAM, 2015).

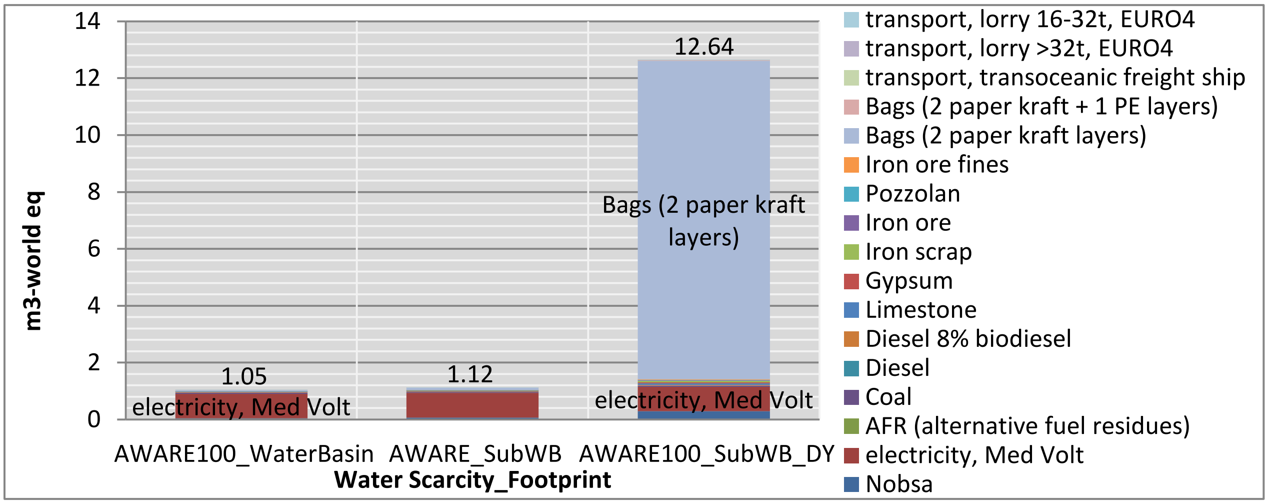


Figure 7. Comparison of AWARE using downscaling and a dry year scenario

For a dry year and when using available downscaled data, relevance of Bags produced in Palmira (Amaime and Cerrito rivers sub-basins) increases significantly; AWARE increases in 1029%, from 1.12 $m^3_{world\ eq}$ /ton to 12.64 $m^3_{world\ eq}$ /ton. A dry year scenario presents a critical hotspot of water scarcity footprint associated to bags production process, therefore the company should take care and investigate about how its supplier manages these situations. Dry conditions in Colombia are cyclic due to influence of coupled ocean-atmosphere phenomena of El Niño, and its influence varies geographically between sub-basins.

7. Analysis of results

- Given the scales of each method, largest absolute value for water scarcity footprint is given by AWARE1000, followed by AWARE100_EWR+50%, AWARE100, AWARE 10, DTA and DTAx. In this case study, all different water scarcity footprint methodologies gave as result that electricity consumption from Colombian matrix was the main hotspot.
- It is pretty difficult for a single company to execute actions in order to reduce water consumption in the electricity matrix and their hydroelectricity dams, therefore the actions to execute by the plant are frequently limited to energy efficiency measures. Hotspot was defined more by water consumption than by water scarcity, because electricity production is a process of origin Colombia's average, and Colombia is of low water stress for all indexes.
- In this case, electricity water footprint was obtained from database. This procedure doesn't consider monthly variability of water consumption, which in the case of hydroelectricity varies importantly between months depending on water balance and can even be negative in some months, when more water is released than entered by precipitation or input of river flow (WD4 ISO14073, 2015).

- Albeit electricity consumption is the hotspot, there may be greater water scarcity reduction potential in other stages. In this sense, adding an analysis excluding electricity process may be of interest for the Company.
- In terms of MJ, energy consumption on plant is 88% carbon, 10% electricity and 2% diesel8%bioldiesel. In comparison, water scarcity footprint is between 75% (DTA) and 85% (AWARE1000) due to electricity consumption. In terms of water scarcity footprint, coal is a better choice, but in terms of water availability footprint, pollution due to coal mining increases its relevance.
- Albeit only accounts for scarcity, AWARE100 gives a pretty larger amount than the WIIX that is a water availability footprint indicator and therefore its communication as a single score index may raise greater awareness.
- The use of different thresholds may increase significantly the absolute value for average water scarcity of a country, even if it is of low water scarcity. In the case of Colombia, scarcity increased around 50% between AWARE10 and AWARE100, and between AWARE100 and AWARE1000. This increase relates to high stress Caribe basin, which is the one with areas and months of AWARE greater than 10, and even though it covers only 9% of national territory.
- For Colombia, water availability change in dry years can be pretty high; therefore it may be important to include dry scenarios in order to identify hotspots during these seasons. These results can be of mayor interest for a company if it has direct operations in areas of temporal water scarcity, because it would be more aware about needs for preparing for these seasons. The company can also work with its supplier for a better water management on hotspots watersheds.

8. Potential problems to be addressed

- For supplies for which only the country of origin is known, its AWARE indicator may be overestimated and therefore its water scarcity footprint may hinder importance as hotspots of other supplies or direct processes, for which there are water basin location available. This is true for all indicators but for AWARE may be of greater concern. Additional analysis for only processes with specific location available may be of interest, especially if company has greater potential of influence over them.
- When excluding processes for which there is not a local water basin of origin available, water scarcity footprint changed significantly when downscaling AWARE100 (increase of 41%). This result increase awareness about downscaling when possible, especially for productive processes where location is known and given that their basins have large areas and changing microclimates.

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Annex I. Used Water Scarcity Indexes

Location	DTA	DTAx	AWARE100 (1/AMD)	AWARE100_EWR+50%	AWARE10	AWARE1000
Global Average	0.78	1.28	20.30	28.00	5.94	289.38
Colombia Av	0.39	0.30	0.77	0.79	0.49	1.15
Spain Av	0.72	1.27	31.49	37.88	5.14	263.44
Basin ID 49500	**0.38**	**0.29**	**0.38**	**0.34**	**0.38**	**0.38**
Downscaled (average year water availability)						
Cities: Nobsa, Tibasosa, Paz del río (Chicamocha River sub-basin)	0.40	0.02	0.66	0.66	0.94	0.66
Sibaté (Bogotá River sub-basin)	0.74	0.05	2.22	2.22	23.86	2.22
Villanueva (Suarez River sub-basin)	0.40	0.02	0.33	0.33	0.48	0.33
Palmira (Amaime and Cerrito rivers sub-basins)	0.55	0.03	0.73	0.73	1.25	0.73

Downscaled and with dry year water availability						
Cities: Nobsa, Tibasosa, Paz del río (Chicamocha River sub-basin)	0.7	0.0	2.7	2.7	100	2.7
Sibaté (Bogotá River sub-basin)	1.5	0.1	100	10	100	1'000
Villanueva (Suarez River sub-basin)	1.0	0.1	100	10	100	1'000
Palmira (Amaime and Cerrito rivers sub-basins)	1.1	0.1	100	10	100	1'000