The Water Footprint of Organizations – Local Measures in Global Supply Chains

Final report WELLE project

GRoW
WATER AS A GLOBAL RESOURCE

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Consortium	Technische Universität Berlin – Chair of Sustainable Engineering (Project coordination, FK 02WGR1429A) Deutsches Kupferinstitut Berufsverband e.V. (FK 02WGR1429E) Evonik Nutrition & Care GmbH (FK 02WGR1429C) Neoperl GmbH (FK 02WGR1429D) Thinkstep AG (FK 02WGR1429F) (now Sphera Solutions, Inc.) Volkswagen AG (FK 02WGR1429B)
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Abbreviations

AWS	Alliance for Water Stewardship
DKI	German Copper Alliance / Deutsches Kupferinstitut Berufsverband
EMAS	Eco-Management and Audit Scheme
EWP	European Water Partnership
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit
IWaSP	International Water Stewardship Program
IWRM	Integriertes Wasser Ressourcen Management
LCA	Life Cycle Assessment
NGO	Non-Governmental Organization
OEF	Organizational Environmental Footprint
OLCA	Organizational Life Cycle Assessment
OWF	Organizational Water Footprint
PEF	Product Environmental Footprint
SETAC	Society of Environmental Toxicology and Chemistry
TUB	Technische Universität Berlin
UNEP	United Nations Environment Programme
WP	Work Package
WULCA	Water Use in LCA

Zusammenfassung

Süßwasser ist für Menschen und Ökosysteme eine überlebenswichtige Ressource. Weltweit sind jedoch viele Regionen von Wasserknappheit betroffen. Organisationen wie bspw. Produktionsbetriebe oder Dienstleistungsunternehmen messen und steuern Wasserverbrauch i.d.R. an ihrem Standort, vernachlässigen aber häufig die indirekte Wassernutzung. Als indirekte Wassernutzung wird der Anteil am Wasserverbrauch bezeichnet, den eine Organisation bspw. durch den Abbau von Rohmaterialien, der Produktion von Zwischenprodukten oder Energieerzeugung entlang von globalen Wertschöpfungsketten verursacht. Dieser indirekte Wasserverbrauch ist häufig um ein Vielfaches höher als der direkte Wasserverbrauch einer Organisation.

Vor der Durchführung des WELLE-Forschungsvorhabens existierte kein standardisierter lebenszyklusbasierter Ansatz zur Analyse des organisationsbezogenen Wasserverbrauchs (im folgenden auch *Wasserfußabdruck*). Vor diesem Hintergrund wurde das vom BMBF geförderte Forschungsvorhaben "Water Footprint for Organizations - Local Measures in Global Supply Chains (WELLE)" von der TU Berlin, Evonik, dem Deutschen Kupferinstitut, Neoperl, thinkstep und Volkswagen ins Leben gerufen. Das Ziel von WELLE war es, Organisationen darin zu unterstützen, ihren vollständigen organisationsbezogenen Wasserfußabdruck zu ermitteln. Darüber hinaus sollten Organisationen befähigt werden, Schwerpunkte ihres Wasserverbrauchs entlang globaler Wertschöpfungsketten zu identifizieren und Maßnahmen zu initiieren, mit denen Wasserverbrauch reduziert werden kann, um in übernutzten Einzugsgebieten Wasserknappheit zu reduzieren.

Im Rahmen des WELLE-Forschungsvorhabens wurde eine Methode zur Analyse eines organisationsbezogenen Wasserfußabdrucks (OWF) entwickelt, die den Wasserverbrauch einer Organisation und den daraus resultierenden lokalen Auswirkungen entlang von Wertschöpfungsketten ermittelt. Der OWF berücksichtigt also entgegen gängiger Praxis nicht nur den direkten Wasserverbrauch am Standort einer Organisation, sondern auch den indirekten Wasserverbrauch, welcher bspw. durch Energieerzeugung und Rohstoffproduktion (vorgelagert), Nutzungsphase und am Lebensende (nachgelagert) auftritt. Zusätzlich wird aber auch der direkte Wasserverbrauch der Organisation berücksichtigt, der bspw. durch eigene Produktionsprozesse, Bewässerung von Grünanlagen, Versorgung der Mitarbeiter usw. verursacht wird.

Den Ausgangspunkt der methodischen Entwicklung des OWF bildete eine Analyse verschiedener bestehender Ansätze zur Ermittlung des Wasserverbrauchs von Produkten und Organisationen (Forin et al. 2018). Anknüpfend an diese Analyse wurde die OWF-Methode basierend auf zwei bestehenden Standards entwickelt. Der Wasser-Fußabdruck (ISO 14046) und organisationsbezogene Ökobilanzierung (UNEP 2015). Eine wissenschaftliche Gegenüberstellung identifizierte sowohl komplementäre als auch widersprüchliche methodische Aspekte beider Standards. Auf Grundlage dieser Analyse wurden methodische Anforderungen an den OWF erarbeitet, welche die Festlegung des Ziels und des Untersuchungsrahmens, die Sachbilanz, die Wirkungsabschätzung und die Auswertung umfassen (Forin et al. 2020a, b). Um Akteuren die OWF-Methode zugänglich zu machen, wurde ein *Practioners‘ Guidance* veröffentlicht, welcher die OWF-Methode klar und prägnant darstellt und in dem jeder Schritt durch ein Fallbeispiel illustriert wird.

Während die meisten Organisationen ein gutes Verständnis ihres direkten Wasserverbrauchs haben, gestaltet sich die Erfassung des indirekten Wasserverbrauchs entlang vorgelagerter Schritte der Wertschöpfungskette häufig als schwierig. Um dieser Problematik entgegenzuwirken, wurde von Thinkstep, basierend auf der GaBi Inventardatenbank, die WELLE-Datenbank mit über 160 Datensätzen entwickelt. Die Datenbank beinhaltet nicht nur Inventardaten zum direkten Wasserverbrauch einer Organisation (bspw. Geschäftsreisen oder den Betrieb einer Kantine), sondern umfasst auch geografisch differenzierte Inventardaten zum Wasserverbrauch der indirekten Aktivitäten einer Organisation wie bspw. Rohstoffabbau oder Energieerzeugung.

Um die Anwendung der Methode und der Datenbank zu erleichtern, wurde das WELLE OWF-Tool entwickelt. Dieses ermöglicht auf Basis des direkten Wasserverbrauchs an Standorten, verwendeter Rohstoffe,

Zwischenprodukte und Energie sowie Geschäftsreisen, der Nutzung von Betriebsgebäuden und anderer Aktivitäten, den OWF online im Webbrowser zu ermitteln.

Die Anwendbarkeit der OWF-Methode wurde von vier Industriepartnern aus verschiedenen Sektoren in Fallstudien demonstriert. Evonik Nutrition & Care GmbH untersuchte zwei Produktionslinien für die chemische und biotechnologische Herstellung von Aminosäuren und deckte einen Hotspot bei einem Zulieferer von Mais in den USA auf. Volkswagen AG ermittelte den OWF für den Produktionsstandort in Uitenhage, Südafrika. Mehr als die Hälfte des Wasser-Fußabdrucks des Werks wurde durch die Produktion von Elastomeren und Stahl-/Eisenkomponenten in verschiedenen Weltregionen verursacht. Der Deutsches Kupferinstitut Berufsverband e.V. führte einen OWF für die gesamte europäische Kupferproduktion durch, welcher maßgeblich durch den Abbau von Kupfererz in Lateinamerika dominiert wurde. Die Neoperl GmbH analysierte OWF des gesamten Unternehmens und identifizierte die eingekauften Materialien Messing und Edelstahl als Verursacher von 74% des OWF.

Neben der Befähigung von Organisationen, ihren OWF zu bestimmen und zu analysieren, war eine weitere zentrale Zielsetzung des WELLE-Forschungsvorhabens, Optionen zur Minderung von Wasserknappheit entlang globaler Wertschöpfungsketten von Organisationen zu identifizieren. Die vier WELLE-Fallstudien und andere Studien haben gezeigt, dass der direkte Wasserverbrauch einer Organisation nur zu weniger als 5% des OWF beiträgt. Aus diesem Grund müssen Minderungsstrategien die gesamte Wertschöpfungskette einer Organisation berücksichtigen. Neben auf den Standort fokussierten Umweltmanagementsystemen (EMAS, ISO 14001) werden *Water Stewardship*, Ökodesign-Ansätze und nachhaltige Beschaffungsstrategien als Gegenmaßnahmen zur Reduzierung eines OWF empfohlen.

Mit der Erstellung eines OWF können Organisationen ihren Wasserverbrauch und die daraus resultierenden Auswirkungen am eigenen Standort und entlang globaler Wertschöpfungsketten ermitteln. Diese Informationen helfen Organisationen Wasserrisiken zu reduzieren und in Einklang mit dem Ziel für nachhaltige Entwicklung 12 (*Nachhaltige/r Konsum und Produktion*) zu einer nachhaltigeren Nutzung der weltweit begrenzten Süßwasserressourcen beizutragen.

Executive Summary

Freshwater is a vital resource for humans and ecosystems but is scarce in many regions around the world. Organizations measure and manage direct water use at their premises but usually neglect the indirect water use associated with global supply chains – even though the latter can be higher by several orders of magnitude.

As of 2015, there was no standardised life-cycle-based approach for analyzing the water consumption of an organization. Against this background, the BMBF funded research project "Water Footprint for Organizations – Local Measures in Global Supply Chains (WELLE)" has been launched by TU Berlin, Evonik, German Copper Institute, Neoperl, thinkstep and Volkswagen. The project aims to support organizations in determining their complete Organizational Water Footprint, identifying local hotspots in global supply chains and taking action to reduce their water use and mitigate water stress at critical basins.

Within the WELLE project a method for analyzing an Organizational Water Footprint has been developed, which analyzes an organization's water use and resulting local impacts throughout its entire value chain. In other words, the Organizational Water Footprint considers not only the direct water use at production facilities, but also the water used indirectly for energy generation and raw material production (upstream in the supply chain) as well as water use during the use and end-of-life phases of products (downstream). Additionally, all aspects of the organization itself are included, such as the water used by the cleaning service, the organization's garden and canteen, etc. As a starting point for the method development, existing methods and approaches for analyzing an organizations water use have been analyzed (Forin et al. 2018). The Organizational Water Footprint method builds on two environmental assessment frameworks which have been identified as suitable for the purpose of this project: Water Footprint (ISO 14046, 2014 and Organizational Life Cycle Assessment (UNEP 2015). A detailed juxtapotation of the two standards was carried out, to identify complimenting as well as conflicting methodological aspects. Based on this analysis, methodological requirements for the organizational water footprint were proposed comprising the goal and scope definition, the inventory analysis, the impact assessment and the interpretation (Forin et al. 2020a, b). To support stakeholders in conducting Organizational Water Footprint studies, a Practitioners' Guidance has been published, which presents the method in a clear and concise way by illustrating each step with a practical example.

While most organizations can monitor their internal activities rather easily, they rely on external data about the water consumption of their indirect upstream activities (e. g. material and energy supply chains). For this reason, the WELLE database has been introduced which provides water consumption data of an organization's indirect activities (material and energy purchase, business trips, canteens, etc.) in a spatially explicit way. Based on thinkstep's Life Cycle Assessment database GaBi 8, ca. 160 datasets are provided.

In order to facilitate the application of the method and the database, a WELLE online tool has been developed which allows for determining an organization's water footprint by entering direct water use data at production sites, purchased goods and energy as well as supporting activities such as business trips or buildings.

In order to test their validity and applicability, the previously developed method, database and online tool have been tested in four case studies conducted by industry partners representing different sectors and scopes. Evonik examined two production lines for the chemical and biotechnological production of amino acids and revealed a hotspot in its corn supply chain in the USA. Volkswagen conducted an organizational water footprint for the production site in Uitenhage, South Africa. More than half of the plant's water footprint has been caused by the production of elastomers and steel/iron components in different world regions. The German Copper Institute conducted a water footprint for the entire European copper production, which was dominated by the mining of copper ore in Latin America. Neoperl analyzed the water footprint of the whole company identifying brass and stainless steel as the two purchased materials which are responsible for 74% of the company's water footprint.

Next to enabling organizations to determine and analyze their water footprints, it was a central goal of the WELLE project to identify options to mitigate water stress at hotspots along organizations' supply chains. The four WELLE case studies and other studies have shown that an organization's direct water consumption contributes to less than 5% of its total water footprint only. For this reason, optimization strategies need to consider an organization's entire value chain. Next to on-site focused environmental management systems (EMAS, ISO 14001), water stewardship measures, ecodesign approaches, and a sustainable procurement strategy are advocated

By analyzing their Water Footprints, organizations can determine water use and resulting local impacts at premises and "beyond the fence" along global supply chains. In this way they can reduce water risks and contribute to a more sustainable use of the world's limited freshwater resources.

Key Results

Reports and Tools

- WELLE Website:

  https://welle.see.tu-berlin.de/

- Organizational Water Footprint Practioners' Guidance:

  https://welle.see.tu-berlin.de/data/OWF_Guide.pdf

- Regionalized water inventory database:

  http://welle.see.tu-berlin.de/data/

- WELLE database documentation:

  http://welle.see.tu-berlin.de/data/WELLE_DB_Documentation.pdf

- Organizational Water Footprint (OWF) online Tool:

  https://wf-tools.see.tu-berlin.de/wf-tools/owf/

Scientific Publications

- Silvia Forin, Markus Berger, and Matthias Finkbeiner. 2018. 'Measuring Water-Related Environmental Impacts of Organizations: Existing Methods and Research Gaps'. *Advanced Sustainable Systems,* 2 (10): 1700157. https://doi.org/10.1002/adsu.201700157.
- Silvia Forin, Natalia Mikosch, Markus Berger, and Matthias Finkbeiner. 2020. 'Organizational Water Footprint: A Methodological Guidance'. *The International Journal of Life Cycle Assessment*, 25: 403–422. https://doi.org/10.1007/s11367-019-01670-2.
- Silvia Forin, Markus Berger, and Matthias Finkbeiner. 2020. 'Comment to "Marginal and Non-Marginal Approaches in Characterization: How Context and Scale Affect the Selection of an Adequate Characterization Factor. The AWARE Model Example"'. *The International Journal of Life Cycle Assessment*, 25: 663–666. https://doi.org/10.1007/s11367-019-01726-3.
- Silvia Forin, Jutta Gossmann, Christoph Weis, Daniel Thylmann, Jonas Bunsen, Markus Berger, and Matthias Finkbeiner. 2020. 'Organizational Water Footprint to Support Decision Making: A Case Study for a German Technological Solutions Provider for the Plumbing Industry'. *Water*, 12(3): 847; https://doi.org/10.3390/w12030847
- Aurélie Wojciechowski, Silvia Forin, Markus Berger, Michael Binder, Matthias Finkbeiner. 2020. 'Combined Organizational and Product Water Scarcity Footprint: a case study on the use of amino acids for chicken production'. submitted.

Additional WELLE project results, publications and other outcomes are in chapter 6 "Communication and Dissemination".

1 Introduction

1.1 Starting point for the project

Freshwater is sustaining life on our planet but is under increasing pressure due to population growth, increased water consumption and pollution as well as climate change. Facing freshwater scarcity is one of the major challenges of the 21st century and included in the Sustainable Development Goals as a fundamental target of the international community (UN 2015). Also, the World Economic Forum has been highlighting the "water crisis" as one of the top global risks for many years (WEF 2020a).

Water resources are unevenly distributed across the globe, which makes water scarcity a local problem at many places around the world. At the same time, international trade is expanding, and supply chains have an increasingly transnational character. Water that is used in basins subjected to scarcity, often located in the Global South, is integrated in production processes of industrialized countries (Lenzen et al. 2013; Tukker et al. 2014). Thus, a sustainable use of the world's limited freshwater resources is a global responsibility.

It should be noted that the term water use denotes the total freshwater input into an organization. Water consumption (consumptive use) is the fraction of water use which is not returning to the originating river basin due to mainly evaporation and transpiration as well as product integration and discharge into other basins or the sea. Water pollution (degradative use) describes a use of water which reduces water quality.

So far, most organizations only measure water use of their own facilities by means of environmental management systems or other internal accounting methods. These approaches, though giving an overview concerning on-site water demand and potential reduction measures at the facility's location, do not account for the whole sphere of influence of an organization on the world's freshwater resources. Water footprint studies of industrial products have revealed that water use at production sites is usually the tip of the iceberg only. The largest part of a product's water use and resulting impacts often occur in supply chains, e. g. in the production of agricultural goods, the mining of mineral resources, or the generation of fossil-based electricity (Berger et al. 2012, 2017; Forin et al. 2019a).

1.2 Aim and Objectives

The aim of this research project was therefore, to develop methodological and practical solutions for determining the water footprint of organizations and, thus, to consider not only direct water use at the production site but also indirect water uses in the energy and material supply chains. Based on the results, opportunities to take actions at local hotspots in global supply chains shall be identified and validated. Typically, an organization is broadly defined as an entity which pursues a specific goal or activity such as producing goods or providing services, for example, organizations, public authorities, NGOs, etc.

In order to achieve the overall aim, the following scientific/technical work objectives were pursued. The concrete work steps for achieving these sub-goals are described in chapter 3.

1) **Development of a method for the water footprint of organizations based on the product water footprint and the organisational life cycle assessment:** By combining the product water footprint and the organizational life cycle assessment, a method was developed which allows to investigate the direct and indirect water consumption of an organization and to show potential local consequences (see WP1) Development of a method for assessing an organizational water footprint).
2) **Providing a geographically explicit water inventory database:** In order to be able to estimate the local consequences of water consumption, information about the place of water consumption is essential. However, especially in the case of indirect water consumption in the energy and material supply chains, such information is often not available. In order to close this crucial information gap, a method for providing geographically explicit water inventory data was developed and a database made available (see WP2) Geographically explicit water inventory database).

3) **Linking the method and database in a water footprint tool:** In order to support the application of the organisational water footprint, an online software tool was developed that links the method and the database (see WP3) Water Footprint Tool).
4) **Creation of the water footprint for case studies of the industrial partners:** In order to test the applicability and informative value, the method of the organizational water footprint, the database and the tool were tested in case studies of the industrial partners (see WP4) Water Footprint Case Studies). In addition to the practical test of the developed method and database, the water footprint studies also served to make the supply chains of the industrial partners more transparent, to strengthen cooperation with suppliers and to uncover optimization potential.
5) **Detailed analysis of the local water risk of relevant sites and suppliers:** After the Water Footprint case studies have identified local hotspots, the concrete existing water risk at the site of water abstraction should be analysed (see WP5) Analysis of local water risk).
6) **Water use mitigation measures in cooperation with local stakeholders:** Concrete water use mitigation measures were initiated to improve the local water use situation (see WP5) Analysis of local water risk).

1.3 WELLE within the GRoW funding measure

The research project presented in this project outline is closely related to the funding policy objectives of the funding directive "Global Resource Water" (FONA-GRoW 2015) and the underlying framework program FONA3 (BMBF 2015). In this consortium, the TU Berlin and several organizations of different sizes and from different sectors have joined efforts to develop solutions to a problem that has long been relevant to them. This not only emphasizes the intended collaborative character of the consortium, but also fully complies with the change in research policy perspective required by FONA, from a promotion of supply to a promotion of demand. By developing a method for analyzing and reducing the water footprint of organizations in their global energy and material supply chains, the project is in line with the research and innovation policy goals of "using resources intelligently and carefully" and "assuming international responsibility". Within FONA, there are many similarities with the objectives set out in the Green Economy Flagship Initiative, such as the "provision of decision-making knowledge". This can be seen especially in the Water Footprint Tool to be created to support concrete business decisions. Especially in the field of raw materials, water and land, the project complies with the principle "to achieve a careful use of finite resources in production [...]" by "considering complete value chains and networks as well as product life cycles". With regard to the funding measure GROW, the project serves the objective of "improved and forward-looking management of water resources". The project objective of developing a method for determining the water footprint of organizations and, if necessary, initiating local measures in global value chains, corresponds in a special way to the overarching principle of "linking local and global action". The project goal of reducing the water footprint of organizations in water-scarce regions and minimizing local consequences for human health and ecosystems supports the achievement of five UN sustainability goals: „Responsible Consumption & Production“, „Clean Water and Sanitation“, „Zero Hunger“, „Life on Land“ and „Life Below Water“ (UN 2015). Within the funding measure, the project is particularly focused on the topic "Global Water Demand" and corresponds exactly to the objective of "Describing the effects of production processes on water systems (water footprint) and the associated risks".

1.4 Project partners

In the research project WELLE "The Water Footprint of Companies: Local Measures in Global Supply Chains", a research institution (TU Berlin), two corporations (Volkswagen and Evonik), a medium-sized company (Neoperl), an industry association (German Copper Institute) and a Life Cycle Assessment database provider (Thinkstep) have joined forces to form a consortium (Table 1). The aim of the consortium was to combine the methodological competence of the TU Berlin, the practical experience of the industry partners and the expertise on inventory databases of Thinkstep to develop a method for organizational water footprint and to implement local improvement measures at hotspots in the global supply chains of the organizations.

The development of a method for determining the water footprint of organizations (WP1.1) was led by the TU Berlin due to the methodological preliminary work on the water footprint and the organisation-related life cycle assessment. The industrial partners contributed their requirements for such a method (WP1.2). As the world's largest provider of inventory databases, Thinkstep was leading WP 2, in which a database for water use in energy and material supply chains was developed in cooperation with the TU Berlin (WP2.1). Furthermore, Thinkstep provided a geographically explicit water inventory database (WP2.2) which is freely accessible. The linking of the method and database in an online Water Footprint Tool (WP3) was pursued by the TU Berlin and Thinkstep. In WP4, each of the 4 industrial partners, with the support of the TU Berlin, conducted an Organizational Water Footprint e.g. for a production site (Volkswagen), two production lines (Evonik), a company (Neoperl) or an industrial sector (German Copper Institute). For the identified hotspots, the TU Berlin, in cooperation with the organizations, carried out an analysis of the locally prevailing water risks (WP5). Based on these results, the organizations, with the support of the TU Berlin and external local partners, examined options to improve the local situation in the river basins by means of mitigation approaches (WP6). Finally, the experiences from the project were summarised by the TU Berlin to provide recommendations for linking the water footprint and Water Stewardship (WP7.1). The industrial partners provided sector-specific recommendations for the implementation of similar projects in their industrial sectors (WP7.2).

