

## Étude N°2024-03

### Empreinte eau et indicateur ACV AWARE : pratiques et recommandations

#### Synthèse (EN)

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## 1. Background and objective of the study

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This study examines how water-related issues—particularly water scarcity—can be addressed through Life Cycle Assessment (LCA) and other methods, evaluates how well LCA captures these issues, and analyzes the strengths and limitations of the AWARE method as the leading water scarcity indicator in LCA. It includes case studies to identify practical challenges and provides recommendations to improve the assessment of water-related impacts in alignment with ISO 14046 and the AWARE method.

The specific objectives of the project included :

- Identify how companies account for and assess water-related issues based on their practices (LCA and beyond), with a particular focus on water scarcity,
- Identify how LCA addresses water-related issues, as well as water-related issues that are not covered by LCA,
- Summarize how LCA guidelines and standards recommend assessing water-related issues,
- Analyze AWARE, as the prevalent water-scarcity LCA method, and compare it to non-LCA metrics and methods,
- Carry out case studies to identify issues of application and interpretation of WF methods, particularly AWARE,
- Formulate practical recommendations in light of the state of the art and the results of the case studies.

This document is a summary of the complete study available online on the ScoreLCA website:

SCORE LCA, Empreinte eau et indicateur ACV AWARE : pratiques et recommandations, 2025, 154 pages, n°2024-03.

## 2. Impact assessment frameworks for water-related environmental issues and normative development

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### 2.1 Definition of water-related environmental issues

Water-related environmental issues can be categorized into different types:

- **Water availability issues** include problems related to situations where the demand for water of a certain quality exceeds the availability of that water in a given region. ISO 14046 (ISO, 2017) differentiates two types of water availability issues: scarcity, which considers only the net physical consumption of water, and availability, which includes also other elements that affect the amount of water available to respond to the needs of humans and ecosystems (loss of quality, changes in habitats).
- **Water degradation issues** are caused by the emission of substances that affect “physical (e.g. thermal), chemical and biological characteristics of water concerning its suitability for an intended use by humans or ecosystems” (ISO, 2017). The modification of these characteristics can lead to direct impacts on humans (human toxicity, microbial diseases via drinking water...) and ecosystems (ecotoxicity, thermal pollution, eutrophication of water...) or indirect impacts, namely the decrease of water availability mentioned above.
- **Issues caused by changes in habitats** result in different environmental water-related issues both directly and indirectly. The flooding of an area due to the construction of a dam or the transformation of land into an agricultural field affects the availability of water resources both directly (increase of evapotranspiration, depletion of groundwater resources) and indirectly (runoff of pesticides, sedimentation, and alteration of natural water flow regimes).

Water-related environmental issues are caused by several factors: Water consumption and over-exploitation, climate change, habitat change and urbanization, pollution from human activities and the discharge of new substances.

The main characteristic of water-related environmental issues is the unequal distribution of water resources on the globe and over time, which, combined with the different intensities of human activity (water consumption and human activities leading to water degradation), results in different intensities of the impacts depending on the region and the season.

## 2.2 Historical context for the assessment of water-related environmental issues

In 2002, Arjen Hoekstra introduced the concept of the water footprint for the first time (Hoekstra & Hung, 2002) (although similar concepts such as virtual water were already developed in the 90s), which quantifies the total volume of freshwater used in the supply chain to produce goods and services and emphasized the need to consider both direct and indirect water consumption of products and companies.

Since this first description, several initiatives and tools appeared, such as the Global Water Tool (GWT), developed by the World Business Council for Sustainable Development (WBCSD) or The Aqueduct Water Risk Atlas (2013), developed by the World Resources Institute (WRI).

Within the LCA community, the first structured initiatives to account for water issues appeared in 2007 when the UNEP/SETAC's Life Cycle Initiative launched the Water Use in LCA (WULCA) working group. Its work focused on developing a general assessment framework for water use, establishing adequate water inventory schemes and developing impact assessment methods to characterize water use. Individual initiatives to develop LCI databases (Quantis Water Database Framework) and LCIA methods appeared over these years. As part of the WULCA working group activities, in 2015, the AWARE method was developed as a consensual method to harmonize practices.

In 2009, ISO launched the works to develop an international standard for water footprint (ISO, 2014).

## 2.3 ISO Water Footprint

A **Water Footprint** (WF) helps to better understand the potential environmental impacts of human activities that are linked to water resources. The general framework of the WF is defined in the standard ISO14046 (ISO, 2014). Since ISO 14046 is based on the LCA framework defined in ISO 14044, the WF strongly resembles a typical LCA but focuses on water-related environmental impacts. It encompasses the four phases: Goal and Scope (G&S), Life Cycle Inventory (LCI), Life Cycle Impact Assessment (LCIA), and Interpretation. Its main specificities include:

- The need to consider both the spatial and temporal dimensions when assessing the impacts of water use;
- The need to include both aspects associated with water quantity and water quality;
- The need to include all water-related categories to calculate a comprehensive WF. In this sense, the norm states that *“If water-related potential environmental impacts have not been comprehensively assessed, then the term water footprint shall only be used with a qualifier”* that *“describes the impact category/categories studied in the water footprint assessment, e.g. “water availability footprint”, “water scarcity footprint”, “water eutrophication footprint”, “water ecotoxicity footprint”, “water acidification footprint”* (ISO, 2014).

## 2.4 Which environmental issues should be covered by a Water Footprint?

Water-related LCIA methods are methods where water is involved as a contaminant exposure media (i.e. Human Toxicity, Acidification, Eutrophication, Thermal Pollution) or a used resource and habitat (Water Depletion and Scarcity, River Fragmentation).

There are three groups of water-related LCIA methods, defined by their impact pathway:

- **“Quantitative” changes of the water compartment:** These impacts regard the hydrological characteristics of a freshwater body. Examples are the human consumption of freshwater and subsequent reduction in water availability, or the change of a river flow regime (and thus water availability and its temporal characteristics) due to the operation of hydropower dams (Dorber et al., 2024).
- **“Qualitative” change of the water compartment** (called “water degradation”): Water degradation commonly results from water-polluting activities, which means that the water body’s chemical or physical properties are changed. One example is the emission of heavy metals into water bodies, which changes the chemical composition of the water and might have toxic effects on aquatic species (Douziech et al., 2024).
- **Changes in the aquatic (freshwater) habitat:** There are currently only a handful of LCIA methods dealing with this impact pathway. One example is the estimation of changes in wetland areas due to water consumption (Verones & Pfister, 2013).

## 3. AWARE method

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### 3.1 AWARE principles

The AWARE method is the only existing consensus-based method in the realm of assessing the impacts of water consumption on water scarcity in LCA. As such, it is widely used by LCA and WF practitioners.

The AWARE method aims to answer to the question: **“What is the potential to deprive another freshwater user (human or ecosystem) by consuming freshwater in this region?”** (Boulay et al., 2018). To do so, the AWARE method aims to quantify the potential impact, via deprivation, of consuming one cubic meter of water on other freshwater users, including humans and ecosystems. This potential impact is assumed to be 1) sensitive to the time of year and the location in which the water consumption occurs, and 2) limited to the local watershed. It is expressed as the “Water Deprivation Potential” based on the hypothesis that *“the potential to deprive another user of water [...] is [...] inversely proportional to the available water remaining”* after human and ecosystem demands have already been satisfied (Boulay et al., 2018).

AWARE is designed as a generic midpoint LCIA method, which means that it is based on a limited set of input variables and does not trace the impacts from water consumption to potentially affected organisms. Instead, it aims to enable a combined assessment of potential impacts on both humans and ecosystems at the same time.

The AWARE model is based on an Availability-Minus-Demand (AMD) approach to address some drawbacks from other existing water-related approaches previously used (Withdrawal-to availability-WTA, Consumption to availability-CTA, Demand-to-availability-DTA). In this approach the difference between available water and the water demands of humans and ecosystems is calculated. The result is divided by the watershed area. Dividing by watershed area allows us to compare the amount of water remaining after satisfying human and ecosystem water demand between differently sized watersheds. Otherwise, larger watersheds might appear to have a high water availability simply because they are large and thus collect more water than a small watershed. Using the AMD instead of the DTA considers human and environmental water requirements while acknowledging the amount of water available per surface area and thus provides a more intuitive result: Regions where human and environmental water demands are low, but water availability is low as well, are still considered water scarce. The final AWARE Characterisation Factor (CF) for watershed  $i$  and month  $j$  is obtained by dividing the  $AMD_{world\_avg}$  by the  $AMD_{ij}$ .

Figure 1 presents a representation of the AMD concept in AWARE and the calculation of the CFs.