Table 1: Brief description of the partners in the research project "Water Footprint for Companies- Local Measures in Global Value Chains"

Technische Universität Berlin	The Department of Sustainable Engineering at the TU Berlin teaches and conducts research on the implementation of the concept of sustainability in day-to-day industrial practice. With regard to the sustainable use of the resource water, the TU Berlin has already conducted more than ten water footprint case studies for industrial partners. In addition, the department has developed methods to analyse the local consequences of water consumption in global value chains. These results are implemented in international working groups of UNEP. Moreover, Prof. Dr. Finkbeiner is chairman of the ISO-Committee TC207/SC5, which developed the international standard on the water footprint (ISO 14046 2014).
Volkswagen AG	The Volkswagen Group, headquartered in Wolfsburg, is one of the leading automobile manufacturers worldwide and the largest automobile producer in Europe. In a study carried out together with the Technical University of Berlin, the water consumption and local consequences along the product life cycle of cars (Polo, Golf, Passat) were investigated. Based on this study, which was the world's first water footprint analysis of a complex technical product, a Water Footprint Tool was developed, with the help of which the water footprint of all VW vehicle models can be approximated.
Evonik AG	Evonik is a global leader in specialty chemicals with three operational segments "Nutrition & Care", "Resource Efficiency" and "Performance Materials" as well as the service segment "Technology & Infrastructure". Evonik focuses on high-growth megatrends-especially health, nutrition, resource efficiency and globalization. The Nutrition & Care segment produces mainly for applications in consumer goods for everyday use, animal nutrition and health; areas in which water is particularly relevant. Evonik has developed methods for measuring resource efficiency (including water efficiency) in cooperation with TU Berlin in a BMBF-funded project (r^3 - ESSENZ).
Neoperl GmbH	Neoperl GmbH offers innovative solutions for the sanitation industry. Neoperl products shape the water jet, regulate the flow rate and protect water from contamination. In

	cooperation with the Technical University of Berlin, Neoperl has investigated the water footprint of a flow regulator and compared the water consumption during production with the water savings during usage.
German Copper Alliance (Deutsches Kupferinstitut Berufsverband e.V.)	The German Copper Institute is the most important technical and scientific advisory centre in Germany for all questions concerning the application of copper and its alloys. It is in charge of the competence centre for life cycle analyses for copper and copper materials and therefore has an extensive inventory database for the mining, refining and processing of copper. In two research projects with the Technical University of Berlin, the water consumption in copper mines, copper refining and semi-finished product production was investigated and its local consequences assessed.
Thinkstep	Thinkstep AG is a consulting firm and a software and database provider that is active in 19 countries and has supported more than 2,000 companies in achieving their sustainability goals. As the provider of the world's leading GaBi LCA inventory database, Thinkstep is currently working to provide geographically explicit water data for its inventory records to enable analysis of the water footprint in industrial applications. For this purpose, an exchange with the TU Berlin has already taken place to achieve this goal.

2 State of scientific and technical knowledge

In the following, the state of scientific and technical knowledge at the beginning of the project regarding water footprint and organizational Life Cycle Assessment is presented (chapter 0).

2.1 Water Footprint

Two billion people live in countries experiencing high water stress, and more than four billion lack access to basic sanitation (UN Water 2019). The "water crisis" is constantly ranked among the top 5 global risks reported by the World Economic Forum in its annual global risk reports (WEF 2020b). The link between the global water crisis and our production and consumption of water intense products has been made transparent by concepts like "Virtual Water". This concept denotes the volumes of water used in the production of goods and services, differentiating the consumption of ground and surface water (blue water), soil moisture (green water), and the pollution of freshwater (gray water). By revealing surprisingly high volumes, like 140 liters per cup of coffee (Chapagain and Hoekstra 2007), up to 15,500 liters per kilogram of beef (Hoekstra and Chapagain 2007) or 2,700 liters per cotton T-shirt (Chapagain et al. 2006), consumers have been made aware of the high "water footprints" (WF) of daily goods. Despite the relevance of global freshwater appropriation figures for awareness raising and analyzes of virtual water trade via imports and exports of products, such volumetric approaches have been criticized for the lack of environmental and socio-economic meaning (Ridoutt and Huang 2012). For instance, the local consequences of consuming 1 m^3 of rainwater in Sweden do not compare to those resulting from the consumption of 1 m^3 of groundwater in Egypt.

In order to add this local component to the WF concept, methods assessing local consequences resulting from water use have been developed within the scope of life cycle assessment (Berger and Finkbeiner 2010). Some of those impact assessment methods estimate the local consequences of water consumption based on freshwater scarcity (Pfister et al. 2009a; Boulay et al. 2017; Berger et al. 2018). Other methods allow to assess the effects of water consumption on:

- human health and well-being (due to malnutrition (Pfister et al. 2009a; Boulay et al. 2011a; Motoshita et al. 2018) or infectious diseases (Boulay et al. 2011a; Motoshita et al. 2011a)
- ecosystems (terrestrial (Pfister et al. 2009a; van Zelm et al. 2011; Lathuillière et al. 2016), aquatic (Hanafiah et al. 2011a; Damiani et al. 2018), coastal (Amores et al. 2013), wetlands (Verones et al. 2013), urban (Nouri et al. 2019)
- freshwater resources (Mila i Canals et al. 2008; Pfister et al. 2009a; Pradinaud et al. 2019)

The scientific advancement of the WF concept and relevance of global freshwater use has led to the development of an international WF standard which specifies principles, requirements and guidelines related to WF analyses of products, processes and organizations (ISO 14046 2014).

In order to present the state of the art which is relevant for the project, impact assessment methods from the life cycle assessment, inventory databases, tools for determining the Water Footprint and the international standard on the Water Footprint (ISO 14046 2014) are presented below. An overview of concepts, standards, tools, databases and data sets as well as impact assessment methods concerning the Waterfootprint is also available via https://wf-tools.see.tu-berlin.de/wf-tools/waterfootprint-toolbox/.

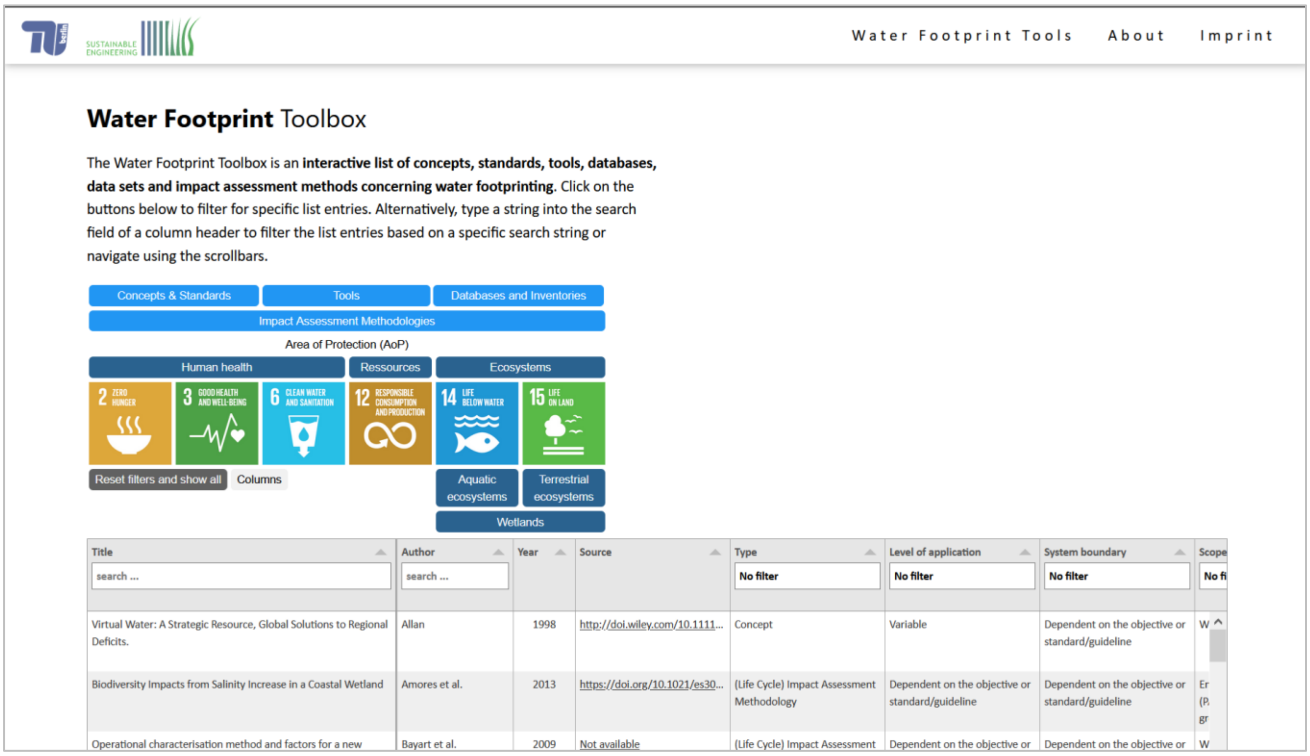

Figure 1: Water footprint methods, databases and tools (https://wf-tools.see.tu-berlin.de/wf-tools/waterfootprint-toolbox/).

2.1.1 Impact assessment methods

Impact assessment models are used to describe the local effects of water consumption. The basis of most generic models (Pfister et al. 2009b; Boulay et al. 2011b; Berger et al. 2014) is a scarcity ratio of local water consumption to local water availability. This indicates the proportion of renewable water resources consumed locally.

In addition to the generic models, there are also numerous specific impact assessment methods that can be used to determine the local impacts of water consumption on the three protected areas "Human health", "ecosystem quality" and "resources" are described by Kounina et al. (2013). The cause-effect chain on human health is currently described by several impact assessment models. On the one hand, health damage caused by malnutrition due to agricultural water scarcity is modelled (Motoshita et al. 2008, 2014; Pfister et al. 2009b; Boulay et al. 2011b). Furthermore, infectious diseases caused by insufficient fresh water quality as a consequence of water consumption have been modelled on a global scale (Motoshita et al. 2011b, 2014; Boulay et al. 2011b).

The impact pathways from water consumption to ecosystem quality are more complicated and the objectives and approaches to determining potential damage are hence more diverse. For terrestrial ecosystems, the potential extinction rate of soil plants, representative of reduced plant growth due to global water consumption, is used as an indicator (Pfister et al. 2009b). More precise impact paths from water consumption to terrestrial species loss were modelled from the relationship between species loss and groundwater levels changing due to water consumption (Zelm et al. 2011). For aquatic ecosystems, Hanafiah et al. (2011b) modelled the effects of reduced river runoff on fish species.

The potential damage to resources has already been described taking into account various aspects. Dewulf et al. (2007) consider the decrease of the cumulative exergy of water resources as potential resource damage resulting from water consumption. On the other hand, the energy demand for water desalination is also attributed to water consumption as potential damage in order to compensate for the scarcity of the resource water resulting from the concept of "backup technology" (Pfister et al. 2009b).

The aim of the above-mentioned methods is to describe the local consequences resulting from water consumption and water scarcity. Established impact assessment models are available to determine the effects caused by water pollution (such as eutrophication, aquatic acidification, chemical toxicity, etc.) e.g. Guinée (2002).

While the methodological diversity of impact assessment models is to be welcomed from a scientific point of view, it poses great challenges for the user. For one thing, the choice of a suitable impact assessment method is not always clear. On the other hand, different methods can also produce different results, as they depict different cause-effect chains. For this reason, an international and interdisciplinary working group of the United Nations Environment Programme (Water Use in LCA - WULCA), of which TU Berlin has been a member since 2010, has developed a consensus model that is recommended for the preparation of water footprints.

This consensus model is abbreviated as AWaRe (Available Water Remaining) and quantifies the relative amount of water still available per area of a water catchment area after human needs and those of the aquatic ecosystem have been met (Boulay et al. 2018). For this purpose, the available water quantity is first calculated and the demand (human and aquatic ecosystem) is subtracted from it. The result is given relative to the area (m^3 m^{-2} $month^{-1}$) and thus represents a virtual area that is necessary to cover the additional water consumption sustainably. In the second step, the value is normalized and inverted with the global average, resulting in a relative value that refers to the average m^3 of water consumed in the world (the global average is a mean value weighted according to consumption). The indicator can range from 0.1 to 1000, where the value 1 corresponds to the global average and, for example, a value of 100 stands for a region where a 100 times smaller amount of remaining water per area is available than the global average. The indicator is calculated at the sub river basin level in monthly resolution and can be aggregated to country and/or annual averages if necessary.

This method quantifies the potential freshwater shortage, both for humans and ecosystems, and is used to calculate a water availability footprint according to (ISO 14046 2014). Characterization factors are available for download on the project homepage: http://www.wulca-waterlca.org/project.html.

2.1.2 Inventory databases

In addition to the water footprint methods discussed above, numerous databases are available for determining the water consumption of various products and materials. The databases can be divided into typical LCA databases, such as GaBi (Thinkstep 2016) and Ecoinvent (Wernet et al. 2016), into sector and country specific databases (Pfister et al. 2011; Ono et al. 2012; OECD and FAO 2013) and into explicit water footprint databases, such as the Quantis Water Database (Vionnet et al. 2012) or the WaterStat database (WFN 2016a). Also, various multi-regional input-output databases contain environmental extensions which pertain water e.g. Eora, Exiobase, World MRIO.

Tools for creating water footprints and for water risk analysis In addition, there are several tools, such as the Global Water Tool (WBCSD 2013), the Local Water Tool (GEMI 2013a), the Water Footprint Assessment Tool (WFN 2016b), Collecting the Drops (GEMI 2013b), Connecting the Drops (GEMI 2013c), the Corporate Water Gauge (CSO 2013) and the Water Risk Filter (WWF 2016), which support organizations in calculating (direct) water consumption and in determining environmental, operational, legal and reputational risks.

2.1.3 ISO standard

The international community recently completed the international standard for the calculation of the water footprint (ISO 14046 2014). With the aim of ensuring transparency, consistency and credibility in the determination and reporting of the water footprint, the standard for the calculation of the water footprint contains principles, requirements and guidelines. After a consistent terminology has been established and the actual principles have been described, the methodological framework is presented and guidelines for reporting and critical review are given.

Analogous to the structure of life cycle assessments (ISO 14044 2006), the procedure for determining the water footprint also includes the definition of the goal and the scope of investigation, the life cycle inventory, the impact assessment and the evaluation of the results. The standard explicitly defines the water footprint as an impact-based indicator. In contrast to the definition of Hoekstra and colleagues (Hoekstra et al. 2011), a purely volumetric water inventory may be specified but not called a "water footprint". Also, the determination of the water footprint can be done independently or be part of a life cycle assessment with other environmentally relevant indicators. The determination of the water footprint always includes a complete investigation of water availability and water pollution. If only individual aspects of this comprehensive study are considered, this should be indicated in the title of the study. For example, a "Water Availability Footprint" would only consider the volume of water consumed and the resulting environmental impacts. In contrast, a "water eutrophication footprint" would examine the environmental impacts of eutrophication caused by water pollution and would not take into account the volume of water consumed.

Instead of recommending a specific method for life cycle inventory and impact assessment, the standard defines criteria that must be met for an ISO-compliant water footprint. For example, elementary flows should contain information on the corresponding quantity, type of water body, water quality, type of water use, geographical location, time and emissions. In the impact assessment, the water availability footprint should be determined using impact assessment models that indicate the contribution of a product to the pressure on water reserves. Similarly, the water footprint should determine the effects of water pollution using impact assessment models that take into account the contribution of a product to the respective environmental problem (eutrophication, acidification, etc.). Ideally, a water footprint profile should be determined that includes several impact categories to determine the effects on water availability and water pollution

2.2 Organizational Life Cycle Assessment

2.2.1 Background

The Organizational Life Cycle Assessment (OLCA) method is used to assess the environmental impacts of organizations, such as companies, public institutions and non-governmental organizations (NGOs) or parts thereof (Martínez Blanco et al. 2015). OLCA was the first time that the life cycle approach has been applied to the assessment of organisations. This was a novelty, as until a few years ago only products were assessed along their entire life cycle (i.e. from raw material extraction to disposal). In the case of organizations, this is operationalised by considering the entire value chain, i.e. the environmental impacts of suppliers, services and personnel are included. Downstream activities such as the use and end-of-life phase of the organisation's products or services are also included in the assessment. The concept of "life cycle responsibility" underlies the consideration of the entire value chain. This refers to the possibility of designing products in such a way that the use and end-of-life phases are more environmentally friendly. In addition, (especially large) organizations can introduce sustainability criteria and requirements for the selection of their suppliers and thus influence the production process outside the factory gates.

2.2.2 Methodological characteristics

The method is essentially based on the product-related life cycle assessment (ISO 14044 2006). Specific adaptations for organisations exist for the functional unit, which is split into a qualitative and a quantitative element. This is because the object of the study, often an organisational unit or division of an international organization, must first be carefully qualitatively delimited due to its complexity (consolidation method). In the life cycle inventory, a distinction is made between various activities that take place inside or outside the organization (direct and indirect activities). This distinction is particularly important in data collection, because access to the data is easier for internal activities. However, the data quality requirements are also higher for direct activities. The indirect activities are also divided into upstream and downstream activities, as the examples in Figure 2 illustrate.

Even though the product-related approach is the starting point for the organisational life cycle assessment, it goes beyond a mere sum of the LCA results of different products. This is mainly due to the fact that supporting activities such as management or capital goods, internal organization canteens, organization outings and business trips are also considered. The holistic view of the organization also makes it possible to carry out a top-down analysis with organization-wide data, even if detailed data on individual products or processes is missing.

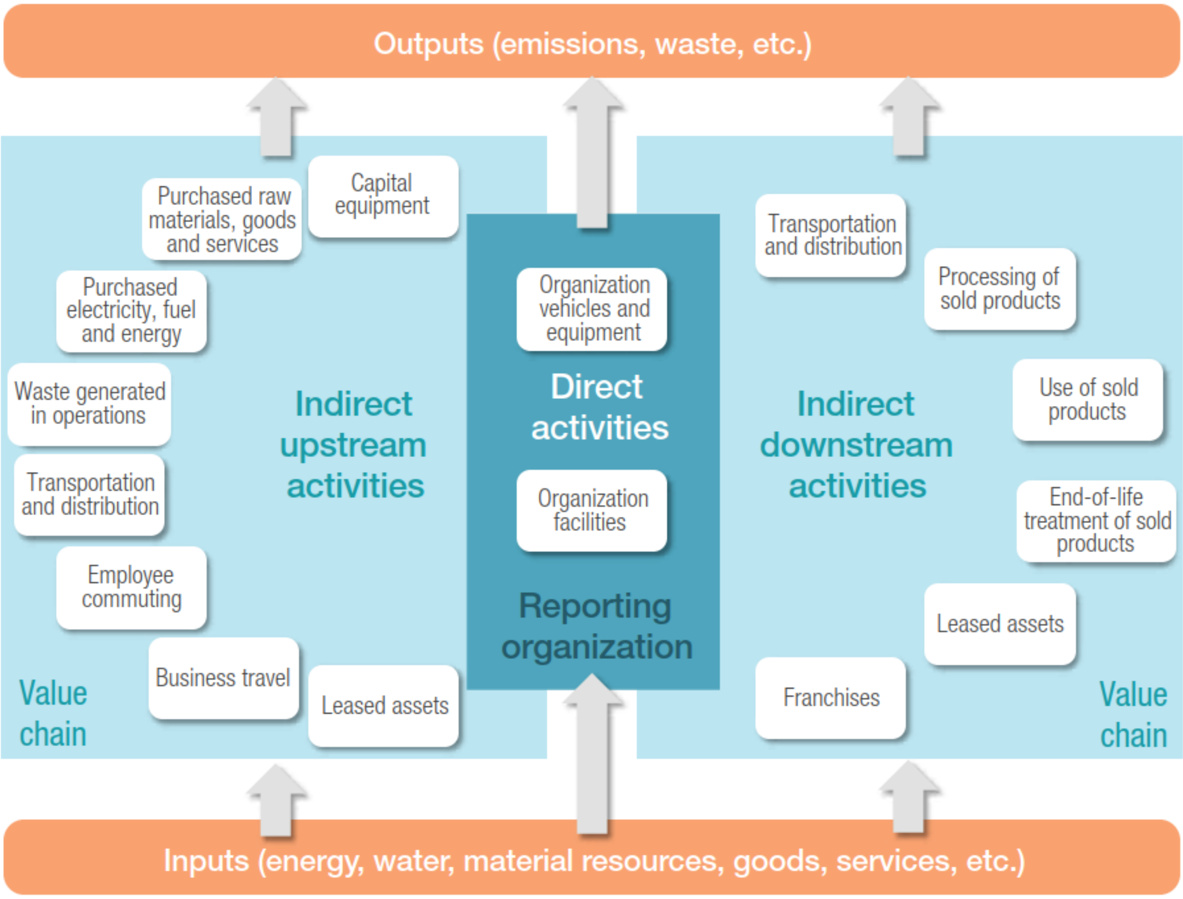

Figure 2: Examples of direct and indirect activities within the organization and along the value chain (Martínez Blanco et al. 2015).

2.2.3 Advantages and Applications

Overall, conducting an OLCA study offers various advantages for the organisation. From an analytical perspective, insights into the value chain can be gained and data collected. Hotspots are identified and the organization's environmental performance is measured. These insights support strategic decisions, provide the basis for environmental communication and can also be used for marketing purposes. The focus on organizations is also advantageous from a strategic point of view because decisions on the procurement of raw materials and intermediate products (with regard to suppliers and regional origin) as well as technical measures to reduce water consumption are not taken at a product level but at an organization level. In particular, globally active organizations with a global value chain have a considerable influence in shaping their environmental policy. An OLCA study is often conducted in conjunction with existing data and evaluations. Existing data from site-related environmental management systems, such as EMAS, can be extended to include activities beyond the factory gates; product-related life cycle assessments can form the basis for a bottom-up view of the overall portfolio through representative products; individual aspect assessments can be extended to include other indicators.

2.2.4 Current Developments

The methodological development for organisational life cycle assessments is an ongoing process. Some of the most notabe publications and guidelines are the ISO Technical Specification (ISO/TS 2014), the UNEP/SETAC "Guidance on Organizational Life Cycle Assessment" (Martínez Blanco et al. 2015), the Organizational Environmental Footprint (OEF) Guide of the European Commission (European Commission 2013), Challenges of organizational LCA (Martínez-Blanco et al. 2019), Facts and figutes from road testing the organizational life cycle assessment (Forin et al. 2019) or Life Cycle Assessment of Organizations (Martinez-Blanco et al. 2017).

The main differences between these concepts are the more prescriptive character of the OEF approach, while the UNEP/SETAC guide focuses on the flexibility of the method. While the focus on comparisons is a core aspect of the OEF, according to ISO this is excluded in case of publication. The UNEP/SETAC Life Cycle Initiative is also linked to the first pilot studies. Among the users are organizations, NGOs and public authorities, local and global actors from different continents and sectors: AKG Gazbeton (Turkey), Banco de México (Mexico), Foundation Emmaüs (France), Junk That Funk (Canada), Mahindra Sanyo Special Steel (India), Maschio Gaspardo (Italy), Natura Cosméticos (Brazil), Thanakorn Vegetable Oil Products (Thailand) As a result of the pilot phase, recommendations for action from the guide will be reviewed and, if necessary, adapted to the experiences and needs of users, remaining challenges will be identified and lessons for future OLCA applications will be drawn.

Mostly, only ecological aspects have been considered in organisational life cycle assessments. With regard to the focus on sustainability, which is increasingly demanded by society, it is however necessary to include other dimensions of sustainability. A first groundbreaking development in this direction is the SOLCA approach, a life cycle-based consideration of social aspects within an organisation (Martínez Blanco et al. 2015).