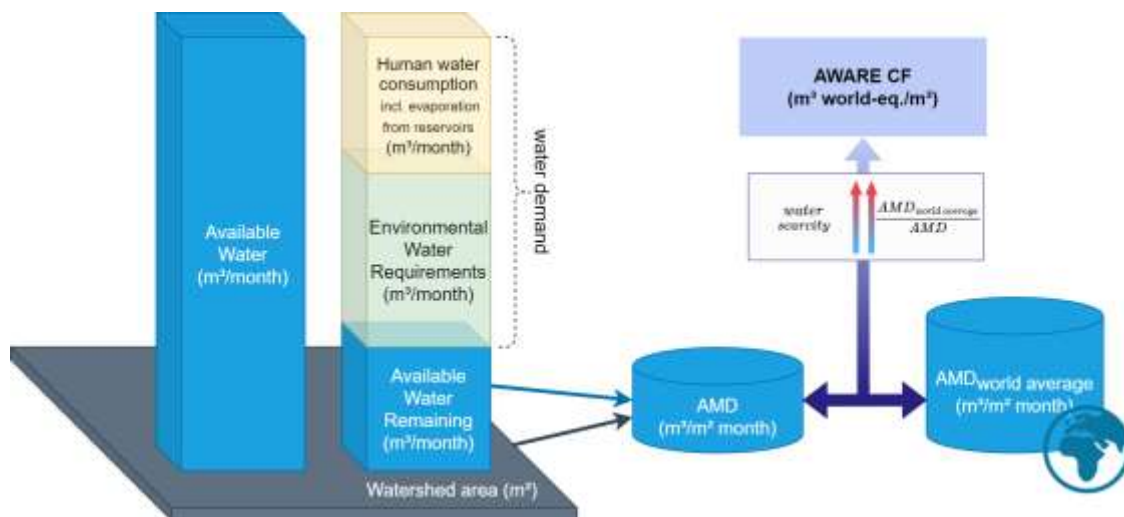


Figure 1. The AWARE concept: The available water remaining per area of a watershed after human water consumption and satisfaction of environmental water requirements, the AMD, is set in relation to the global average AMD where water is consumed. This comparison results in the AWARE CF.

The AWARE CFs are expressed in  $\text{m}^3$  world-equivalent per  $\text{m}^3$  consumed ( $\text{m}^3$  world-eq./ $\text{m}^3$ ). If the CF for a watershed and month is larger than  $1 \text{ m}^3$  world-eq./ $\text{m}^3$ , this means that the watershed has less available water remaining per area in this month than the global average. For example, a CF of  $10 \text{ m}^3$  world-eq./ $\text{m}^3$  indicates that the available water remaining in the watershed and the month analyzed is one-tenth of the available water remaining for random water consumption worldwide (in 2010).

The AWARE CFs are subject to cut-offs: Values below  $0.1 \text{ m}^3$  world-eq./ $\text{m}^3$  and values exceeding  $100 \text{ m}^3$  world-eq./ $\text{m}^3$  are set to these limits. The range of 0.1 to 100 was deemed an appropriate balance between allowing differentiation of as many basins as possible and not distorting results due to a few very high CFs.

### 3.2 Spatial and temporal differentiations

**AWARE CFs are calculated on basin resolution for every month of the year, with large watersheds divided into sub-watersheds.**

In LCA, however, practitioners often do not know the exact month of the water consumption and require annual CFs, which can be used with their annual water consumption inventory. Calculating annual CFs as an arithmetic average of all months is not recommended, since it can be misleading for seasonal water use, especially for irrigation. Since most irrigation occurs in warm and dry months with high CFs, an arithmetic average of all months would underestimate the potential impact of water consumption. Instead, the annual average should reflect the seasonal pattern of water consumption of the assessed activity. This is, like in the calculation of the  $\text{AMD}_{\text{world avg}}$ , achieved by weighting the months according to their water consumption. To better represent the seasonal patterns of water consumption for specific water use sectors, three types of annual CFs differentiated by the type of water use are provided for AWARE:

- **Annual average CF for unknown water use**, weighted by the entire monthly human water consumption, encompassing irrigation, households, industry, livestock farming, and electricity production.
- **Annual average CF for agricultural use**, weighted by the monthly irrigation water consumption inventory.
- **Annual average CF for non-agricultural use**, weighted by non-agricultural water consumption. Since non-agricultural water consumption is assumed to be constant throughout

the year, this equals an arithmetic average of the monthly CFs. Note that this is the way water consumption is modelled in WaterGAP2 (Müller Schmied et al., 2014).

Two different spatial aggregation levels from watershed to lower resolutions are available online:

- **Country-scale CFs**, provided as Excel Files on <https://wulca-waterlca.org/aware/download-aware-factors/> (last accessed 2024-09-20).
- **CFs aggregated to subnational administrative regions**, available here: <https://wulca-waterlca.org/aware/sub-national-aware/> (last accessed 2024-09-20, documented in (Boulay & Lenoir, 2020)).

### 3.3 Calculation and interpretation of the AWARE score

To obtain the Water Deprivation Potential ( $WDP_{ij}$ ) of freshwater consumption in watershed  $i$  and month  $j$ , the AWARE CF must be multiplied by the net volume of freshwater consumed in  $m^3$  ( $netC_{ij}$  in Equation 1). This multiplication results in the  $WDP_{ij}$  of the assessed water consumption in the respective watershed and month, expressed in  $m^3$  world-equivalents.

Equation 1: Calculation of AWARE score

$$Water\ Deprivation\ Potential\ (WDP)_{ij} = AWARE\ CF_{ij} \cdot netC_{ij} \ [m^3\ world - eq.]$$

Figure 2 shows the water flows entering and exiting a unit process that allow the calculation of the net consumption.

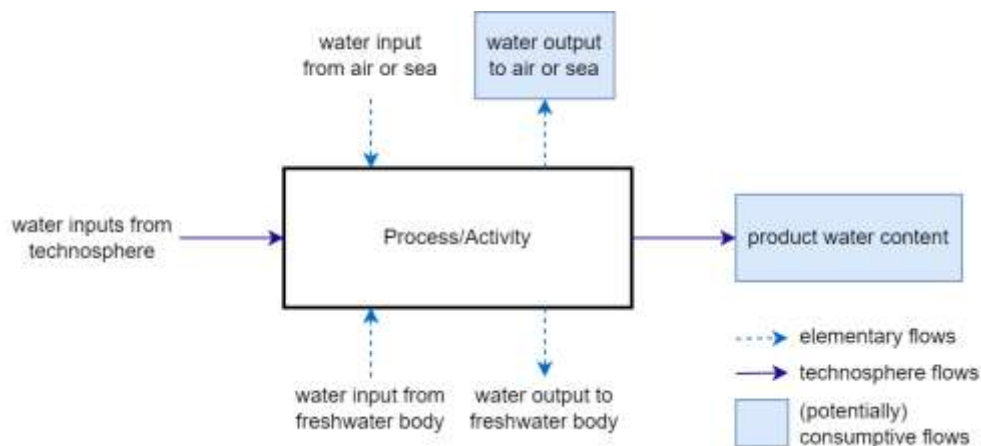


Figure 2. Water consumption in a simple LCA process.

Two approaches can be taken to calculate the net freshwater consumption  $netC_{ij}$  of a process:

- **The “watershed differential” approach: Balancing  $IN_{freshwater\ bodies}$  and  $OUT_{freshwater\ bodies}$ .** Freshwater bodies here are surface water (lakes, rivers) and groundwater. The watershed differential represents the difference between the water “taken from” and “released to” the freshwater bodies in a watershed by the studied process. This does not mean that for a calculation of the  $netC$  a Water Scarcity Footprint (WSF) modeler needs to know which exact watershed the  $netC$  is linked to. Assuming that water withdrawal and release of most technological processes occur in the same region, the knowledge of how much water is withdrawn or released for a certain process in most cases is sufficient for calculating the  $netC$  with the watershed differential approach.
- **The “consumptive flows” approach: Balancing  $IN_{technosphere}$ ,  $OUT_{technosphere}$ ,  $IN_{air, ocean}$ , and  $OUT_{air, ocean}$ .** This approach only considers water flows which are not directly linked to the watershed’s freshwater bodies. These represent the reasons why the process consumes water or releases water back to the watershed: Because it is incorporated into technosphere flows

the process uses or produces (e.g., a can of tomato soup), because it is captured from rain or air moisture, evaporated, or because it is taken from or released to the ocean. Note that water inflows from precipitation are an edge case to be treated carefully.

### 3.4 Extensions and edge cases of AWARE

Three advanced developments of AWARE allow for more robust results calculation and interpretation:

- **Marginal vs. Non-Marginal Use:** AWARE CFs are valid only for small-scale water consumption (<5% of total human water consumption in the watershed-HWC). For larger inventories, non-marginal (average) CFs should be used. These are available and can be applied manually, but they are not yet operational in LCA software.
- **Uncertainty:** Uncertainty in AWARE mainly stems from spatial and temporal aggregation rather than input data. Reducing it requires refining geographic and seasonal detail. Uncertainty parameters are available and can be implemented in tools like openLCA or Brightway.
- **Prospective CFs:** Future AWARE CFs account for climate and demand shifts. They exist for some scenarios (e.g., EU 2050), but their use is not yet integrated into LCA tools and requires manual mapping.

There are several edge cases in which the application of AWARE CFs might be less clear than in standard activities.

- **Dams and reservoirs:** monthly balances of inflow/outflow better represent should be used to calculate net water consumption. Positive effects during dry months may offset increased evaporation.
- **Fossil groundwater:** not covered by AWARE, as it only applies to renewable water. As fossil groundwater is a non-renewable resource, it should ideally be assessed under the Resource Area of Protection, not as freshwater consumption.
- **Rainwater harvesting:** only the fraction of rainwater that would contribute to runoff should be taken into account when calculating net consumption.
- **Brine and wastewater:** AWARE characterizes water resources only if the original source was freshwater and the discharge is to a freshwater body. Water quality impacts must be handled separately.
- **Freshwater use near the sea:** the withdrawn of freshwater near the sea could affect the resource available via salinization phenomena.
- **Agricultural ponds filled with groundwater:** withdrawals in wet months and return flows in dry months can significantly alter the WSF; pond-filling should match monthly CFs.

### 3.5 Critical analysis of AWARE

Main critical points of AWARE include:

- **Input Data Limitations:** AWARE relies on low spatial resolution, uncertain hydrological datasets, namely in dry regions. Data lack representation of key elements like desalination, glacier melt, or water transfers between watersheds.
- **Methodological Limits – Availability:** the method does not explicitly take into account water storage, inter-basin transfers or the distinction between renewable and fossil groundwater. These omissions can distort availability assessments.
- **Methodological Limits – Environmental water requirements (EWR):** EWRs are modeled in a simplistic way, without taking into account the differences between ecosystem types and regulatory operations and infrastructures.
- **General Methodological Limits:** AWARE remains a scarcity method, neglecting the impact of the quality in the final availability.
- **General Methodological Limits:** The use of area in the calculation of the AMDs in some cases makes the CFs sensitive to the way the watershed boundaries are set. This is relevant for rivers such as the Nile, where discharge does not increase proportionally to the additional catchment area when moving downstream.