3 Work plan and methodology

In order to achieve the scientific and technical work objectives mentioned in chapter 1.4, seven content-related work packages were defined. First, a method for the water footprint of organizations (WP1) and a database necessary for practical application (WP2) was created. Both components were integrated into an online tool (WP3), to support organizations in the analysis of their water footprint. The industrial partners represented in the consortium tested the online tool and the underlying method/database by conducting a relevant case study (WP4). The knowledge gained from the case study was used to improve the method, database and tool. In addition, the locally existing water risk was determined for the water consumption identified as relevant in the energy and material supply chains (WP5). For the hotspots identified, a water stewardship (water stress mitigation) process was initiated for each case study to mitigate water use at hotspots (WP6). This involved recommendations for a local Water Stewardship approach, ecodesign, sustainable procurement or a combination of the afore-mentioned. In addition to the content of the work packages, an organisational work package was defined, which includes project management and coordinates the exploitation of the results (WP8; not displayed).

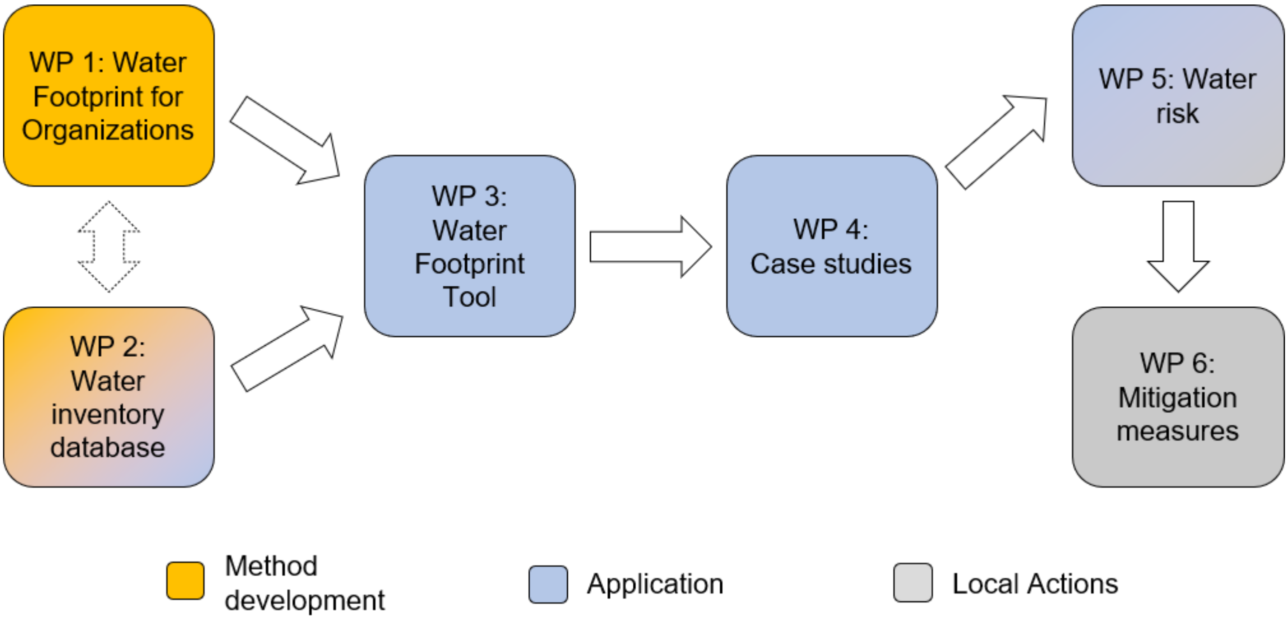

Figure 3: Content structure of the research project

3.1 WP1) Development of a method for assessing an organizational water footprint

This work package consisted of the conception of a water footprint method for organizations. Organizational water footprints offer the possibility to analyse not only the direct water consumption at the production site (Scope 1) but also the indirect water uses in the energy (Scope 2) and material supply chains (Scope 3) and their potential consequences. In addition to considering water consumption in upstream energy and material supply chains, the organizational water footprint should also consider the downstream life cycle phases of the products produced by an organization (cradle-to-grave). For example, an organizational water footprint of a washing machine manufacturer should also consider the water consumption during the use of the appliances. In contrast to product-related water footprints, the absolute impact of an organization on global water resources can be analyzed. In addition, the relevance of otherwise neglected organization infrastructure (buildings and facilities, cleaning, canteens, etc.) can be determined. Furthermore, organizational water footprints enable a significance analysis of individual organization divisions, suppliers and individual product lines. The focus on organizations is also advantageous from a strategic point of view because decisions on the procurement of raw materials and intermediate products (with regard to suppliers and regional origin) as well as technical measures to reduce water consumption are not taken at product level but at an organizational level. In particular, globally active organizations with a global value chain have a considerable influence in shaping their environmental policy. In this respect, the use of the organisational life cycle assessment method plays an important role, as this was, among other aspects, designed for communication with stakeholder.

As a starting point, a review of methods and tools for analyzing an organization's water use was conducted to identify the strength and weaknesses of existing approaches using a criteria-based evaluation scheme (system boundaries, transparency, scientific robustness, etc.). For the development of the organizational water footprint, the methodological specifications of the product water footprint and the organizational life cycle assessment were analysed in detail to identify complementary as well as conflicting methodological elements. The organizational water footprint method was developed by combining the strength of the two approaches. In addition to the methodological focus of this work package, the industrial partners were also involved in the method development to ensure the applicability and relevance of the method from the organizations' point of view. Finally, a Practitioner's Guidance was developed to support organizations in applying the OWF method.

3.2 WP2) Geographically explicit water inventory database

Today, the biggest hurdle for the application of the water footprint is the lack of regionalized inventory data, which are indispensable for an assessment of local consequences. For this reason, the TU Berlin in cooperation with Volkswagen has developed a top-down regionalisation approach (Berger et al. 2012). As shown in Figure 4 using plastics as an example, the total water consumption of a material can be broken down into the water consumption of the individual stages of the value chain (here oil production, refining, polymerisation, component manufacture) with the help of inventory databases. Based on the mix of importing countries and the supplier structure, the water consumption of the value-added stages is now allocated to the individual countries of origin.

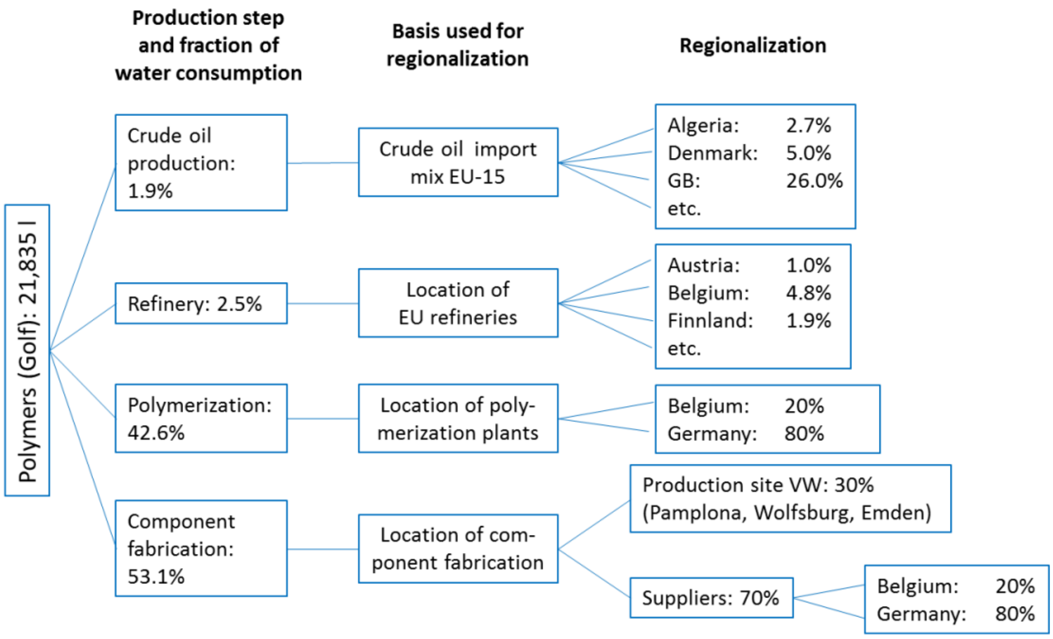

Figure 4: Top-down regionalisation of water consumption for plastics using the example of a VW Golf (aggregated presentation-actually divided into individual groups of plastics)

However, this procedure for the preparation of geographically explicit water inventories involves the assumption that the water consumption of a value-added stage (e.g. refinery) is the same in all participating countries. Despite this limitation, the procedure is used in many case studies, as it is currently the only way to create the geographically explicit water inventories that are indispensable for water footprint studies.

Parallel to the TU Berlin's top-down approach, database provider Thinkstep followed a bottom-up approach in which the geographical origin of water consumption was taken into account directly when creating a data set.

3.2.1 WP2.1) Further development and automation of the bottom-up regionalisation approach

Starting point for developing water inventories with a bottom-up approach was the GaBi Life Cycle Inventory database. The database contains over 10.000 life cycle inventories of various products across many sectors. The data sets include information about water use and water consumption, but in the past, these inventory flows were not referring to specific regions. The bottom-up approach required an allocation of such generic inventory flows to their specific location. However, such a "regionalisation" according to the bottom-up approach is labour-intensive and increases the number of data points in the GaBi database. Instead of about ten inventory flows (groundwater, surface water, etc.) hundreds of inventory flows (groundwater from Chile, surface water from South Africa, etc.) had be collected and managed. Thinkstep has already implemented the regionalization of water inventory data in the GaBi database for the water consumption hotspots renewable resources and energy production using a bottom-up approach (usually accounting for 70-80% of water consumption in GaBi data sets). Within this project, the GaBi database was investigated for which other data sets a regionalisation of the water inventory data is possible using the bottom-up approach. These were for example, well-documented processes with clear regional references, specific data sets from industry associations, or water inventory data sets without complex background systems, such as oil or ore production. In comparison to the top-down approach, the bottom-up approach is the more precise method for regionalisation of inventory data, as country specific inventories are maintained, accounting for country specific water consumption intensity.

3.2.2 WP2.2) Linking the bottom-up and the top-down approach to an integrated regionalisation method

The bottom-up approach was preferred if the structure of the datasets and the confidentiality of data allowed it. In some cases, following this approach was not possible, either because the underlaying country and industry specific data is confidential, or did not cover the most important production regions. In these cases, an average water consumption is derived from the available data and then mapped to different countries according to production statistics ("top-down" approach).

In an intensive cooperation between Thinkstep and the TU Berlin, the bottom-up and top-down approach were therefore combined to an integrated method for the regionalization of inventory data. As far as possible, water inventory data in data sets with complex background systems were regionalized using the bottom-up approach. Data gaps were then filled using the top-down regionalisation method. The part of the water inventory data that could not be regionalised directly due to missing data was regionalised retrospectively based on research on supplier structure and organization locations. The method developed by the TU Berlin and adapted in various industries was adapted and specified for the respective data gap.

3.2.3 WP2.3) Provision of geographically explicit water inventory data sets

Based on the integrated regionalization approach and the GaBi database comprising more than 10,000 data sets, a geographically explicit water inventory database was generated. It contains some material and process data sets relevant for the industrial partners, which can be used for the case studies (WP 4).

3.3 WP3) Water Footprint Tool

After developing the method for the organizational water footprint WP1 and the required water inventory database (WP2) a user-friendly online tool was developed with an external IT service provider to support the application of the organizational water footprint by e.g. companies.

3.4 WP4) Water Footprint Case Studies

The organizational water footprint method (WP1), the database (WP2) and the Water Footprint online tool (WP3) were applied in one case study per industrial partner. Since the industry partners covered different sectors and since, international corporations (Volkswagen and Evonik) as well as an industry association (German Copper Institute) and a medium-sized company (Neoperl), are represented in the consortium, a broad applicability and acceptance was ensured. The previously developed approaches WP 1-3 were refined based on the knowledge gained throughout the project. As a concrete result, the direct and indirect water consumption of the organizations was determined, the local consequences were estimated and thus hotspots in the global value chains were identified.

As shown in WP1, the object of investigation of the organizational water footprint can be an entire organization, a division, a production site, a product line or even an entire industry. For this reason, the case studies were selected to cover the widest possible range of applications.

As described in the following, Evonik examined two production lines for the chemical and biotechnological production of amino acids. Volkswagen conducted an organizational water footprint for the production site in Uitenhage, South Africa. The German Copper Institute prepared a water footprint for the entire European copper production and Neoperl analyzed the water footprint of the entire company.

3.4.1 WP4.1) Evonik: Water footprint of a chemical and biotechnological production line for amino acids

Evonik analyzed and compared the water footprint of two production lines for the chemical and biotechnological production of amino acids within the Nutrition & Care segment. For the chemical synthesis, the product MetAMINO® was selected, which is produced at Evonik's Antwerp site (Belgium). For the biotechnological route the product Biolys® was chosen, which is produced at the Blair site (Nebraska, USA).

In addition to the water consumption at the production site (Scope 1), the water consumption in the cultivation of renewable raw materials (Scope 3) plays an important role, especially in the biotechnological production line. In the case of Biolys®, it is corn from which dextrose is obtained, which is then processed further by fermentation to amino acids. Since the corn also originates from the Blair region in Nebraska, and corn processing is also carried out by a supplier in the immediate vicinity of the Evonik plant, all process steps relevant from a water footprint perspective are carried out in one region. Furthermore, the required data was available and there was good contact with suppliers to analyze the supply chains in more detail.

In addition to the water footprint of the production of Biolys® and MetAMINO®, the water savings resulting from the application of the products were also included in the assessment. Without amino acids in the feed, the crude protein content must be significantly higher to compensate for the amino acid deficits. The use of Biolys® and MetAMINO® therefore saves feed and, thus, also water needed for its cultivation. With a high crude protein content, the animals would also have to drink more water in order to excrete excess nitrogen through the urine. Since excess carbon is easily consumed which leads to an increase in body temperature, the animals would also have to drink more to regulate the temperature.

In addition to the case study presented here as part of this research project, Evonik has agreed to conduct three additional water footprint studies for the production lines of the following amino acids (These case studies were financed from own resources without support from FONA-GROW):

- ThreAMINO®: Production site Kaba, Hungary
- TrypAMINO®: Slovenská L'upca, Slovakia
- ValAMINO®: Slovenská L'upca, Slovakia

3.4.2 WP4.2) Volkswagen: Wasserfußabdruck des Produktionsstandortes Uitenhage, Südafrika

Within the scope of the WELLE research project, Volkswagen assessed the organizational water footprint of Volkswagen's production plant in Uitenhage, South Africa. With approximately 4,000 employees (effective 2016), Volkswagen's automobile production plant in Uitenhage is the biggest automobile production plant in Africa. The product portfolio comprises the Volkswagen Polo as well as engines that are used in the Polos manufactured in Uitenhage but also in other Volkswagen automobile production plants.

In addition to the direct on-site water consumption (scope 1), the water consumption necessary for the on-site energy provision (scope 2) as well as the water consumption in material and component production along the supply chain and in the use phase of the plant's products (scope 3) were to be analyzed. In the next step, potential local consequences were to be examined in order to determine hotspots in the supply chains.

For several reasons, the Uitenhage plant appeared particularly suited for an organizational water footprint case study:

- The Uitenhage plant is located in a predominantly water-scarce country.
- The data availability for on-site energy and water consumption had been examined in advance and had been considered to be of high quality.
- The required data was accessible directly from Wolfsburg.
- The environmental department in Wolfsburg and the environmental department in Uitenhage cooperate on a regular basis. Thus, an exchange of information and potentially necessary appointments on site were deemed unproblematic.
- It was expected that one hotspot in the material supply chain would be the platinum-group-metal mines in South Africa. Thus, the direct water consumption as well as the mentioned hotspot would be located in the same country.

3.4.3 WP4.3) German Copper Institute: Water footprint of European copper production

Within the framework of this research project, the German Copper Institute extended its product-related studies already carried out with the TU Berlin into a water footprint of the entire European copper production. As the most important prerequisite, the German Copper Institute, in its function as a "Competence Centre for Life Cycle Analyses", has direct access to regularly collected LCA inventory data of copper ore, copper concentrate, copper cathodes, copper anodes and copper semi-finished products. In combination with data on the composition and origin of the European copper consumption mix and annual production quantities, the global annual water consumption of European copper production was determined.

In the product water footprints of a copper sheet and a copper pipe which were conducted together with the Technical University of Berlin, water inventory data had already been collected and local impacts had been discussed with operators of copper mines and copper smelters. The resulting findings and contacts with organizations represented an important support for the project.

3.4.4 WP4.4) Neoperl: Water footprint of the Neoperl GmbH

In cooperation with the TU Berlin, Neoperl has already created and published a product water footprint of a flow regulator (Berger et al. 2015). Now this study was extended from a product to an organizational water footprint of Neoperl GmbH. For this purpose, both the direct water consumption of the production site and company headquarters in Müllheim (Scope 1) and the indirect water consumption from the energy (Scope 2) and material prechains (Scope 3) were considered. With the help of impact assessment models, the resulting potential consequences were analyzed and, thus, hotspots in the supply chains identified. In addition to the analysis of the water consumption resulting from production, the positive effect of water saving through the use of Neoperl products was also considered in the organization's water footprint.

3.5 WP5) Analysis of local water risk

Even if the water footprint can identify local hotspots in global value chains, it often does not allow a detailed statement about the real and often complex conditions at the premises of the organizations or suppliers. Here the site-specific water risk analysis (Wagnitz and Kraljevic 2014) can be used to examine the local water situation. The aim is to analyse the local water risk in five potential hotspots (own sites or suppliers) per case study.

In accordance with the water risk filter method (WWF 2016), the physical, regulatory and reputational risk - in relation to the river basin in general and to the organization in particular - will be evaluated. The river basin-related risks are based on 19 site-specific risk indicators. The organization-related risk assessments carried out according to the same criteria as the river basin assessment. It consists of a specific organization questionnaire on the site and automatically assigned general information of the respective industrial sector (Wagnitz and Kraljevic 2014).

3.6 WP6) Mitigation measures

The organizational water footprint allows for analyzing water use and resulting local impacts along an organization’s value chain. However, in order to reach an improvement, the analysis needs to be followed by concrete measures to mitigate water stress at local hotspots in global supply chains. In close cooperation with the industry partners, different mitigation measures ranging from water stewardship approaches, ecodesign measures to sustainable procurement strategies were discussed, tested in the case studies and (if successful) recommended in the Practitioners’ Guidance.

4 Project results

The following section presents the results obtained in the project according to the structure of the work packages described above. The contribution of the project partners to the work packages is as follows:

- WP1: Development of the Organizational Water Footprint (OWF) method (TU Berlin, all)
- WP2: Geographically explicit water inventory database (thinkstep, TU Berlin)
- WP3: Water Footprint Tool (TU Berlin, thinkstep)
- WP4: Case studies
    - WP4.1: OWF of the EU Primary Copper production (German Copper Institute / Deutsches Kupferinstitut Berufsverband e.V.)
    - WP4.2: OWF of amino acid production lines (Evonik Industries AG)
    - WP4.3: OWF of Neoperl GmbH (Neoperl GmbH)
    - WP4.4: OWF of Volkswagen’s production site Uitenhage in South Africa (Volkswa AG)
- WP5: Analysis of water risk (TU Berlin, all)
- WP6: Measures to mitigate water stress at hotspots in supply chains (TU Berlin, all)

4.1 Development of the Organizational Water Footprint (OWF) method

4.1 Development of the Organizational Water Footprint (OWF) method (TU Berlin, WP1)

4.1.1 Review of existing approaches

Existing approaches for measuring an organization's water use have been analyzed in order to: i) provide guidance for practitioners concerning the suitability of available methods and tools for different applications; ii) provide a scientifically robust criteria-based comparison identifying the strengths and weaknesses of existing approaches to stimulate future method development. Eight literature-based criteria for a suitable method for organizations are identified: documentation and transparency, scientific soundness, environmental relevance, organizational system boundaries, broadness of application, ease of application, stakeholder's acceptance, and transformative potential, specified by a total of 22 subcriteria. Nine existing approaches for measuring water-related impacts of organizations are evaluated accordingly.

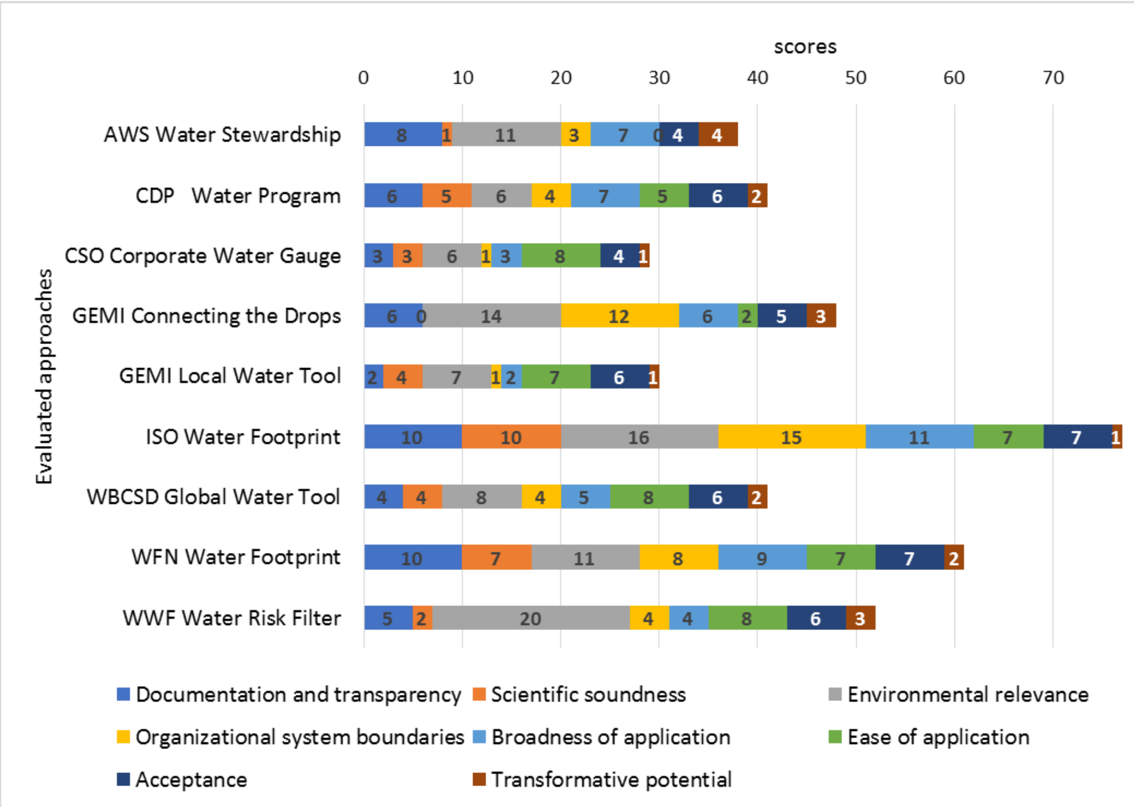

Figure 5: Scores attributed to the evaluated approaches.