- **Advantages:** AWARE is transparent, easy to interpret, integrates spatial–temporal variability, and was developed via consensus, ensuring broad acceptance. Its simplicity also enables recalculation with local data, supporting robust comparative assessments.
- **Implementation Issues:** Many LCA tools lack full regionalization and use outdated or inconsistent CFs, leading to inaccuracies. While some issues can be mitigated (e.g., via Regioinvent), full alignment requires tool-specific customization and remains a challenge.

## 4. Non-LCA water-related assessment methods and their comparison to LCA methods

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Several non-LCA water-related assessment methods are compared to the LCA-based method WSF using AWARE. The choice of the methods studied is based on responses to the survey and the most retrieved methods in the literature. Four methods are presented.

- **Aqueduct Water Risk Atlas (WRI):** A web-based tool that maps global water-related risks using high-resolution data and over a dozen indicators. It supports decision-making for corporations and policymakers by assessing physical, regulatory, and reputational risks, and includes projections under climate change scenarios.
- **Global Water Tool (WBCSD):** An Excel-based tool (discontinued in 2019) that helped businesses map water use and assess risks using site-specific and external datasets. It offered high-level vulnerability screening across operations and supply chains.
- **Water Risk Filter (WWF):** A web platform using over 100 global indicators to evaluate physical, regulatory, and reputational water risks. It enables site-specific and scenario-based assessments and is integrated within reporting frameworks for corporate water stewardship.
- **Water Footprint Network (WFN):** Provides a methodology to quantify freshwater use and pollution via green, blue, and grey water footprints, helping assess the environmental impact of goods and services across their life cycles. The WFN assessment uses a similar approach as the LCA based, with four differentiated phases (Goal and scope, accounting phase, sustainability assessment phase, response formulation).

The comparison was based on three categories: general approach, technical characteristics, and operational features, focusing especially on how these tools address water scarcity and related issues. Main insights are the following

- **General Definition and Approach:** AWARE is the only fully LCA-compliant method with a dedicated water scarcity focus and life cycle perspective, recommended by standards such as PEF and GLAM. In contrast, tools like Aqueduct and WWF prioritize broader water risk assessment (including quality and reputational risks), mainly for corporate-level applications. Only AWARE and WFN incorporate a full life cycle scope.
- **Technical Characteristics:** AWARE, Aqueduct, and WWF tools provide high spatial (watershed-level) and temporal (monthly or seasonal) detail. AWARE uses the AMD approach, while others use WTA, CTA, or inventory-based metrics. Scenario modelling is available in Aqueduct and WWF, with uncertainty not fully addressed.
- **Operational Characteristics:** AWARE is integrated within LCA software and depends on regional water consumption data. Aqueduct and WWF's tools are web-based platforms; the Global Water Tool was Excel-based but is now discontinued. WFN offers both an online tool and partial integration with LCA software. All tools require similar inventory inputs (withdrawals, consumption, emissions), except the outdated WBCSD tool.

## 5. Current practices and limitations

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This section examines current practices for calculating a WSF in Life Cycle Assessment, focusing on how water flows are integrated in LCI databases, how water scarcity indicators are implemented in LCIA

methods, and how calculations are operationalized in LCA software. It also highlights interpretation challenges related to spatial and temporal differentiation or uncertainty treatment.

- **LCI Databases:** Major databases like ecoinvent, Sphera, and Agribalyse provide spatially differentiated water inflow/outflow data essential for WSF calculation, though temporal detail is generally lacking. Only ecoinvent and Sphera balance water flows according to ISO 14046. Rainwater and additional information (e.g., water content) are not generally included. Some inconsistencies remain in some databases (e.g., lack of temporal tags or imbalance in Agri-footprint and USLCI).
- **LCIA Methods:** Most mainstream LCIA methods (EF 3.1, GLAM, IMPACT World+) adopt AWARE to characterize water scarcity at the country level. LC-IMPACT is an exception, using the Water Stress Index (WSI) to derive endpoint (DALYs and species.yr). These methods also cover other environmental impacts (e.g., acidification, eutrophication, ecotoxicity), enabling comprehensive WF.
- **Operationalization in LCA Software:** All tools (e.g., openLCA, Brightway) implement WSF using the “differential of flows” method. Temporal resolution is available (e.g., agri/non-agri CFs) but cannot be fully exploited due to lack of information in LCI datasets. Spatial refinement and uncertainty handling are possible in some tools but not systematically implemented. Only openLCA and Brightway allow, in theory, Monte Carlo analyses including CFs uncertainty.
- **Interpretation Challenges:** The watershed differential approach can lead to misleading results when input/output flows originate from different regions or when technosphere flows are involved (e.g., tap water, wastewater). Monte Carlo simulations may yield invalid results (e.g., negative water balances) due to the independence of water in/out elementary flows.