The approaches show diverging performance. Based on the overall evaluation results, taking Water Footprint (ISO 14046) as a global information tool is recommended, in combination with the Water Stewardship approach, to link assessment results to concrete mitigation measures.

A detailed presentation and discussion of results can be found in the following journal publication:

- Forin, Silvia, Markus Berger, and Matthias Finkbeiner. 2018. 'Measuring Water-Related Environmental Impacts of Organizations: Existing Methods and Research Gaps'. *Advanced Sustainable Systems* 2 (10): 1700157. https://doi.org/10.1002/adsu.201700157.

4.1.2 Method development

The organizational water footprint denotes an organization's water use and resulting local impacts throughout its entire value chain. In other words, the Organizational Water Footprint (OWF) considers not only an organization's water use at its production facilities, but also the water used for energy generation and raw material production (upstream in the supply chain) as well as water use during the use and end-of-life phases of products (downstream). Additionally, all aspects of the organization itself are included, such as the water used by the cleaning service, the organization's garden and canteen, etc.

The Organizational Water Footprint method follows the life cycle approach and builds upon the experience of two existing environmental assessment frameworks: water footprint and organizational life cycle assessment. Both frameworks have been standardized by the International Organization for Standardization and rely on the established Life Cycle Assessment (LCA) method. The technical specification ISO/TS 14072 (ISO 14072, 2014) refers to the application of life cycle assessment to organizations and is specified by the Guidance on Organizational Life Cycle Assessment (O-LCA) (UNEP 2015). O-LCA is a multi-impact method, i.e. it considers multiple environmental impacts (e.g. global warming, toxicity, acidification, etc.), not only those caused by water use. Water consumption and water pollution related impacts can be included in organizational LCA too – among other impacts. The reference standard for water footprint, ISO 14046 (ISO 14046, 2014), does not exclude organizations but has been developed by taking a product life cycle perspective.

As a starting point for the method development, a detailed juxtapotation of the two standards was carried out, to identify complimenting as well as conflicting methodological aspects. Based on this analysis, methodological requirements for the organizational water footprint were proposed.

Following the LCA framework, the method is divided into four phases: 1) Goal and scope definition, 2) Inventory analysis 3) Impact assessment and 4) Interpretation

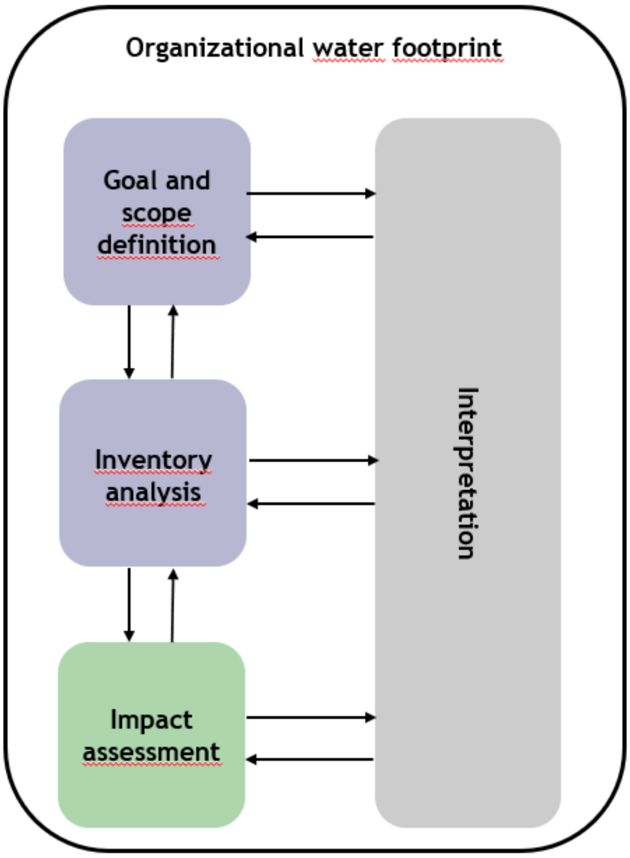

Figure 6: The four phases of the Organizational Water Footprint method

4.1 Development of the Organizational Water Footprint (OWF) method

The **goal and scope** phase sets the framework for the Organizational Water Footprint study and describes why and how the Organizational Water Footprint study is conducted.

In the **inventory analysis**, data is collected for all relevant water inputs and outputs:

- drawn from the environment and entering the system (as defined in the scoping phase) without previous human transformation and
- leaving the system and released to the environment without subsequent human transformation.

The water inputs and outputs are collected for the processes taking place within the system boundary, i. e. not only the organization itself, but also primary and intermediate materials, energy carriers, the use and end-of-life phase.

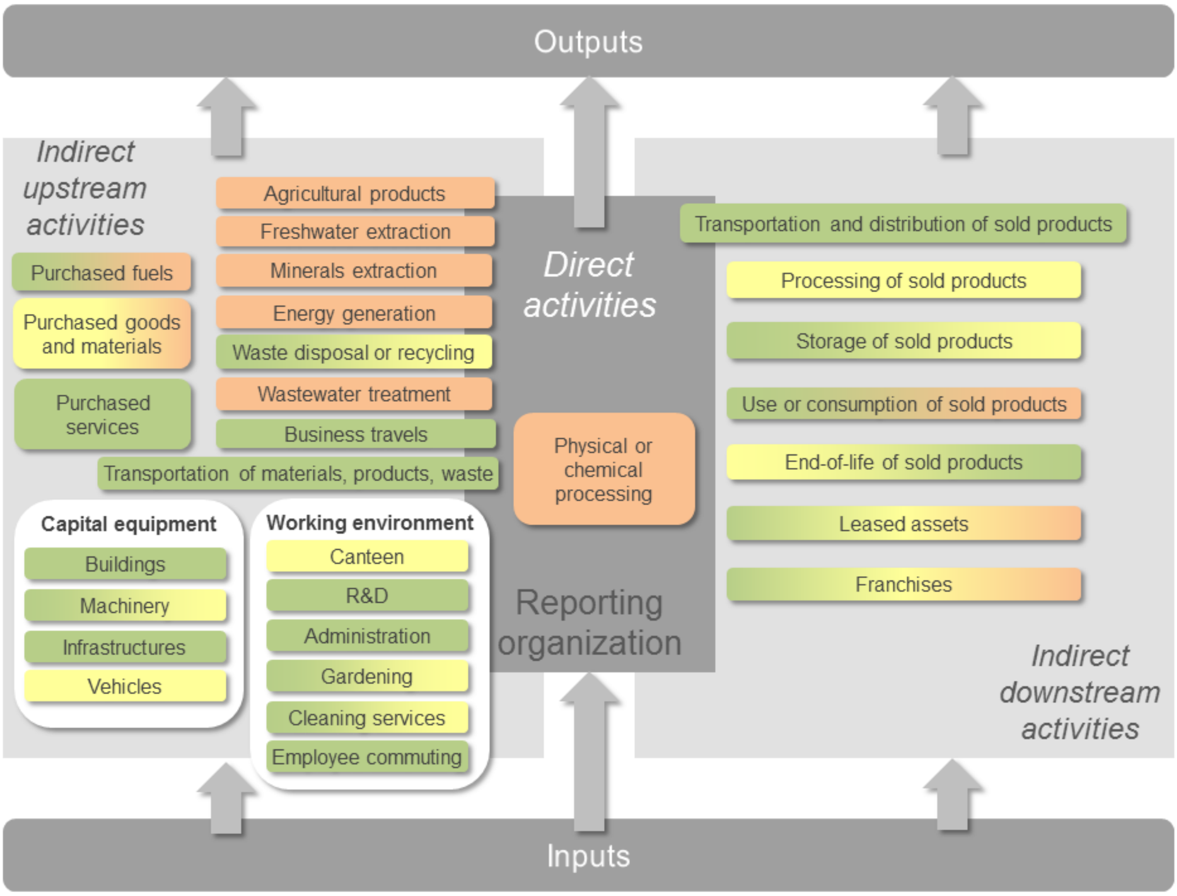

Figure 7: Direct and indirect activities carried out by an organization (example for the producing industry), and guidelines for prioritizing data collection for a water scarcity footprint study (red: high priority; yellow: average priority; green: low priority)

The inventory analysis reveals the volumes of water consumed in different regions along an organization's supply chain. However, a water consumption of 1 m³ in a water abundant region does not compare to consuming the same amount of water in a water scarce area. Therefore, the **impact assessment** step translates the volumes of water consumption into potential local impacts.

The **interpretation** phase of an OWF study includes:

- Presenting and discussing relevant water consumption patterns and resulting local impacts along the organization's value chain;
- Identifying significant issues, which strongly influence the Organizational Water Footprint. This can include certain activities (e. g. a purchased materials) as well as modelling choices (e. g. cut-off criteria) or assumptions (e. g. concerning the location of sub-suppliers);

- Analyzing the completeness of data for significant issues as well as the consistency with the goal and scope definition;
- Performing sensitivity analyses for significant issues, i. e. changing the parameters, modelling choices or assumptions to check, how sensitive the results react to these changes;
- Identifying limitations of the study;
- Drawing conclusions and providing recommendations;

A detailed comparison of the methodological requirements of the (Product) Water Footprint and the Organizational Life Cycle Assessment as well as the methodological aspects of the developed Organizational Water Footprint method can be found in the following journal publications:

- Forin, Silvia, Natalia Mikosch, Markus Berger, and Matthias Finkbeiner. 2019. 'Organizational Water Footprint: A Methodological Guidance'. *The International Journal of Life Cycle Assessment*, online-first. https://doi.org/10.1007/s11367-019-01670-2.
- Forin, Silvia, Markus Berger, and Matthias Finkbeiner. 2020. 'Comment to "Marginal and Non-Marginal Approaches in Characterization: How Context and Scale Affect the Selection of an Adequate Characterization Factor. The AWARE Model Example"'. *The International Journal of Life Cycle Assessment*, online-first. https://doi.org/10.1007/s11367-019-01726-3.

4.1.3 Practitioner's Guidance

In order to support organizations in applying the OWF method, a Practitioner's Guidance has been developed which provides practical support for each methodological step of an OWF. The guidance is available via: https://welle.see.tu-berlin.de/Organizational_Water_Footprint_(OWF)_Practitioners_Guidance.pdf

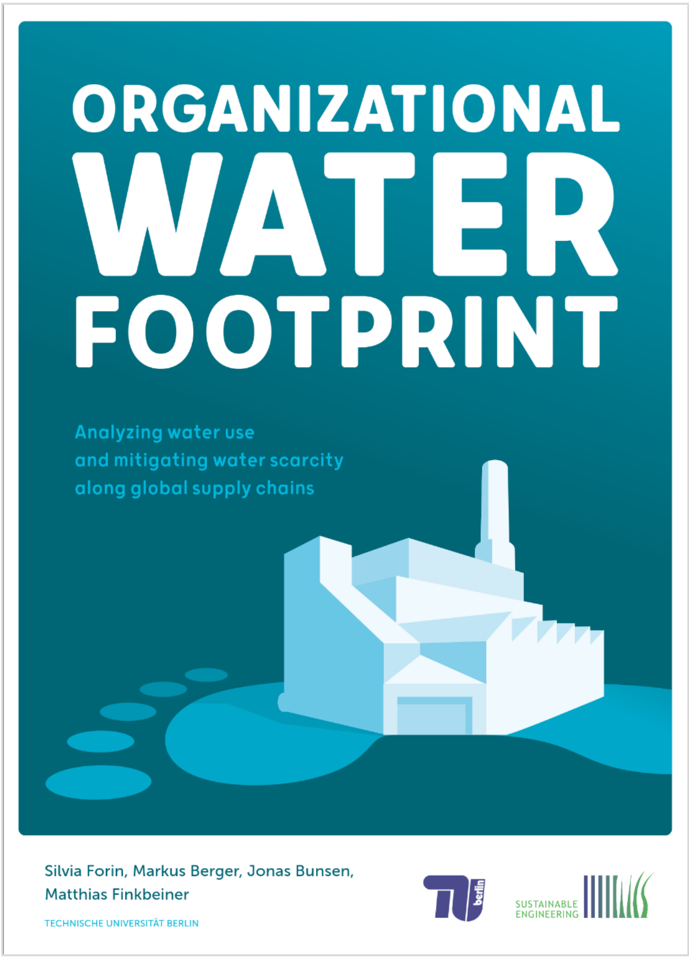

Figure 8: Organizational Water Footprint – Practitioners' Guidance.

4.2 Geographically explicit water inventory database (Thinkstep AG & TU Berlin, WP2)

While most organizations can monitor their internal activities rather easily, they rely on external data about the water consumption of their indirect upstream activities (e. g. material and energy supply chains). Thinkstep's life cycle inventory database GaBi 8 can be used for this purpose as it contains water use and consumption data related to the production of materials, the generation of energy, transports, etc. However, information concerning the volumes of water consumed per kg of a material or per kWh electric energy is not sufficient to enable the analysis of water scarcity footprints. Spatial information on where the water consumption has occurred throughout the supply chains is needed in order to combine it with local scarcity data and, in this way, to enable analyzing the resulting local impacts. Such spatially explicit water inventory data is currently available for relevant processes in the GaBi 8 database (energy and agricultural datasets), however, not for abiotic materials, manufacturing processes, transports, etc. Therefore, a WELLE water database has been created by enhancing datasets from the GaBi database as follows:

Relevant datasets were identified by the industry partners participating in the WELLE project. These datasets were investigated comprehensively and modified to provide the required spatially explicit water consumption data.

In general, two approaches were taken. In a "bottom-up" approach spatial information from the underlying LCA models was used to convert unspecific water flows to country specific flows. In the other "top-down" approach unspecific water consumption data was mapped to different countries according to production statistics. Further, aggregated datasets (unit processes) are provided in a disaggregated form, allowing for the selection of country specific energy and material mixes or market mixes based on several countries.

Thinkstep has published a comprehensive introduction into the water assessment in the GaBi software and related databases (Pieper et al. 2018). The WELLE database, which contains spatially explicit water inventories for about 150 material and energy datasets can be accessed online (http://welle.see.tu-berlin.de/#database) along with a detailed description of the database development (http://welle.see.tu-berlin.de/data/WELLE_Database_Documentation.pdf). It is also integrated into the WELLE Tool presented in the following section.

In addition to this freely available database, the geographically explicit water inventory data sets are integrated into the commercial GaBi database by means of a so-called test kit. Since Thinkstep will continue to pursue the developed integrated regionalization approach even after the work package is completed, the number of data sets will gradually increase. The medium to long-term goal is to be able to offer the water inventory data of all data sets of the GaBi database geographically explicit.

4.3 Organizational Water Footprint online-tool (TU Berlin & Thinkstep AG, WP3)

The WELLE tool is a free online application[1] which assists organizations in calculating their organizational water footprint following the OWF method. Users can enter the direct water use at premises as well as indirect upstream activities (e.g. purchased materials and energy), indirect downstream activities (e.g. water consumed in products' use phases), and supporting activities (e.g. business trips) as listed in Table 2. By linking this information to the activity specific water consumption data provided by the WELLE database, the organization's water consumption along its value chain is determined. Further, the WELLE Tool applies country-average characterization factors to the country specific water consumption data available in the WELLE database and, in this way, allows for analyzing the resulting local impacts.

In the following, input and result sections of the WELLE Tool are summarized.

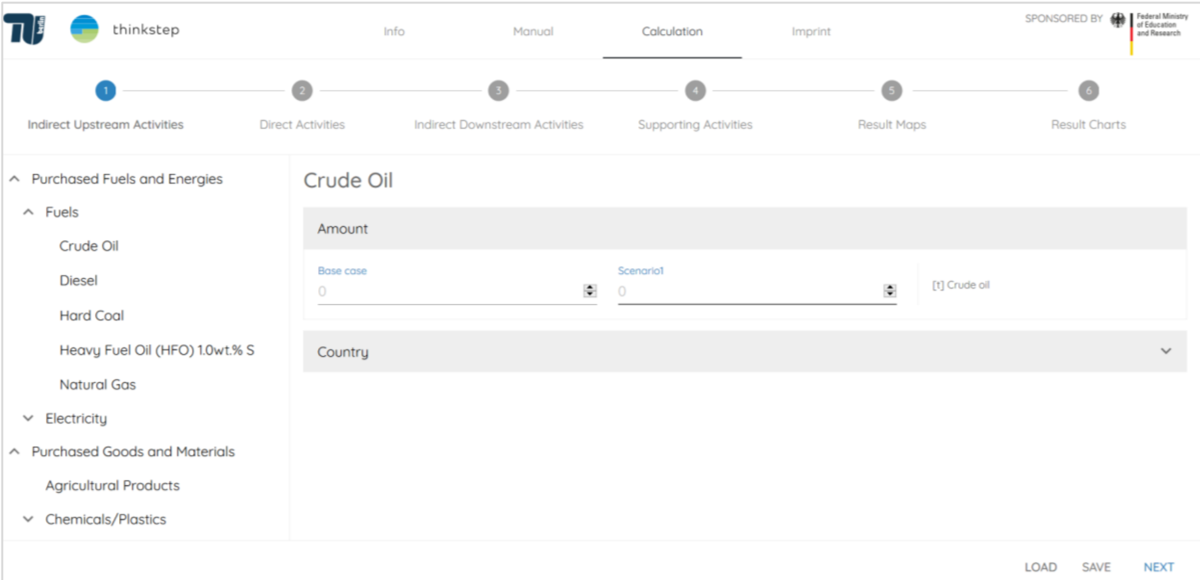

Figure 9: Input mask of the WELLE OWF Tool

4.3.1 Indirect upstream activities

Indirect upstream activities comprise an organization's energy and material supply chains. For fuels and energy, users of the WELLE Tool can distinguish between different types of fuel and sources of energy e.g. crude oil, diesel, hard coal, heavy fuel, natural gas, grid mix electricity, electricity from biomass, hydro power, electricity from lignite, electricity from natural gas, nuclear power, photovoltaic or electricity from wind power. For purchased materials, users of the WELLE Tool can choose from a wide range of materials that are often purchased by organizations such as chemicals, polymers, metals, agricultural products, or packaging materials.

4.3.2 Direct activities

Direct activities comprise processes at an organization's premises. Typically, direct activities refer to the manufacturing of products or the provision of services. Users of the WELLE-Tool can distinguish between different types of input water such as deionized water, freshwater extraction from natural water sources as well as tap water. Analogously, users can specify water discharge (output) which is separated as the release of freshwater or wastewater.

[1] The WELLE OWF Tool is available via https://wf-tools.see.tu-berlin.de/wf-tools/owf/.

4.3.3 Indirect downstream activities

Indirect downstream activities comprise of downstream life cycle stages of an organization's products or services e.g. processing of sold products, storage of sold products, use or consumption of sold products, end-of-life of sold products as well as leased assets and franchises. Users of the WELLE tool can enter the water consumption occurring in these downstream activities and the respective locations directly.

4.3.4 Supporting activities

Supporting activities comprise overhead activities that are required to keep an organization operating. Users of the WELLE tool can enter activities such as employee commuting, provision of food to employees in a canteen, business travels by plane, train and road transportation (which can also be represented through amount of purchased diesel), maintaining a work environment (work places, administration, cleaning services, gardening, research and development) as well as capital equipment of an organization (building, machinery, organization cars).

Table 2: Input sections of the WELLE OWF Tool.

Indirect upstream activities	Purchased Fuels and Energies	Fuels	Crude Oil
			Diesel
			Hard Coal
			Heavy Fuel Oil (HFO) 1.0wt.% S
			Natural Gas
		Electricity	From Grid
			From Biomass (solid)
			From Hard Coal
			From Heavy Fuel (HFO)
			From Hydro Power
			From Lignite
			From Natural Gas
			From Nuclear
			From Photovoltaic
			From Wind Power
	Purchased Goods and Materials	Agricultural Products	US: Corn grains
			US: Soy bean oil, conditioned
			Generic Agricultural Product
		Chemicals/Plastics	Acrylonitrile Butadiene Styrene Granulate (ABS)
			Polyvinylchloride Granulate (S-PVC)
			Polyethylene Terephthalate Fibers (PET)
			Polybutylene Terephthalate Granulate (PBT)
			Polyethylene Low Density Granulate (LDPE/PE-LD)
			Polyethylene High Density Granulate (HDPE/PE-HD)
			Polyoxymethylene Granulate (POM)
			Polyamide 6.6 Granulate (PA 6.6) (HMDA)
			Polypropylene Granulate (PP)
			Nitrile Butadiene Rubber (NBR)
			Polysulfone (PSU)
			Epoxy resin (EP)
			Polyethylene Cross-Linked (PEXa)
			Polyethylene Terephthalate Granulate (PET)
			Polyamide 6 Granulate (PA 6)
			Ethylene Propylene Diene Elastomer (EPDM)
		Metals	Aluminum
			Cast Iron
			Steel Alloyed
			Steel Non-Alloyed
			Stainless Steel
			Brass
			Lead
			Silver
			Gold
			Nickel
			Copper
			Tin
		Other Purchased Materials	Wooden Pallet
			Silicone

			Cardboard
			Generic Product/Others
	Purchased services	Generic	Generic
Direct activities	Direct water use	Input	Deionized water
			Freshwater extraction
			Tap water
		Output	Freshwater release
			Wastewater
Indirect downstream activities	End-of-Life of Sold products		
	Franchises		
	Leased Assets		
	Processing of Sold Products		
	Storage of Sold Products		
	Use or Consumption of Sold Products		
Supporting Activities	Business Travels	Travel by plane	
		Travel by Train	
		Travel by Car and Truck	
	Employee Commuting	Travel by Train	
		Travel by Plane	
		Travel by Car <2 L	
		Travel by Car > L	
	Canteen	Days per year	Meat
			Soft Drink
			Vegan
			Vegetarian
	Capital equipment	Building	
		Machinery	
		Organization cars	
	Working Environment	Work places	
		Administration	
		Cleaning Services	
		Gardening	
		Research & Development	

4.3.5 Results

Results are displayed on a world map and in stacked bar charts for the default and an (optional) alternative scenario.

4.3.5.1 Result maps

Four maps display the volumetric water consumption (blue water footprint) as well as the water scarcity footprint (impact assessment result determined based on AWARE) for both scenarios. Upon clicking on a country, the individual contributions of the four activities. are displayed.