## 6. Case studies for Water Scarcity Footprint

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Two case studies illustrating the applicability and challenges of using the AWARE method to perform a WSF using AWARE.

### 6.1 Case Study 1: Application of the Water Scarcity Footprint to reservoir operations for hydroelectricity generation

This case study explores the WSF of reservoirs in hydroelectricity generation, using the AWARE. It emphasizes how different levels of spatiotemporal details can improve the accuracy of water scarcity assessments for reservoirs. The study also highlights challenges such as multifunctionality, the representativity of input data, and reservoir multifunctionality.

Reservoirs represent a complex case for AWARE as they both manage and consume water within a watershed. Their operation typically reduces downstream discharge and increases evaporation due to expanded surface areas, yet they also enhance water availability during dry seasons. To assess a reservoir’s WSF, it is necessary to quantify relevant flows—mainly inflow, outflow, precipitation, and evaporation—while considering storage capacity. Given data collection limitations, especially for evaporation, the case study applies the watershed differential approach to compute net freshwater consumption.

The AWARE score for hydroelectricity generation can be refined by increasing the spatial and temporal resolution of the inventory in openLCA. This case study evaluates three spatialization levels—global default, country, and watershed—and shows that finer spatial detail significantly diminishes results uncertainty. Temporalization is then explored using annual aggregations (non-agri) and monthly CFs, revealing how seasonal variability influences results.

Figure 3 presents the results of refining the calculation by increasing the spatial and the temporal resolution of the CFs. Temporalization drastically changes the AWARE score in comparison to regionalization since it accounts for the extra water supply in the dry season. Indeed, reservoirs WSF should prioritize temporalization, particularly if monthly water balance and CFs have high temporal variability.

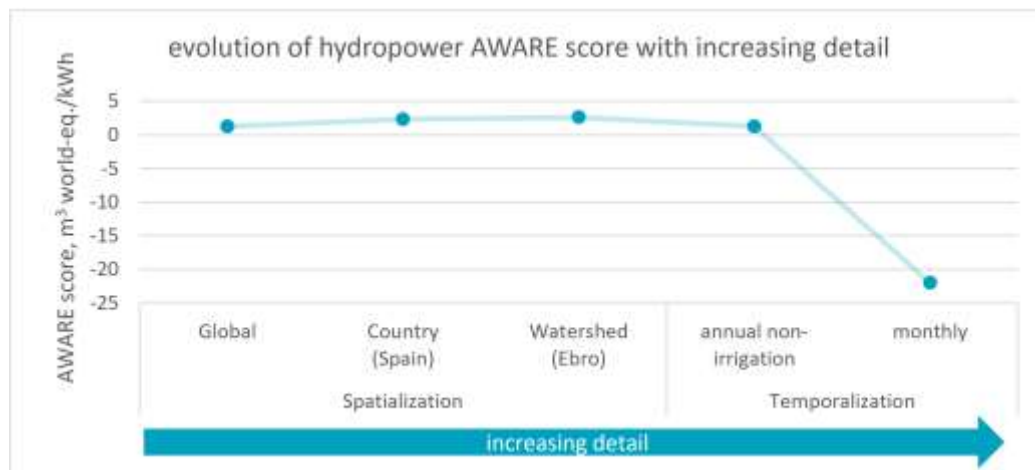


Figure 3: Evolution of hydropower AWARE score with increasing detail as shown in this case study. Note that steps 5 & 6 are skipped since they are calculated for a different unit (not per kWh).

Implementing AWARE for real reservoirs introduces multiple challenges that diverge from simplified case studies. Those key challenges are:

- The influence of temporal data accuracy;
- Reservoir multifunctionality: When reservoirs serve multiple functions (e.g., hydropower and municipal supply), impacts must be allocated based on volume or energy use, following the ISO 14044 hierarchy section 4.3.4.2 step 2 which favours underlying physical criteria, and its amendment 2 section D.3.1 since "the relative production of co-products can be independently varied";
- Additional ecosystem services: Reservoirs also provide regulating, provisioning, and cultural services (e.g., flood protection, fishing), which complicate impact allocation; volume-based allocation is often preferred but not applicable to all services;
- Temporal representativeness: Interannual variability in inflow/outflow data affects WSF scores. Data used must be representative of the long-term hydrological regime;
- Irrigation modelling: Water used for irrigation from stored reservoirs requires nuanced modelling to avoid double-counting or misrepresenting consumption;
- Non-marginal consumption: Reservoirs often consume water at scales that invalidate marginal CFs. Non-marginal CFs are recommended for large-scale assessments.