4.3 Organizational Water Footprint online-tool

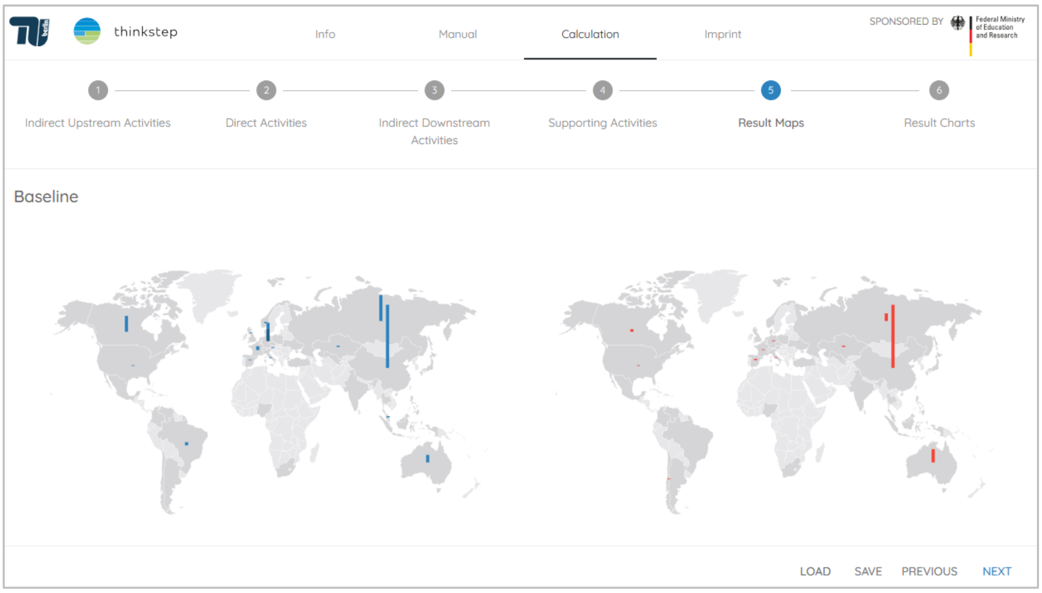

Figure 10: Visualization of the regional water consumption impacts

4.3.5.2 Result charts

The stacked bar charts display the volumetric water consumption (blue water footprint) as well as the water scarcity footprint (impact assessment result determined based on AWARE) for both scenarios within one chart at a time. Separate charts for the input sections *indirect upstream activities*, *direct activities* and *indirect downstream activities* as well as overall results are available. Different colors allow the user to conclude on what specific activities contribute to the aggregated result e.g. purchased fuels and energies, purchased goods and materials, services etc.

Figure 11: Visualization of the water consumption per lie cycle stage

4.4 Organizational Water Footprint case studies (WP4)

4.4.1 Organizational Water Footprint of amino acid production lines (Evonik Industries AG)

4.4.1.1 Goal

Evonik Nutrition & Care GmbH is one of the world's largest producers of essential amino acids for livestock production, especially for chicken and pork. As building blocks of protein, amino acids used in animal feed are a major factor for animal growth.

Two main different production methods of the amino acids exist at Evonik: the chemical process used for the production of methionine and the biological process based on corn fermentation, used for the production of lysine.

A first goal of the study was to assess the organizational water scarcity footprint (WSF) of two production lines of amino acids: methionine produced in Antwerp, Belgium and lysine produced in Blair, Nebraska, USA, according to the OWF method and in line with the ISO standard 14046 and ISO/TS 14072. For that, blue water consumption and the resulting impact throughout the value chain was assessed to determine where the hotspots in Evonik's product portfolio regarding the Organizational Water Footprint are located.

Then, the Organizational Water Footprint for the application of amino acids for swine production was investigated. This was done in order to check if the effects already known for some impact categories like Global Warming are also available for the Water Footprint: it was indeed already shown that the amino acids supplementation allows a reduction of the greenhouse gas emissions of livestock production.

The present work relies on a comparative LCA already conducted in 2015 on the use of amino acids for poultry and swine production (Haasken 2015).

Besides production-related materials and processes, also activities taking place on the organizational level were taken into account (so-called supporting activities in the OWF method). A strong focus was put on primary data collection, for both organization activities and suppliers. In addition, the regional specificities related to scarcity issues were investigated in depth.

4.4.1.2 Scope

This OWF study is organized into two parts:

1) Cradle-to-gate for the production lines of amino acids
2) Cradle-to-farm gate exit for swine production

For the first part of the study, the production lines of methionine in Antwerp and of lysine in Blair are considered as the "organizations". The reporting unit is 1 ton of amino acids and is based on the reference year 2014 for mass and energy balances and 2018 for all the specific data required for calculating supporting activities like sales volume, number of meals sold in the canteen, number of business travels etc.

For the second part of the study, the functional unit is 1 ton of swine live-weight. The system boundaries include all processes involved from the cultivation of crops to swine production.

Whereas primary data are used for the production of amino acids, the remaining supply chain was modelled using literature and LCA databases. The study of swine production was realized without and with amino acids supplementation in order to compare the impact of both solutions. Livestock production (animal feed composition, farming process, manure management) was modelled based on literature data (Kebreab et al. 2016). Europe was considered for production of animal feed and for husbandry.

Primarily, the GaBi software (Thinkstep 2016) and database (version 6.115) were used for LCA modelling. For supporting activities according to the OWF method, the organizational water footprint tool developed within the WELLE project was used.

4.4 Organizational Water Footprint case studies

In line with ISO/TS 14072 and following the recommendations for Organizational Water Footprint, the first part of the case study is not intended for comparative assertions for public disclosure. That is, the results should not be compared to other organizations as they have different reporting flows and different methodological settings may have been applied

In this study, water consumption resulting from some organizational categories like canteen or business travels were assessed at the organization or site level and then related to the production of 1 ton of respective amino acids, while some other categories (e.g. raw materials and energy consumption) have directly been assessed at the product level. Both approaches have consequently been combined: organizational and product water footprint.

4.4.1.3 Inventory analysis

Data collection approach, kind of data used, reference year and tool used for the assessment are described in the next table.

Table 3: Overview of data and tools used for assessing the OWF categories

OWF category	**Kind of data used**	**Reference year**	**Software or tool used for the assessment**
Direct activities (amount of groundwater required for the production process, cooling water, waste water)	Primary data from the production line for 1 ton of amino acid	2014	GaBi
Indirect upstream activities (purchased fuel, energy, transports, raw materials)	Primary data from the production line for 1 ton of amino acid	2014	GaBi
Indirect supporting activities - Business travels	Internal reporting systems already used for the data gathering for the Evonik Carbon Footprint. Data are available on the amount of kilometer driven by employees by private cars, train, rental cars and plane for the whole organization. An allocation to the respective production line was made knowing the number of employees working for each of the considered production lines	2018	Organizational Water Footprint Tool
Indirect supporting activities - Commuting	Own estimation based on the estimated distance between employee's residence and production site driven by cars (no public transport available at the both sites), number of working days known as well as number of employees working for the production line.	2018	Organizational Water Footprint Tool
Indirect supporting activities - canteen	Number of meals, soups and soft drinks sold in the canteen in Antwerp is available from the canteen operator. Share of vegetarian, non-vegetarian and vegan meals and soups estimated. The calculation was made for the whole plant and allocated to the methionine production line based on the number of employees. There is no canteen at the Blair	2018	Water Footprint Tool

	site. According to the OWF method, it can be excluded as out of system boundaries.		
Indirect supporting activities – organization vehicles	The number of organization vehicles is known for Germany based on available reporting systems. This number was extrapolated to the production lines of methionine and lysine putting into relation the number of employees in Germany versus the number of employees at the production lines.	2018	Water Footprint Tool
Indirect supporting activities - Buildings	Area covered by buildings used for the two production lines was estimated.	2018	Water Footprint Tool
Indirect supporting activities - Machinery	Not considered due to a lack of data		
Direct supporting activities – Administration, cleaning services, gardening, R&D	Not considered due to a lack of data		

The country of origin of the raw materials has been checked with procurement departments and data sets representative of the respective country have been used as far as possible, when available in the GaBi database. Most raw materials used for methionine production come from Belgium or Netherlands. Only Methanol is produced outside of Europe (Trinidad for the considered year). However, a data set representative of a production in Trinidad was not available in the GaBi database, as well as primary data from the supplier. An approximation was made with a German dataset after discussion with expert from thinkstep, that judged processes and scarcity similar enough for a good approximation (i.e. that the water scarcity of Trinidad is similar as in Germany).

Raw materials required for the production of lysine are supplied from the US. As far as possible, US data sets from the GaBi database have been used, or replaced by German/European datasets when not available, and if the approximation was judged as acceptable. Lysine is produced by fermentation, using glucose from corn as main feedstock (corn wet milling process) cultivated near the production site. However, no primary information is available about the specific amount of water required for irrigation and consequently data from the GaBi database representative for corn cultivation in USA have been used.

The publication from Kebreab et al. (2016) was used as reference for modelling animal feed, and husbandry for the final production of 1 ton of swine live weight. Swine production include water consumption at different levels of the value chain: upstream for the feed ingredients manufacturing (including amino acids) and for the farming process. The quantity of manure as well as the emissions of ammonia, NOx and methane have been calculated according to the methodology described in the study. A credit was finally applied considering that manure is used as fertilizer, based on its amount of nitrogen and phosphate. Feed mix composition without and with amino acids supplementation was also taken from the same publication, representative for Europe (Table 4).

Based on several literature studies and discussions with animal nutrition experts at Evonik, an overall reduction of ~5% of the amount of drinking amount consumed by the animals at the farm was assumed.

Table 4: Animal feed composition

Composition (kg/ton)	No AA supplementation	Supplementation
Wheat	**344**	**382**
Corn	**145**	**143**

Barley	**213**	**288**
Wheat bran	**11**	**22**
Rapeseed meal	**3**	**54**
Soybean meal	**232**	**67**
Rapeseed oil	**7**	**3**
Lysine	**0**	**4**
Threonine	**0**	**1**
Tryptophane	**0**	**0,2**
Methionine	**0**	**0,4**
Mono Calcium Phosphate	**7**	**7**
Salts	**4**	**4**
Dried whey	**3**	**3**
Calcium bicarbonate	**16**	**16**
Vitamin/premix	**5**	**5**

Evonik data sets have been used for methionine, lysine, tryptophan and threonine. It implies that the modelling of threonine and tryptophan was also regionalized based on the same effort that was put for regionalizing the Evonik models of lysine and methionine, as described above. Data sets from the GaBi database have been used for the other ingredients.

Assessment of Blue Water Consumption of the two amino acids production lines

The Blue Water consumption of both production lines was assessed (Figure 12 and Figure 13) related to 1 ton of methionine and lysine. The assessment was made with the GaBi software and databases (9.2.0.62). Supporting activities have been assessed for the whole year 2018 with the OWF tool and for the whole production lines. Results have then been divided by the corresponding sales volumes of the year 2018 to relate to the reporting unit.

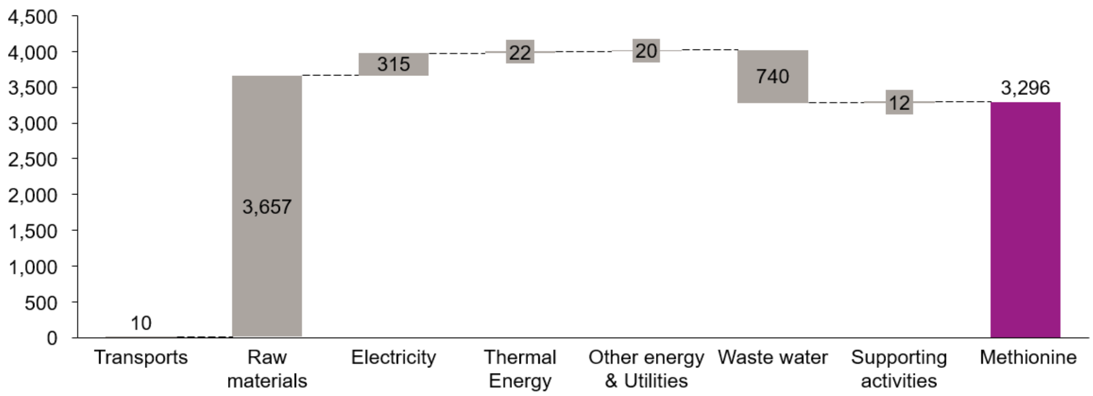

Figure 12: Blue Water Consumption for 1 ton Methionine, produced in Antwerp (kg water per ton)

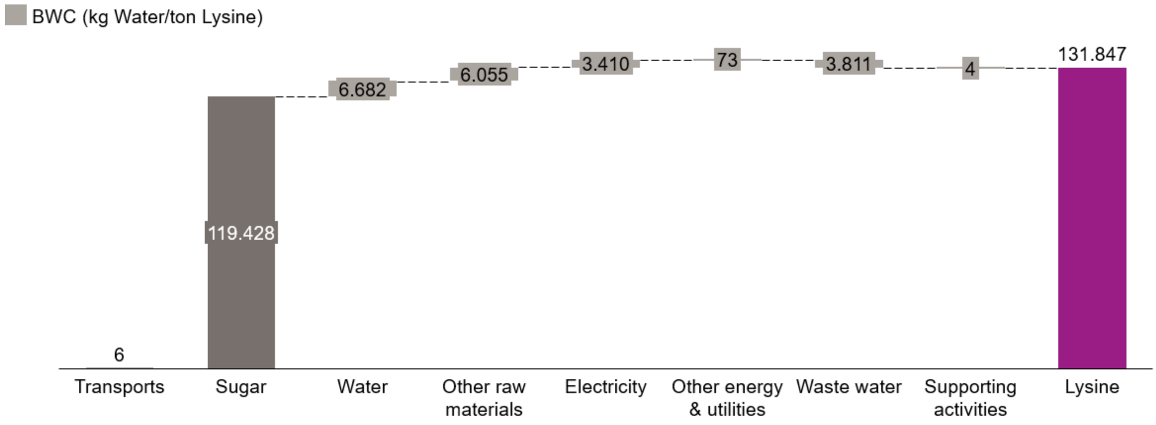

Figure 13: Blue Water Consumption for 1 ton Lysine, produced in Blair (kg water per ton)

First, the blue water consumption (BWC) of lysine is approx. 9 times higher than the one of methionine due to the high amount of water required for corn irrigation. BWC is a good indicator to identify hotspots and to know where the focus of mitigation measures should be set when the intention is an optimization of the water consumption for the organization's whole portfolio.

Regarding lysine, the water required for producing glucose (and especially irrigation water for corn cultivation) contributes to ~90% of the total BWC. Energy and utilities contribute to ~2.5% while the water required for the fermentation only contributes to 5%. Supporting activities have a low contribution to the overall water consumption: ~3%.

For methionine, the relative contributions are similar: strongly dominated by raw materials (only petrochemicals), then energy and utilities. Within the raw materials, ammonia and propene have the main impact. Supporting activities again have a very low contribution (~0,4%). The sub categories that have the main impact are: canteen and capital equipment.

The water consumption from supporting activities for methionine is ~3 times higher than the one of lysine because of the impact from the sub-category "canteen" in Antwerp (which has not been considered in Blair) as there is no canteen at the site.

4.4.1.4 Impact Assessment

Assessment of the production lines of amino acids

In order to assess the WSF of both production lines, it was necessary to determine the corresponding characterization factor according to the AWARE impact assessment method. The latter represents local water stress, as precise as possible.

The following pictures show the water scarcity according to the geodata provided by the AWARE method (Boulay et al. 2018) for a radius of 150 km around Blair and in the relevant counties for the corn supplied for lysine production. Blue represents a low water stress while red represent a very high water stress.

Instead of using national characterization factors from AWARE for the corn cultivation, a regional factor was calculated based on information about the counties of cultivation of corn and the respective share. While the AWARE CF of the USA is 33.8, the CF representative for corn used for the lysine production is ~ 20 (weighted factor based on area of corn cultivated in specific counties).

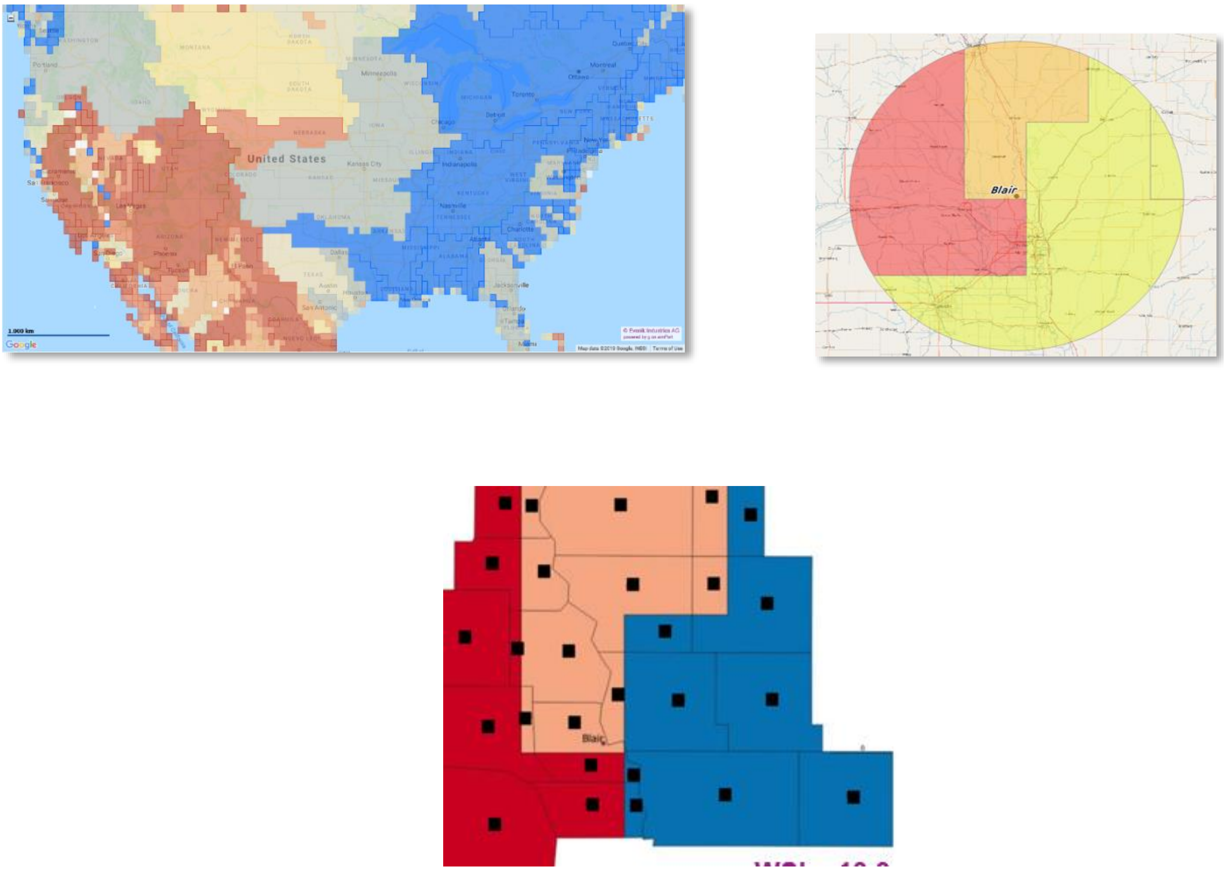

Figure 14: Water scarcity (geodata provided by the method developers) in USA, around Blair and in the respective counties relevant for corn supply

In the case of USA, using a national CF for calculating the WSF of lysine would be extremely sensitive because of the strong discrepancies between different basins. It was confirmed by suppliers that corn is sourced locally, in a radius of 150 km around the production site. This area includes three different water basins, and for each basin a specific characterization factor is available. To obtain a more precise estimation of the water scarcity impacts, an intensive exchange was initiated with the sugar supplier in order to have more information about precise corn cultivation area. Data about the percentage of corn cultivated of the different counties of the region were provided by suppliers.

Based on the experience gathered with the calculation of the WSF of methionine and lysine, the Evonik model of threonine and tryptophane was also regionalized (European production, at the time of study) and improved to better depict local water scarcity issues.

The potential water scarcity impacts linked to blue water consumption were calculated according to the AWARE method, using high CF for unspecified (Figure 15 and Figure 16).

Country specific characterization factors have been used for all raw materials, except for corn, where a more representative CF was calculated based on information provided by suppliers, as explained above.

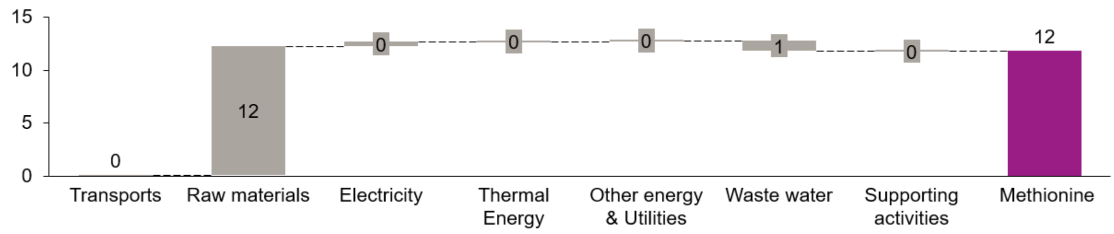

Figure 15: Water Scarcity Footprint of 1 ton of methionine

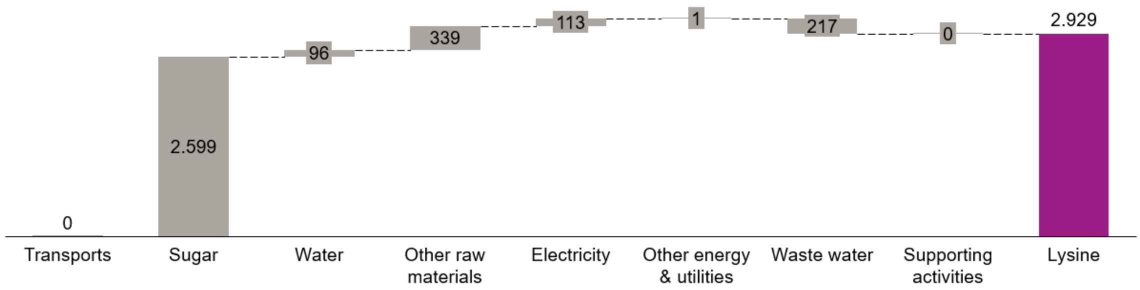

Figure 16: Final results Cradle to Gate case study: Water Scarcity Footprint [m³ world equivalent) per ton of lysine (AWARE high CF for non-characterized flows)

The contributions of the different categories to the overall water scarcity footprint remain similar compared to the one for Blue Water Consumption:

- For lysine: 88% for sugar, 11% for the other raw materials, 3% from direct water consumption, 4% for energy and utilities and < 0.1% for supporting activities.
- For methionine: 46% from raw materials, ~23% from energy and utilities and <1% from supporting activities. Within the category raw material, the contribution of the raw material "potassium hydroxide" becomes higher than for the Blue Water Consumption, due to the scarcity of some countries of its production (a European market mix was considered).

Assessment of the Water Scarcity Footprint for 1 ton of swine live weight

In the following graphics, the Water Scarcity Footprint was assessed according to the AWARE method, for 1 ton of swine live weight, without as well as with supplementation of Evonik amino acids (AA). A weighted average AWARE characterization factor was calculated, based on the countries of swine production in Europe: +19, what corresponds to a "high water scarcity class" in GaBi for the farming process.

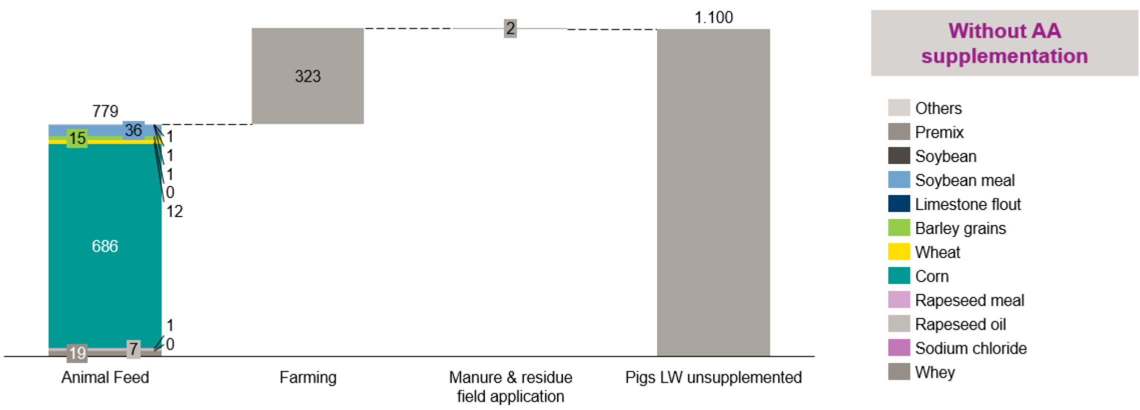

Figure 17: Water Scarcity Footprint [m³ world equivalent) per ton of swine live weight without AA supplementation (AWARE low CF for non-characterized flows)

4.4 Organizational Water Footprint case studies

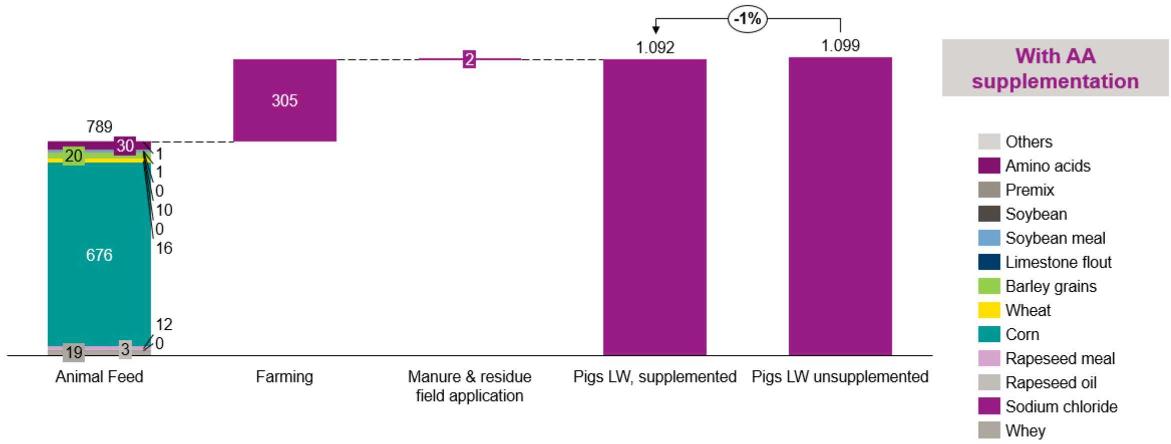

Figure 18: Water Scarcity Footprint [m³ world equivalent) per ton of swine live weight without AA supplementation (AWARE low CF for non-characterized flows)

With or without supplementation, the main contributor to the WSF of 1 ton swine is the animal feed (~98%) and especially corn. The contribution through the supplemented farming process, hatchery, as well as manure management and residue field application (fertilizer credit) have a very low contribution.

The high impact of animal feed is due to the high amount of corn in the feed. Indeed, corn requires a large amount of water for irrigation and is moreover cultivated in some regions with a higher water scarcity (considering the European market mix of corn cultivation) if compared with other ingredients used as protein source like soy from Brazil South America or wheat from Germany, regions that have a very low water stress.

The characterization factor used for corn cultivation is based on the market mix of European corn considered in the GaBi data set. The main countries of origin are Romania, Italy and France. Italy has a very high AWARE factor (~44).

4.4.1.5 Interpretation

The case study of the WSF of the production lines of methionine and lysine allows us to identify value chain hotspots when regional scarcity is taken into account. Those case studies are also helpful in order to determine where to focus optimization strategies when the goal is to reduce the water consumption of the whole portfolio, in order e.g. to fulfill internal organization targets[2].

Concerning lysine, the high contribution of corn irrigation was expected but not in this order of magnitude. Indeed, a larger contribution of the direct water used for fermentation was expected, as fermentation processes are known to require a lot water, in comparison with classical chemical processes. The impact of the direct water used for fermentation is low, because most is returned to the same watershed and consequently not considered as consumed.

In order to optimize the WSF of lysine, the focus should be on optimizing the process itself, especially the fermentation yield that is a key for reducing sugar consumption.

A second option to mitigate the high WSF is to supply a corn coming from a region with a lower water scarcity. As explained above, corn is cultivated in an area of 150 km^2 around Blair. Some counties have a higher scarcity than others in this area. A discussion will be initiated at the procurement level to know if a supply of corn from the water richer counties/basins is technically feasible. Additionally, the water use intensity in agricultural production can be tackled through multi-stakeholder initiatives at the local level, i.e. by sharing best practices in term of fertilizer used, irrigation, etc.

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[2] https://corporate.evonik.com/en/responsibility/evonik-has-adopted-a-sustainability-strategy-2020-123643.html (accessed 27.08.2020)

Concerning methionine, the lower WSF can be explained by the fact that only petrochemical raw materials are used, the process does not require a large amount of water and finally the production site is located in a non-water stressed area. Nonetheless, monitoring the country of origin of the raw materials is important as some of them might come from water stressed regions. It should be noticed that the WSF of methionine might change from year to year when suppliers or country of origin change. Therefore, it is advisable to track the water footprint performance on a regular basis.

Data required for assessing the supporting activities such as the amount of kilometre driven by employees by cars, train, etc. are already gathered by the reporting system used for the yearly calculation of the organizational carbon footprint. Consequently, another reporting system would not be necessary if the organizational water scarcity footprint would need to be assessed. The low contribution of supporting activities justifies their exclusion in future water footprint case studies for amino acids at the product level.

Concerning the Water Footprint of swine production, the amino acids supplementation in Europe does not result in a major reduction of the water consumption (only 1% reduction). It can be explained by the use of corn in similar quantities without and with supplementation, that has the main impact on the WF of swine. When the WF of swine production is intended to be reduced, the replacement of corn by other protein sources will be the main drivers. The additional water consumption because of amino acids production is almost compensated by the water savings at the farm, due to reduced amount of drinking water consumed by the animals. However, these both aspects have a relatively low effect compared to the water required for corn cultivation. These conclusions drown for swine production might strongly differ for other regions, and also for chicken production due to completely different feeding scenarios. It will be the object of a next study

4.4.1.6 Analysis of the local water risk (WP5)

The Water footprint assessment of the two amino acids production lines showed that the lysine production is a main hotspot due to the high consumption of renewable feedstock that requires irrigation but also due to local water scarcity around the production site. Due to long year relations with the supplier of glucose that is located at the site, the raw material glucose for lysine production was chosen for starting a deeper discussion on this topic.

For methionine production, the possibility of developing water stewardship measures was judged as not feasible due to the international sourcing of the two main raw materials. The supplier and consequently the country of supplies might change from year to year. However, it is currently discussed with the Evonik procurement department if sustainability aspects (e.g. water scarcity footprint) can play a bigger role in the choice of the suppliers.

4.4.1.7 Mitigation measures (WP6)

First of all, an exchange was started with the local supplier of glucose and several teleconferences have been organized. The goal and scope of our analysis was presented, the importance of using primary data for glucose was also discussed, as well as having more information about the area of cultivation of corn. Despite much efforts, no primary data could be provided by the supplier. Concerning the area of cultivation of corn, the share of corn cultivated in the specific states around the production site was provided. This information was highly helpful to calculate a more precise (i.e. weighted) AWARE characterization factor. An exchange was also initiated by the Evonik procurement department via a questionnaire on the sustainability performance of the purchased raw materials.

These activities happened during the last two years but could still not lead to any concreate mitigation measures. These processes take a longer time than the project itself but will be continued by Evonik. One option could be to develop a “mass balance approach” in order to purchase a feedstock coming from the area with the lower footprint.

4.4 Organizational Water Footprint case studies

Independent to our work within the present project, the State of Nebraska, where the lysine production side is located, runs a public project on the local water scarcity´assessment and management. This will give Evonik further opportunities to progress for mitigation options.

4.4.2 Organizational Water Footprint of Volkswagen's production site Uitenhage in South Africa (Volkswagen AG, WP4)

4.4.2.1 Goal

Volkswagen's water footprint study conducted within the WELLE research project pursued four different aims:

1) Identify water-related environmental hotspots for the Uitenhage automobile production plant in South Africa.
2) Identify the water-related risk exposure of Vokswagen's automobile production plant in Uitenhage and its value chain.
3) Understand risks and impact reduction opportunities for Volkswagen's automobile production plant in Uitenhage as well as prior and subsequent life cycle stages.
4) If possible, reduce pressure on the environment, especially in regions with high water stress.

4.4.2.2 Scope

The subject of this case study was the Volkswagen plant at Uitenhage, South Africa. With approximately 4,000 employees and a yearly output of approximately 124,000 vehicles and an additional 122,000 engines (as of 2016), it is the biggest automotive plant in Africa. Moreover, it is a production plant with a relatively straightforward production portfolio, the bulk of which consists of the Volkswagen Polo and the corresponding EA111 engines. Additionally, it lies in a water-scarce region, thus being suited for this case study.

The reporting period (or *reference year*) was the year 2016. The most current year for which complete data with regard to production volumes, water consumption, and energy demand were available at the start of the WELLE research project.

The reporting flow was defined as the units (vehicles and engines) produced within the reporting period.

The study was intended as a cradle-to-grave study, incorporating the whole life cycle of the products. Indirect upstream activities comprised the supply chain from raw material extraction to the production of supplier parts as well as the energy demand for the plant itself. The direct activities consisted of the on-site water consumption, whereas the indirect downstream activities comprised the transport of the products, their use phase, and their recovery. Concerning use phase and recovery, a steady production volume over the years was assumed. This means that the entire use phase of the units produced was taken into account, with each product having a lifetime of ten years and a service life of 200,000 kilometers.

4.4.2.3 Inventory analysis

The inventory analysis was subdivided into the following stages: Indirect upstream activities, direct activities, and indirect downstream activities. In general, the data collection followed a bottom-up approach.

For the on-site activities, data for each relevant section of the plant (e.g. press shop, body shop, paint shop, assembly, etc.) were available with regard to water consumption, electricity demand, and natural gas demand. For analyzing the water consumption of the energy and natural gas demands, the data for the South African energy mixes were used.

For the remaining indirect upstream activities (raw material extraction and supplier parts production) as well as for the indirect downstream activities (logistics, fuel provision, and end-of-life recovery), product LCAs for the respective products were created and their data summed up, based on the production volumes in the reference period.

The machinery for the in-house production, the construction of buildings on site, employee commuting, and business travels were not considered in this case study, because previous internal studies suggested that these factors do not have a great impact on the overall (water) footprint.

Inventory analysis of products

On the product level, the assessed processes and substances were modelled on the level of elementary flows, meaning that only those substance and energy flows transgressed the assessment boundaries that were extracted and released, respectively, from and into nature without human action. The only exception were the material fractions created in the recovery phase.

The production phases for vehicles and engines (hereafter products) were inventoried by modelling the production and manufacturing processes of all parts and components used in the respective product. This modelling comprised all steps from raw material extraction to the production of semi-finished products to the production of the actual parts and finally the product.

In the use phases, all relevant processes from the raw material extraction to the fuel provision to the direct product operation were modelled. The fuel provision analysis comprised the raw material transport from deposit to refinery, the fuel refining and the fuel transport from refinery to gas station. The allocation for the engines produced (and not subsequently installed in a vehicle on site) was conducted by weight portion. During the use phase, maintenance (such as oil change, replacement of tires, etc.) was not considered.

The recovery phase was modelled using a generic model for the recovery of passenger vehicles. In this context, generic means that the model parameters are predetermined depending on the vehicle segment.

For the secondary materials emerging from the recovery processes, no credits within the lifecycle assessment were issued. Only the water consumption of the recovery processes was analyzed. This corresponds to a worst-case assumption, since in reality, secondary materials from vehicle recovery are often fed in the global production cycles. By this possible recirculation, primary materials can be replaced, thus avoiding environmental impacts in the production phase.

The product data in the product LCAs (information on e.g. bills of material, quantities, weights, materials, fuel consumption, recovery rates, and recovery procedures) originated from Volkswagen-internal data. The process data (information on production and manufacturing processes, e.g. electricity provision, material production and semi-finished product manufacturing, mechanical assembly, and production of fuel and operating supplies) originated either from commercial databases (in this case the GaBi database [service pack 36] from thinkstep) or—case-specific—from Volkswagen (paint shop, final assembly, press-quenched steel, recovery) or suppliers (tire and glass manufacturers).

The indicator used for the inventory analysis was the Blue Water Consumption indicator of the GaBi database from thinkstep. The regionalization of the water inventory was also done based on thinkstep data (cf. section 3.2).

Results of the initial inventory analysis

The results of the initial inventory analysis are shown in the figures below. Figure 19 shows the water consumption distribution between indirect upstream activities, direct activities, and indirect downstream activities. The direct activities contribute only 2 % to the overall water consumption, with the upstream and downstream activities contributing each about half to the water consumption.

4.4 Organizational Water Footprint case studies

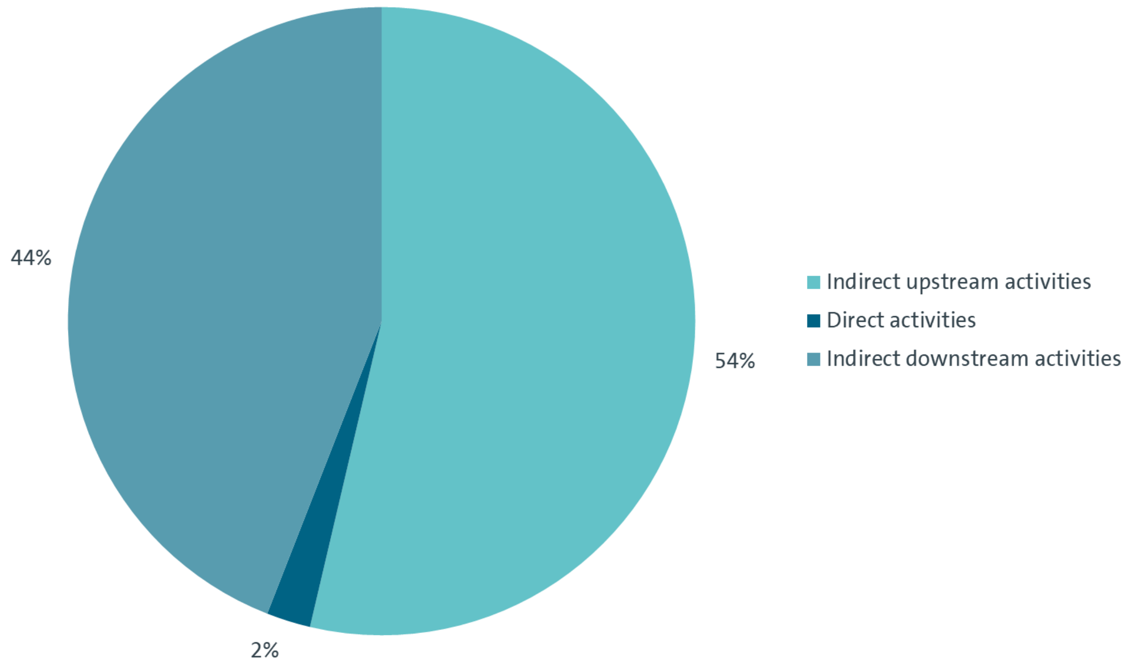


Figure 19: Initial water consumption distribution of Uitenhage plant

A deeper analysis of the downstream activities revealed that more than 95 % of the water consumption in this part of the supply chain originated from the fuel production, in particular from the bio-fuel part of most current fuels. The detailed results for the initial analysis of the upstream activities on the material level are shown in Figure 20.

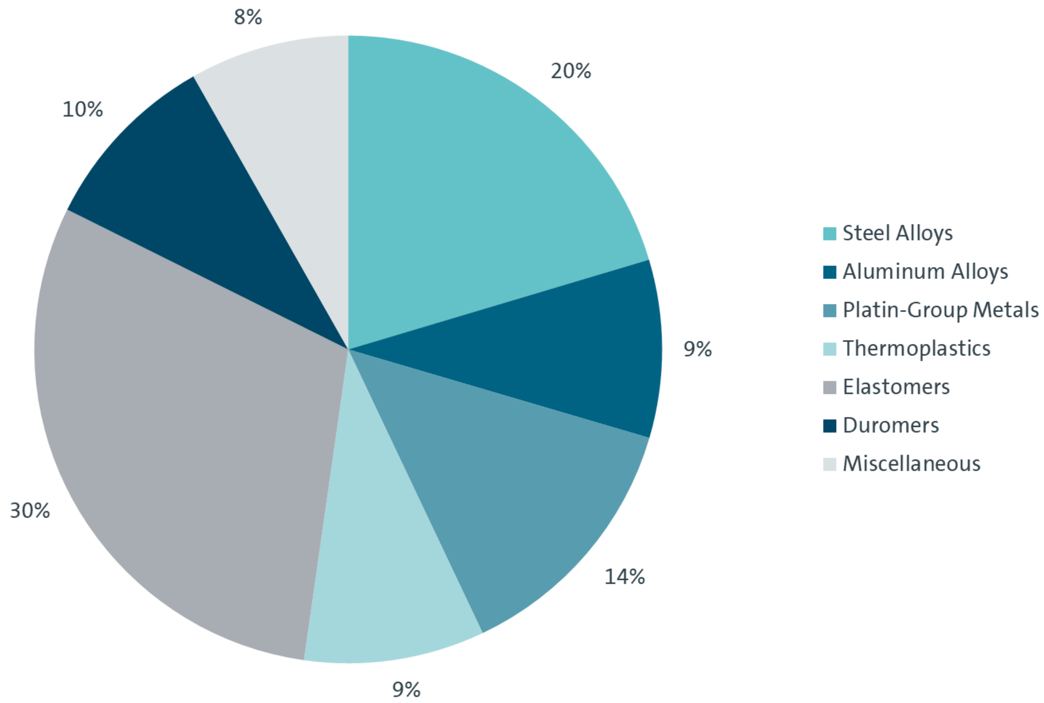


Figure 20: Initial water consumption distribution in the supply chain

Within the upstream value chain, several hotspots were identified. The two biggest ones, elastomers with 30 % and steel alloys with 20 %, respectively, were hotspots comprising a widely varied supply chain, making it difficult to attribute the water consumption to a specific supplier or a specific set of suppliers. The platinum-group metals, however, making up the third hotspot with 14 %, were characterized by a relatively short supply chain as there are only a handful of platinum-group-metal mining organizations, most of which have their operations in South Africa. Thus, it seemed that the initial assumption of platinum-group metals being a hotspot on which to try implementation of water-stewardship measures had been justified.

4.4.2.4 Impact Assessment

The indicator used for describing the environmental impact of the water consumption was the water depletion index (WDI) according to the WAVE model (Berger et al. 2014).

The initial impact assessment results for this case study are shown in Figure 21, with a regionalization based on the geographically explicit water inventory database by thinkstep (cf. section 3.2), broken down to the country level. Only those results are displayed here that contributed at least 1 % to the water consumption and/or the water depletion index.

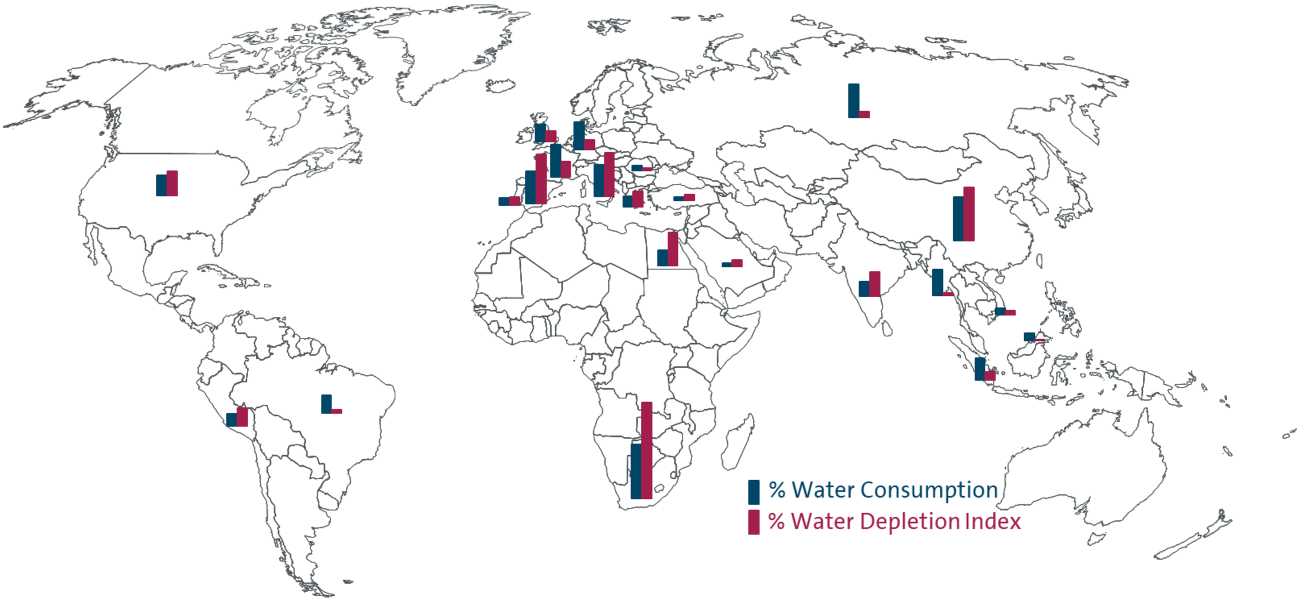


Figure 21: Initial Impact Assessment and Regionalization

The main water use impacts were distributed over 22 countries, with the highest impact in South Africa, Europe (including Russia), China, Southeast Asia, and the United States of America. High potential water consumption in a region did not necessarily lead to potential high water stress in the same region (e.g. in Southeast Asia). On the other hand, a relatively low potential water consumption (e.g. in Egypt) could lead to a comparatively high potential water stress.

4.4.2.5 Interpretation

As expected, South Africa emerged from the Organizational Water Footprint assessment as the major hotspot for water consumption and water stress. This was caused not only by the abovementioned platinum-group metals, but also by the energy and water consumption of Volkswagen's automobile production plant in Uitenhage. Additional contributions were caused by several minor material categories that were per default attributed to the country (South Africa) in which the assessed production facility is located (due to insufficient regionalization data).