## 6.2 Case Study 2: Application of the Water Scarcity Footprint to an industrial process using bio-based inputs

This case study focuses on the ethanol production process from maize in Iowa (US), using a genericecoinvent dataset. The analysis focuses on several key aspects: the data collection and net water consumption, the calculation of the WSF and its refinement using more precise spatial and temporal data, the exploration of an edge case described in section 3.4, and putting into perspective the contribution of the scarcity issues to a comprehensive WF using complete LCIA methods.

To calculate the ethanol production dataset's net water consumption, all water flows are accounted for, both from the environment (elementary flows like cooling water or evaporation) and the technosphere (tap water, wastewater treatment, and water content in maize). The water balance reveals a slight imbalance (inputs exceed outputs by 5%) which may stem from data gaps or allocation methods. This imbalance leads to an overestimated net consumption when using the watershed differential approach. This kind of imbalance needs to be adjusted, particularly the watershed differential results in a negative value.

Figure 4 resumes the comparison of the refining steps scenarios. The inventory regionalization process (i.e. using the most representative technologies of the studied region) is the most important refining step in this case. Indeed, the amount of water used for irrigation appears as the main contributor to the baseline scenario final score and the inventory regionalization step results in a significant reduction (as

irrigation amount is much lower in the state than in the country average). The refining using more accurate spatial and temporal CFs can be based on the standard deviation of the spatial and temporal aggregation per country<sup>1</sup>; the higher should be prioritise. The spatialization (scenario 3) results also in a reduction, as the CF of the watershed studied has a notably lower value than the US country average. Scenario 4, including temporalization, does not present differences compared to scenario 3 since unknown CF and agricultural CF present close values in the studied watershed. This step could be performed more precisely by collecting the actual water consumption per month and using monthly CFs.

Due to the inputs of seawater not included in the calculation, the edge case (scenario 5) presents negative values (i.e. diminishing the water scarcity) for the tap water and the direct use of water. This results in a total value lower than the previous scenarios.

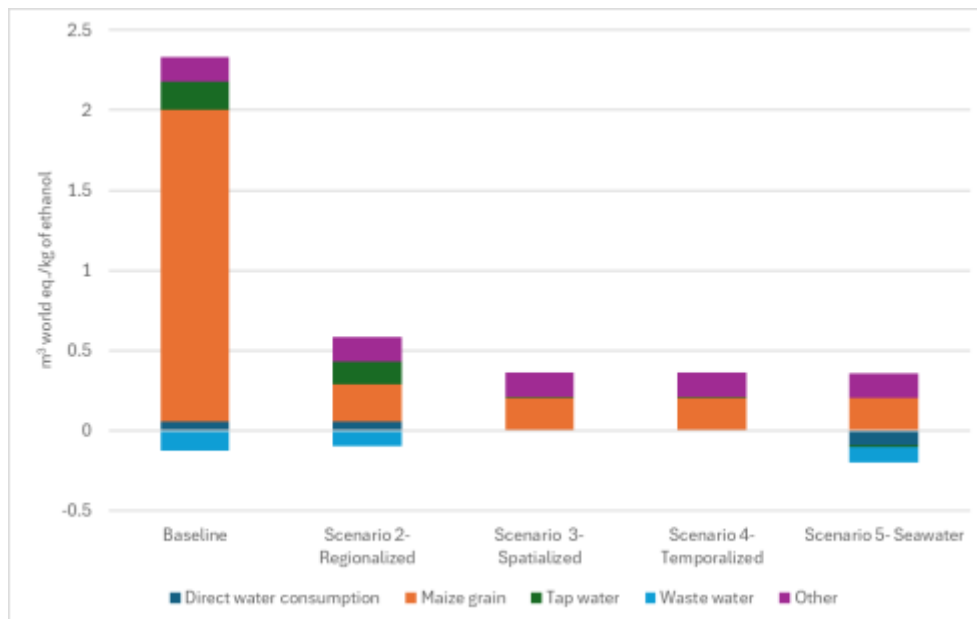


Figure 4: Results for 1kg of ethanol produced in the US using AWARE 1.2. Scenario comparison.

To illustrate potential burden shifting between scarcity and other water-related issues, two different comprehensive LCIA methodologies were used: The European Commission's EF method (calculated at the single score) and Impact World+ (endpoint). Only water-related categories in these methods are included for comparison. In both cases, the contribution of the water consumption categories is low (less than 5% of the total score). This result is just an example of the importance of considering the a more comprehensive water footprint by including categories other than water scarcity. This conclusion can not be extrapolated to all situations and analyses, because in other studies, the contribution of water scarcity could be major.

Key challenges when performing case study 2:

- The water balance and the interpretation and identification of the main contributors to the impact;
- The refining of the results using more precise CFs, both from a geographic (spatialization) and temporal (temporalization) point of view. This step can be challenging and time-consuming due to Simapro's configuration, but the increase in the representativeness and robustness of the results can be worth it. Prioritizing these two refining steps depends strongly on the variability of the CFs from the geographical and temporal points of view.
- The potential burden shifting between impact categories due to the use of a single-category method such as AWARE.

<sup>1</sup> Information available at <https://wulca-waterlca.org/aware/download-aware-factors/>

## 7. Recommendations

When performing a WF, ISO 14046 provides a general framework but leaves room for methodological interpretation, which creates challenges at each phase of the assessment. More than 50 challenges and recommendations were formulated in the final report, targeting different stakeholders in the LCA community: Practitioners (**P**), LCI database developers (**DB**), LCIA method developers (**MD**), and LCA software developers (**SD**). Table 1 presents a selection of the identified challenges with the corresponding recommendations.

Table 1: General challenges and recommendations for performing a Water Footprint according to ISO14046<sup>2</sup>

Phase	Challenges	Main recommendations
Goal and Scope	Definition of and adhering to spatial and temporal system boundaries	<b>P</b> : Define your system boundaries considering spatial and temporal specificities
	Selection of impact categories and LCIA methodologies	General: Create community consensus on impact methods to use for other impact categories than water scarcity
Life Cycle Inventory	Collecting the required data attributes (time, space) for the elementary flows to correctly assign regionalized and temporalized CFs	<b>MD</b> : Clearly state data requirements and potentially create harmonized WF LCIA methods, stating data requirements <b>DB</b> : increase alignment of databases with widely used WF data requirements
	Handling low-quality or missing data in the LCI	<b>P</b> : Clearly state where data is missing (transparency in reporting); use literature values; perform a data quality assessment; <b>P</b> : Using parameters for water-related data to facilitate sensitivity analyses and refinement of the model
	Background LCI database selection:	<b>P</b> : Ensure suitability of LCI database with the selected LCIA methods; <b>DB</b> : Clearly state the compatibility of DB with LCIA methods
	LCA software selection	<b>P</b> : Adapt the software choice to the level of detail needed for the objectives <b>SD</b> : Develop software to facilitate refining of results (ex: inclusion of geospatial approach for geographical refining)
Life Cycle Impact Assessment and interpretation	Interpret results from water-related impact methods which also contain non-water-related impacts	<b>P</b> : Avoid double-counting of impacts; <b>MD</b> : Provide WF-specific versions of impact methods where non-water related impacts are neglected
	Interpret/refine regionalized impacts	<b>P</b> : Focus on main contributors or assessing regional hot spots; use map plots; avoid the use of Rest-of-World or non-regionalized processes

The use of AWARE to calculate a WSF also presents specific challenges. Table 2 presents a selection of the identified challenges with the corresponding recommendations.

<sup>2</sup> Practitioners (**P**); LCI database developers (**DB**); LCIA method developers (**MD**); LCA software developers (**SD**)

Table 2: General challenges and recommendations for performing a Water Footprint according to ISO14046

Phase	Challenges	Main recommendations
<i>Goal and Scope</i>	Identification of current version of AWARE, AWARE updates	<p><b>P:</b> Use WULCA website as the main source of information about the current AWARE version and updates</p> <p><b>P:</b> Test whether using the recent version of AWARE would change the results</p> <p><b>MD:</b> AWARE developers: provide information on potential changes in results due to updates;</p>
<i>Life Cycle Inventory</i>	Identification of the types of water flows to be collected	<p><b>P:</b> If possible, collect all water flows to set up a consistent mass balance of the processes</p> <p><b>P:</b> Else, focus on processes required for watershed differential or consumptive flows approach. Ensure correct interpretation by LCA software</p>
	Lack of temporal/spatial water use data for the use of native AWARE CF	<p><b>P:</b> Use sector- or crop-specific (spatio-)temporal aggregations of the AWARE CFs when available</p> <p><b>P:</b> Use an iterative approach with different temporalization levels:</p> <p><b>DB:</b> Provide monthly resolution of LCI databases or at least archetypes for temporal distinct uses (agri, non-agri)</p> <p><b>MD:</b> Create further sector-specific aggregated CFs</p>
<i>Life Cycle Impact Assessment and interpretation</i>	Prioritize efforts between spatialization or temporalization	<b>P:</b> Use the provided standard deviations to identify the dimension to prioritize
	Finding the most contributing flows when using watershed differential	<p><b>SD:</b> Provide functions to assess the net elementary flow balance associated with a process</p> <p><b>MD, DB &amp; SD:</b> modify the approach to calculate water consumption</p>
	Software: lacking support for seasonal elementary flow changes and monthly resolution CFs	<p><b>P:</b> Calculation of custom weighted annual CFs and manual insertion of this CF in the LCA model</p> <p><b>P:</b> Use an iterative approach to refine main contributors manually</p> <p><b>SD:</b> Support monthly CFs and functions to assign these to (seasonally varying) elementary flows</p>
	Lack of technical know-how for using spatial data and maps	<p><b>MD:</b> Provide maps that can be integrated in LCA software</p> <p><b>SD:</b> Allow and automate the use of native spatial resolution in LCIA calculations</p>