Looking at the initial data, approximately one third of the water consumption and accompanying water stress caused in South Africa could be attributed to the platinum-group metals; a high contribution, in particular when considering that only a few grams of platinum-group metals are used in each car.

Platinum-group metals also made up more than 40 % of water consumption in Russia (the rest consisting of steel, aluminum, and fuel production), but other than in South Africa, this water consumption did not cause much water stress.

Thus, after determining water consumption and water stress by rather generic data, it seemed logical to analyze the local water risk of platinum-group metals in South Africa in more detail.

4.4.2.6 Analysis of the local water risk (WP5)

After determining regionalized water consumption and water stress and confirming that platinum-group metals mined in South Africa were indeed a hotspot in terms of water consumption as well as in terms if causing water stress, the local water risk in South Africa was analyzed.

In a first step, sustainability reports of the South African platinum-mining organizations and their operations were analyzed. Of these, only the sustainability development report 2018 of Lonmin (Lonmin 2018) reported a water consumption per ounce of PGMs produced that was suited to compare it with the data so far gathered.

In the Lonmin report, a substantial mismatch between the water consumption data reported and those used by thinkstep was revealed. Whereas the thinkstep GaBi database (as of service pack 36) assumed a water consumption of 44 to 51 m^3 per ounce of PGMs, Lonmin reported only a water consumption of 6.23 m^3 per ounce of PGMs for 2018 (for previous years, it had been even lower at 5.58 to 5.76 m^3 per ounce of PGMs). After communication with thinkstep, it became clear that the thinkstep data contained calculation errors and that the data reported by Lonmin were more accurate.

With these new information and corrected data provided by thinkstep, the water inventory analysis as well as the impact assessment and the regionalization needed to be repeated, with the following results (cf. Figure 22and Figure 23).

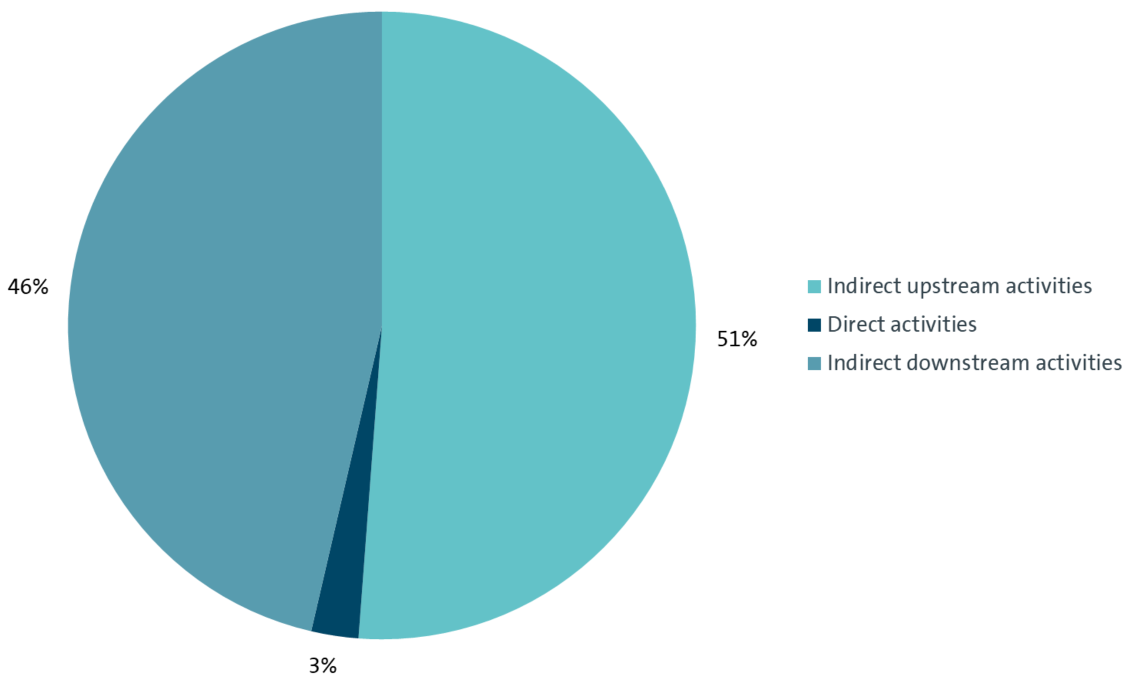


Figure 22: Corrected water consumption distribution of Uitenhage plant

The reduction in water consumption due to the corrected platinum-group-metal data led to a lower overall water footprint, a reduction of the indirect upstream activities' proportion by three percentage points, with a corresponding increase of the direct activities' proportion by one percentage point and the downstream activities' proportion by two percentage points. The overall picture of upstream and downstream activities each contributing roughly half to the water consumption with a neglectable direct activities' contribution remained approximately the same.

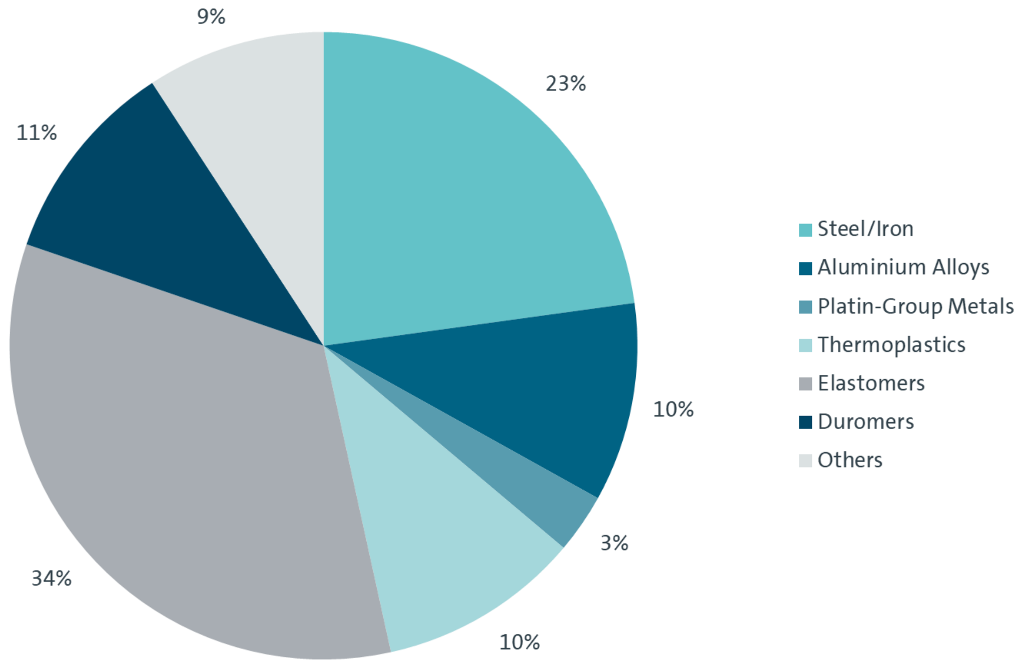


Figure 23: Corrected water consumption distribution in the supply chain

As expected, the contribution of platinum-group metals to the upstream activities' water consumption was reduced significantly (from 14% to 3%; with regard to the whole water footprint to 1.5%), thus effectively eliminating the previously expected hotspot. Thus, it made no sense to focus on platinum-group metals anymore.

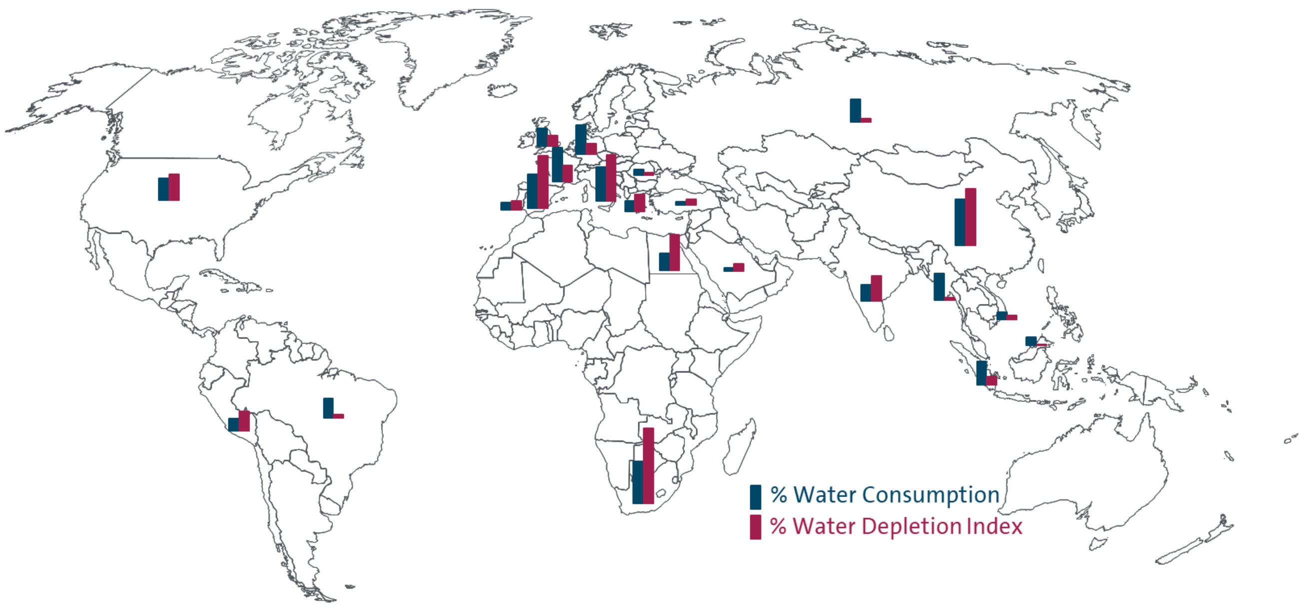


Figure 24: Corrected Impact Assessment and Regionalization

4.4 Organizational Water Footprint case studies

Following the corrections of platinum-group-metal data, the contribution of South Africa to the water consumption sank from 11.4% to 8.8%, leaving the possibility of further reduction. The remaining water consumption, as mentioned above, was divided between the plant's direct water consumption, the water consumption caused by its energy consumption, and several minor material categories that were per default attributed to the country of the plant (due to having no sufficient regionalization data).

Of these, only water and energy consumption at the plant would have been suited for an attempt at mitigation measures. However, these parameters were and are subject to reduction goals under different Volkswagen programs (Think.Blue Factory in the past and currently goTOzero), making additional efforts moot.

Other upstream hotspots identified, steel alloys and elastomers, were then analyzed in greater detail, but finally eliminated from the list of possible mitigation candidates. For steel alloys, the supply chain was too heterogenous and complex for mitigation measures within the scope of this project. And while the production of elastomers, and here the production of natural rubber in particular, lead to a significant water consumption, it did not cause a corresponding water stress as the production of natural rubber is mainly located in the Southeast Asian tropics, a region abundant with rain.

After having determined that the indirect upstream activities as well as the direct activities did not contain any more hotspots worth pursuing, the only possible way for analyzing possible mitigation measures were the downstream activities.

4.4.2.7 Mitigation measures (WP6)

As mentioned before, more than 95 % of the downstream water consumption originated from the fuel production, in particular from the bio-fuel part of most current fuels. Significant parts of water consumption in the United States, Peru, Spain, Italy, and Egypt could be attributed to the crop production for this bio-fuel portion. However, local water mitigation measures in these countries were not deemed promising, as introducing change to business practices of external stakeholders from the fuel industry was regarded challenging. Therefore, alternative mitigation measures were examined. Two scenarios were analyzed in detail: the use of alternative fuels from waste, and the electrification of vehicles.

For estimating the effects of using alternative fuels from waste, TU Berlin developed an Excel tool to assess several scenarios based on the kind of alternative fuel and on the percentage of the vehicle fleet fueled by the respective fuels (cf. Figure 25). For most vehicle segments, the percentage of fleet customers is more than 50 %. Based on experience, only vehicles used by Volkswagen and those used by fleet customers can be influenced to use specific kinds of fuels. For this scenario, we assumed a ratio of 20 % of the vehicle fleet being fueled by alternative fuels, a conservative value concerning the percentage of fleet customers, but admittedly a quite optimistic one with regard to the availability of alternative fuels from waste.

		Scenario 1		
		Alternative fuel 1		
		S1.1 Alternative fuel 1	S1.2 Alternative fuel 1	S1.3 Alternative fuel 1
Parameters	**Unit**	Baseline (no alt. fuel)	First fuelling with alt. fuel	Fleet customers with alt. fuel
Water consumption biofuel	m³/MJ	8,0E-07	8,0E-07	8,0E-07
Water consumption conv. fuel	m³/MJ	1,4E-04	1,4E-04	1,4E-04
Energy density biofuel	MJ/L	34,1	34,1	34,1
Energy density conv. fuel	MJ/L	34,1	34,1	34,1
Vehicle production and properties				
Total vehicle production per year	[-]			
Vehicles' average energy consumption	kWh/Km	0,5	0,5	0,5
Total mileage per vehicle	Kilometres	200.000	200.000	200.000
Downstream fuel usage				
First fuelling per vehicle conv. fuel (considered *downstream*)	MJ	500	500	500
Fuel type for first fuelling	[-]	Conv. fuel	Biofuel	Biofuel
Share of mileage run on biofuel	%	0%	0%	20%
Total water footprint (WF)				
Upstream (indirect)	m³			
On-site	m³			
Downstream (indirect)	m³	-	-	-

Figure 25: Excel tool for calculating the effects of alternative fuels

For the electrification scenario, a battery-electric vehicle (BEV) for the A0 vehicle segment (same vehicle segment as the Polo) needed to be modelled. This was done by using the lifecycle assessments of current A-segment (Golf segment) BEVs as basis. The vehicle weight, battery capacity, and fuel consumption were then scaled down in order to match a vehicle of the A0 segment. The electricity for the use phase was defined as green electricity (here, electricity from wind energy).

Then, the use of alternative fuels from waste as well as a change to electrified vehicles was calculated with regard to the change in water consumption. The results are shown in Figure 26.

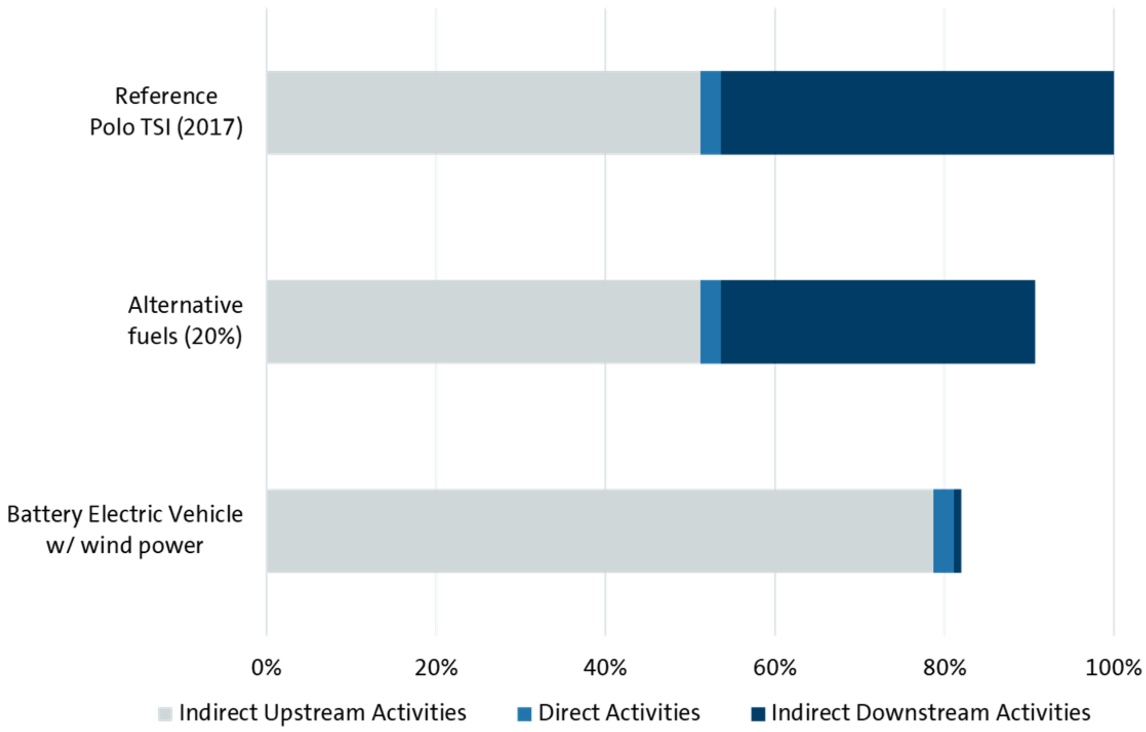


Figure 26: Potential water footprint reduction in alternative mitigation scenarios

With alternative fuels like ethanol from straw or HVO from plant oil waste, the overall water footprint could be reduced by 10 % (assuming that 20 % of the vehicles are fueled by such alternative fuels). Simultaneously, the water consumption (and induction of water stress) in countries like the United States of America, Peru, Egypt, Spain, and Italy could be significantly reduced as there would be less need for growing crops for vintage biofuels.

The same holds true for switching production to battery-electric vehicles powered by wind energy. Although the water consumption in the supply chains is as of now by a factor of approximately 1.5 higher (due to the increased vehicle weight, the battery, and slightly altered material compositions), the water consumption in the use phase is nearly eliminated, which leads to a decrease in overall water consumption of nearly 20 %.

Both scenarios are not classical water stewardship measures, but can still contribute to reducing the Organizational Water Footprint of the Volkswagen plant in Uitenhage, South Africa.

4.4.3 Organizational Water Footprint of the EU Primary Copper production (German Copper Alliance, WP4)

4.4.3.1 Goal

Copper is one of the most important functional materials and thus is in ubiquitary use in both, the commercial as well as in private technospheres around the globe. As an enabler for modern life and in line with the SDGs 7, 11 and 13, the amount of copper used is linked to the number of people living all over the world. In addition, on the one hand, it is well known that the world population is constantly growing. On the other hand, changes in technologies are required towards a decarbonized world. Both developments are running in parallel and both of them are correlated with an increasing demand of copper.

That is why it is necessary to ensure that the value chain of this material is sustainable and any resource, needed for the production of copper, is dealt with in a responsible way (SDG 12). This is especially true for river basins and other freshwater sources. Those need to be very well managed to avoid waters suffering from contamination or artificial shortage to make sure that both, environmental as well as human population demands can be met.

The goal of this Organizational Water Footprint study was to screen and assess the supply chain of the European copper cathode from cradle (mine) to gate (cathode) to discover hotspots of water-use along that value chain. Using this method, potential areas of concern have been identified and allow for developing first recommendations for a best possible management of effected areas. Bottlenecks for both, environmental health criteria as well as a sustainable production measures can thus be minimized.

4.4.3.2 Scope

Due to the fact that copper is a commodity produced and marketed all around the world, the study was limited to the production of copper cathode in Europe, seen as a good proxy for this sector. The total consumption of copper in EU is estimated to 4 mio tons. The domestic production is nearly 2 mio tons and that the basis of the study with the reference year 2015[3]. As ca. 75% of the copper cathodes produced in Europe are based on imported copper concentrate, water consumption data from the corresponding export regions were taken into account. The main regions for concentrate supply are Southern-, Northern- and Latin-America (e.g. Chile, Canada, USA, Mexico) as well as parts of Europe (e.g. Poland, Spain, Sweden). For primary copper production, Spain, Bulgaria, Finland and Poland were considered. Secondary production in Austria, Germany and Spain was also taken into account. The water consumption for the energy supply to the system considered was also accounted for. Infrastructure was not included.

4.4.3.3 Inventory analysis

The data collection took place according to ISO-rules for life cycle inventory. Every process step was screened and its water flow, if any existing, was inventoried. The water-consumption for energy was inventoried also. At the inventory level the source of the water intake was not specified. The focus was put on the water demand for either the process or of the system. Figure 27 shows a scheme of the system boundary.

[3] https://copperalliance.eu/about-us/europes-copper-industry (accessed 23.03.2020)

4.4 Organizational Water Footprint case studies

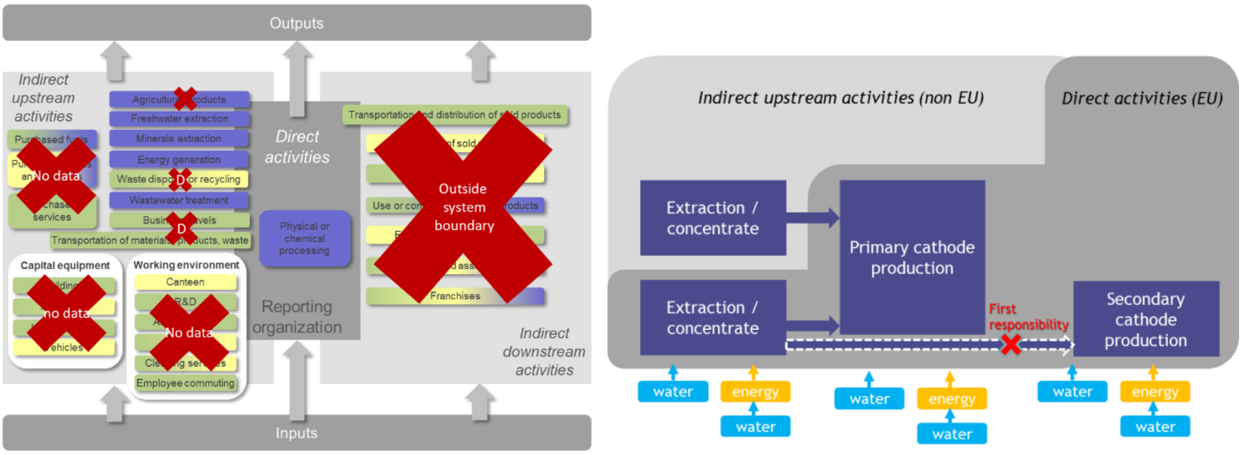


Figure 27: Scheme of the system boundry considered; left: general limitations; right: EU Copper production.

The functional unit is “one tonne of copper cathode produced in EU”. The EU-market has a volume of 4 million tonnes[4]. The inventory covered approximately 50% produced inside EU. All data are based on reference year 2015/2016.

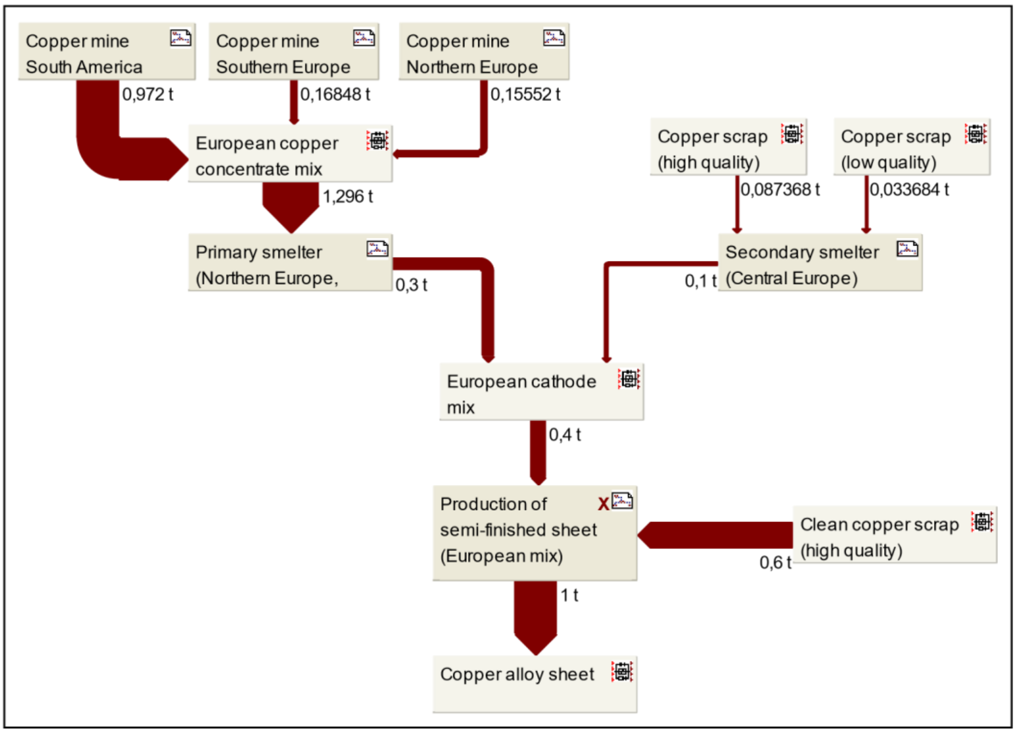


Figure 28: Composition of average European copper semi-finished products from primary and secondary copper and origin of copper ore (Water Footprint Study of the German Copper Institute with the Technical University of Berlin).

4.4.3.4 Impact Assessment

The water consumption of the EU copper cathode production system considered is approx. 59 tons per ton of copper cathode. It can be seen that roughly half of that amount of water is linked to direct activities within EU (smelting, refining and concentrate production) and the other half is allocated to the concentrate supply to EU, mainly in Nord-, Middle- and South-America. That water consumption is therefore part of indirect upstream activities. The contribution of energy carriers and of secondary smelting and refining is of minor importance (Figure 29).

[4] https://copperalliance.eu/uploads/2019/01/where-does-europe-get-its-copper.png (accessed 27.08.2020)

4.4 Organizational Water Footprint case studies

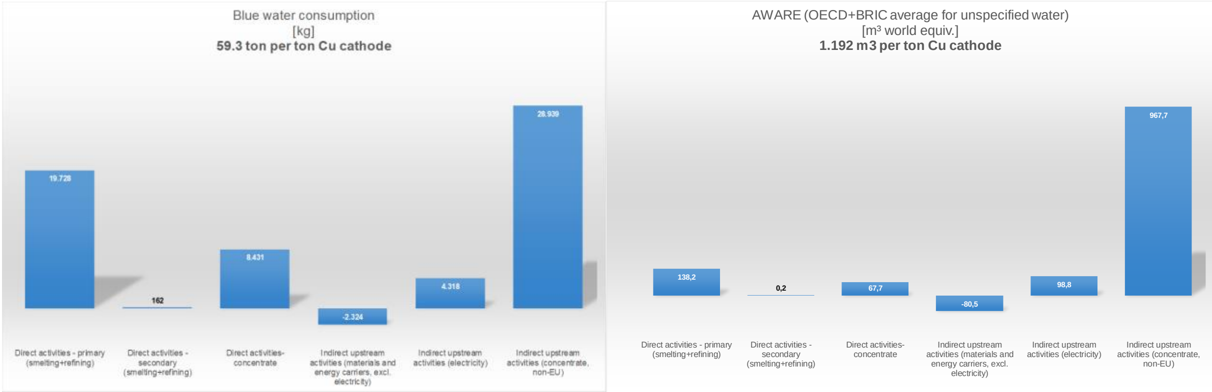


Figure 29: Blue water consumption (left) and Water footprint (right) for copper cathode produced in EU

Using the water footprinting calculation method AWaRe, the water footprint was calculated based on the "water risk non-agri " and "basin-level" AWARE factors. A closer look on the granularity highlighted local hotspots in eastern Europe and in South-America. While the water consumption was nearly balanced between Europe´s internal and external production steps along the copper cathode production chain, the water stress risk is clearly shifted to the external part of the chain, the non-EU indirect upstream activities with approx. 1,000 m³ vs. less than 150 m³ for internal EU-activities (see Figure 30). The impact share is thus 80% outside Europe and 20% for the rest (see Table 5 and Figure 30). The negative values in the last column of table 1 are due to the credits given to the system as compensation of co- and by-products along the production chain (inter alia e.g. sulphuric acid, precious metals).

Table 5: Share of the different compartments of the European copper cathode production chain

	Concentrate outside EU	Concentrate inside EU	Production (smelting/refining inside EU	Electricity inside EU	Material and energy (all credits)[5]
Blue Water Consumption	49%	14%	32%	7%	-4%
Water Footprint (AWaRe)	81%	6%	12%	8%	-7%

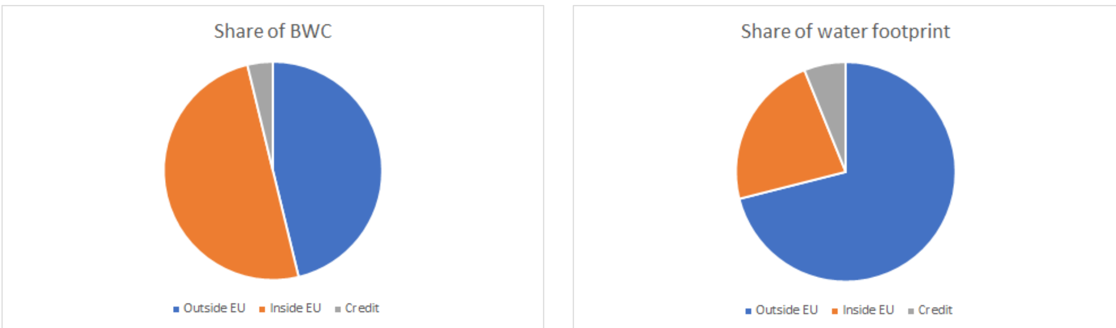


Figure 30: Change in the share blue water consumption (left) vs. water footprint according to AWaRe (right)

[5] The negative values are linked to credits given for co-/by-products

4.4 Organizational Water Footprint case studies

Based on the above results as well as the identified hotspots, stakeholders along the supply chain are able to take action (e.g. water saving, concerted action for local water management).

In principle, water abatement measures in the copper production chain is directly linked to the technology used. Best practices and efficient systems cannot tolerate inefficient use of operating materials or consumables. Water is used at different stages or process steps in the copper cathode production chain (Figure 31).

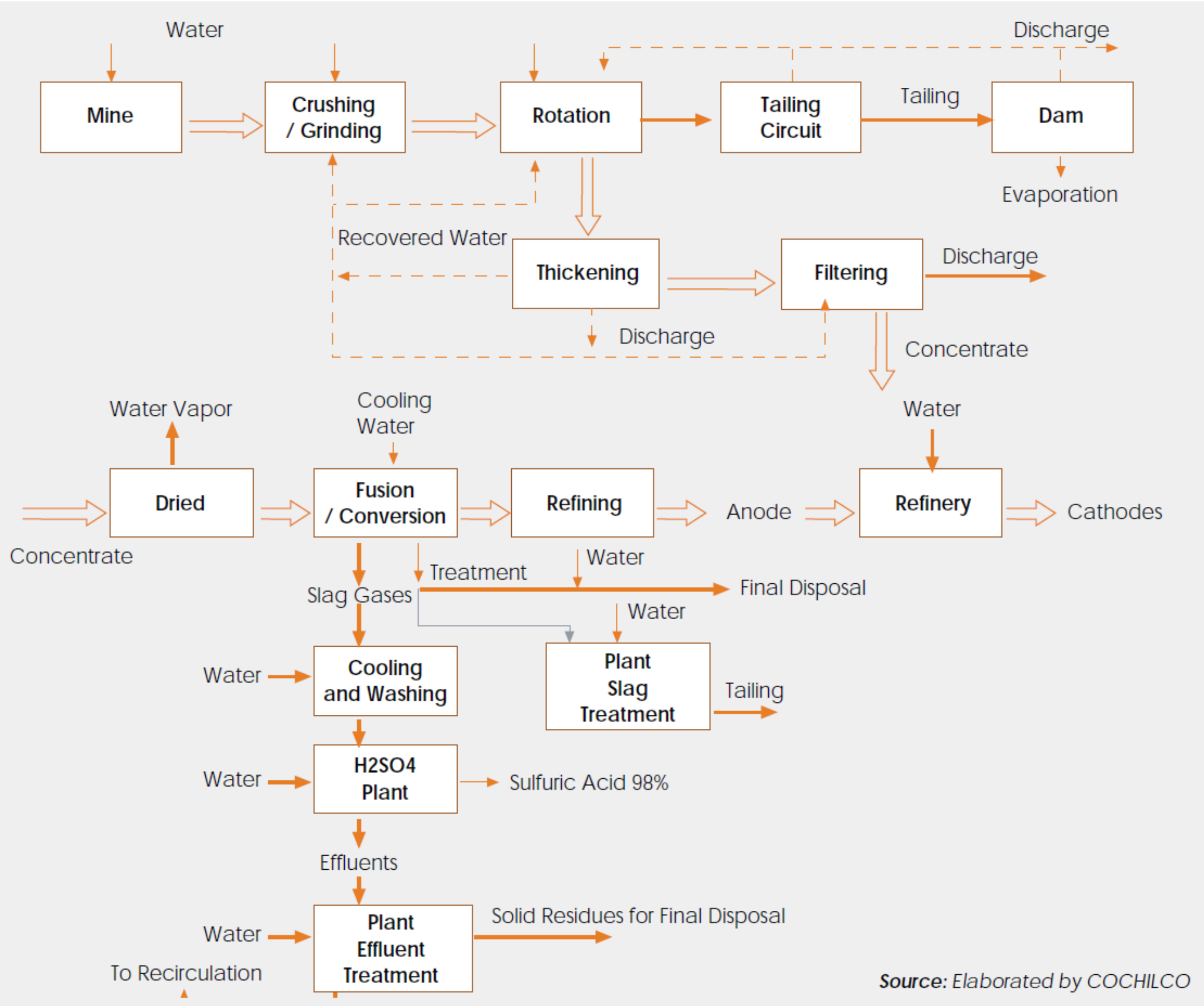


Figure 31: Scheme of water flows for a pyrometallurgical production route as it is common in Europe

In many of the processes a close loop management of water is possible and state of the art (e.g. smelting, electrolysis). At mine and beneficiation level, concentrate needs to be kept wet to avoid dusting. Challenges are open systems (e.g. tailing – not modeled here) or dust control action e.g. wetting of the production site in dry and windy regions.

4.4.3.5 Interpretation

The study highlighted that the hotspot of the copper cathode production in Europe is with 80% linked to indirect upstream activities located outside of Europe. It is sourced from the 75% concentrate import to Europe. South America is the main source region. The water consumption caused by the production and transport of this concentrate is of major importance.

4.4 Organizational Water Footprint case studies

The survey of both, of the system as well as of potential actions indicates, that in water-rich regions (e.g. Northern Europe), the main challenge for a best possible management of water sheds is the correct handling of drainage systems and methods: Here, pit water become surface water during the production and needs related handling to avoid unwanted effects such as pollution (not focus of this project). In contrast, a potential conflict due to water shortages is unlikely to happen.

In arid regions (e.g. partly southern Europe or desert regions in America), the situation is different. Despite the efficient use of water in the production processes, there may be conflicts with the community, agriculture or other sectors.

For the extractive industry in a water-deficient region, the optimal use of water is an existential question. In addition to the high risk of evaporation, the issue of availability is a major problem. This is why the best available technologies are used. This shows also that the issue of mitigation is a technological one. However, new technologies are costly. At this point, in discussions with the European stakeholders, the question was raised on how to achieve best a significant impact for the water saving. With the reduction of the European water risk to zero, the non-European share (80% water risk) will not be significantly affected. The processes taking place at non-EU sites are outside the control of European organizations and do not offer any opportunities to exert influence.

An approach to this challenge could be the community-solidarity approach along the whole supply chain. Supports and actions need to be intensified there, where the greatest impact can be reached. This would be a paradigm shift in the policy that needs to be discussed at all levels of the chain (mine, smelter, fabrication) in order to reach a meaningful consensus.

4.4.3.6 Analysis of the local water risk (WP5)

Looking at the EU-local situation direct activities, the primary production represents 32% BWC respectively 12% AWaRe (see Table 5). The hotspot could be tracked and identified in eastern Europe (Figure 32). While in dry region e.g. desert areas in America the lack of water might represent the challenge to deal with, in eastern Europe water is abundant. One of the major copper production stakeholders is KGHM in Poland. However, if one considers all activities both the mining/beneficiation and the smelting/refining KGHM is rather a netto producing company as through their mining activities enough water is drained and used for all processes requesting water[6]. Nevertheless, water use and water treatment remain extremely important for a sustainable production. This require best practice of water management as shown by KGHM.

[6] https://kghm.com/en/sustainable-development/environment/water-management (accessed 27.08.2020)

4.4 Organizational Water Footprint case studies

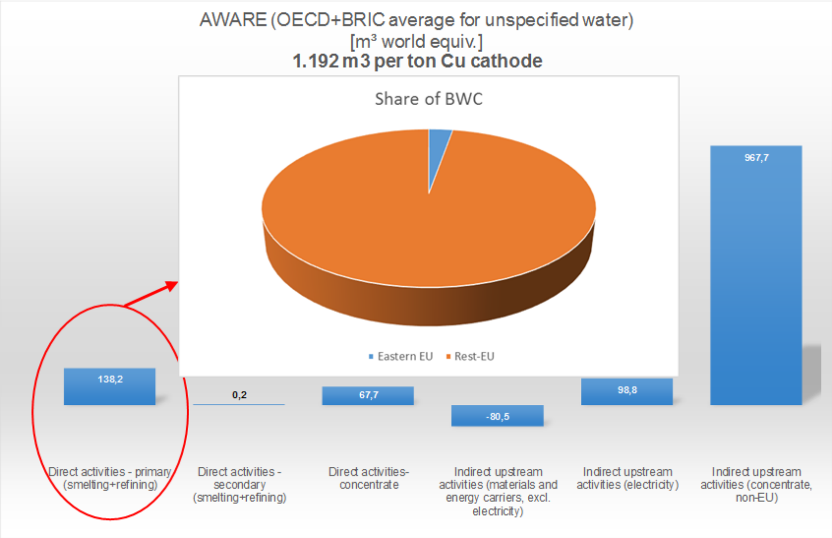


Figure 32: Hotspot of local water risk

4.4.3.7 Mitigation measures (WP6)

As part of the mitigation strategy, discussions took place with relevant stakeholders in the copper production chain (workshop with Aurubis in Hamburg), discussions planned with Coldelco in Chile and KGHM in Poland.

At Aurubis as well as at KGHM both located in Europe, the share of the local activities does not represent the hotspots of the whole supply chain (mining to copper cathode). However, Europe water risk stream is dominated by eastern Europe. Taken individually KGHM is making best use of the drainage water from their mines and Aurubis is located at the embouchure of the Elbe near to the Baltic sea. Therefore, the challenge is more the water contamination (not the focus of WELLE) and the optimal water management to keep the production as efficient and sustainable as possible.

4.4 Organizational Water Footprint case studies

4.4.4 Organizational Water Footprint of Neoperl GmbH (Neoperl GmbH, WP4)

The following chapter is based on the following publication which is a direct output of the WELLE research project:

Forin, Silvia, Jutta Gossmann, Christoph Weis, Daniel Thylmann, Jonas Bunsen, Markus Berger, and Matthias Finkbeiner. 2020. 'Organizational Water Footprint to Support Decision Making: A Case Study for a German Technological Solutions Provider for the Plumbing Industry *https://welle.see.tu-berlin.de/data/np_case_study.pdf.*

4.4.4.1 Goal

Neoperl offers water-saving products for a large number of applications in faucets, showers or kitchens, in private bathrooms, hotels or public toilets. NEOPERL® water savers ensure that as much water as necessary is used, but as little as possible to provide comfort of use while conserving water. Following and expanding this approach, the study aimed at determining the organization's freshwater consumption and the resulting potential impacts throughout the value chain. Based on the study results, options to reduce water consumption were identified and considered at the management level. In addition, the study intended to increase awareness on local scarcity issues worldwide and the perception of Sustainable Development Goal 6 (ensuring availability and sustainable management of water and sanitation for all) within the organization and in external communication activities.

4.4.4.2 Scope

The organization investigated in this Organizational Water Footprint study is NEOPERL GmbH which has a production site located in Müllheim, Germany. The reference period considered is the solar year 2016, the last period prior to the start of the study for which complete data was available. The reporting unit is the amount of sold products during the reporting year 2016 (554,000,000) and is based on organization-own records for the reference year 2016 and according to Neoperl's own product categorization system.

The study was conducted cradle-to-gate, considering direct activities and indirect upstream activities (mainly material purchase). The assessment from 2016 also included supporting activities such as physical infrastructure (e.g. buildings and machines) and working place related activities (e.g. canteen service for employees). Indirect downstream activities (e.g. end-of-life of sold products; see below) were excluded. Products, though deployed in water distribution devices, do not use water themselves; some rather foster water savings through the application of flow regulators. A scenario analysis including water savings was carried out in the interpretation phase. The end-of-life phase was not included because Neoperl's products are mainly sold as intermediate products and embodied in final devices, distributed all around the world. It was not possible to track their final destination nor to predict their end-of-life fate. However, the products are typically in use for at least 10 years.

4.4.4.3 Inventory analysis

Prioritization of data collection effort for water scarcity footprint

The inventory data needed for the study is the freshwater consumption related to NEOPERL's operations and upstream supply chain, and the location at which freshwater consumption takes place. In line with the organizational modelling introduced by the Guidance on Organizational LCA (Martínez Blanco et al. 2016).

Adopted from the OWF method, the inventory is categorized into activities, which are in turn grouped according to their position within the value chain into direct activities, indirect upstream activities, and indirect downstream activities (excluded in cradle-to-gate assessments). The categorization is shown in the following figure:

4.4 Organizational Water Footprint case studies

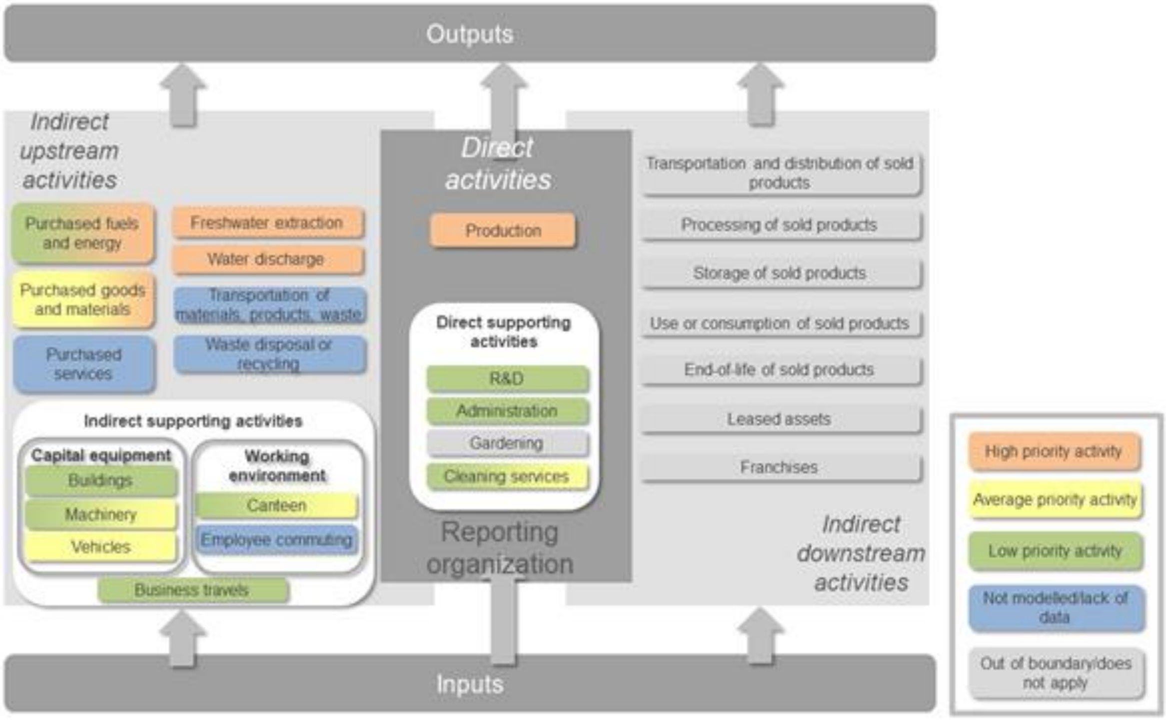


Figure 33: Neoperl's organization model for the organizational water scarcity footprint case study.

The highlighted (non-grey) activities are those carried out within the organization. Grey activities are out of the system boundary or do not apply for the organization. Blue activities are taking place at Neoperl, but were not modelled due to missing data.

Broad activities, such as purchased goods and materials, were further categorized into material groups (e.g. metals, chemicals/plastics) and materials (e.g. steel, aluminum, PET), in line with the WELLE tool.

Primary freshwater consumption data was available for direct activities at the facility level. Direct freshwater consumption refers to all on site activities: production, administration, research and development, and cleaning. It was calculated as water input (tap water dataset in the WELLE database) minus water output (wastewater dataset) for the overall production site, since no separated water metering was available for different activities within the facility gates. For purchased energy, goods and materials, secondary freshwater consumption data and process location information from the WELLE database was used. The amount of purchased energy, goods and materials was determined via purchase records following the top-down data collection approach suggested by the Guidance on Organizational LCA (Martínez Blanco et al. 2016).

The freshwater consumption of supporting activities was estimated via proxy data sets available in the WELLE database. Freshwater consumption caused by business travels was estimated via the amount of purchased Diesel. The estimation is limited to business travels by car, since the no complete records of business travels by other means of transport (train, plane) was available. For the canteen, the average amount of canteen clients per day was multiplied by 230 working days per year. The meal mix “with meat” from the water consumption database as well as one soft drink per person per meal were assumed. The upstream freshwater consumption through workplaces (furniture and electronic devices) was assessed by using a proxy dataset assuming each workplace endowed with one table, one chair, one laptop and one screen.

Capital equipment was included and assessed through proxy values. For organization-own vehicles, a proxy freshwater consumption value for a vehicle and the vehicle lifetime was considered. For machinery and buildings, the material composition was considered, divided by the estimated lifetime. The material data was retrieved from organization-own records.

4.4 Organizational Water Footprint case studies

Inventory analysis results

Neoperl's total freshwater consumption in 2016 was approx. 109,667 m³ out of which only 2% occur at the production site. 96% of water consumption takes place in the upstream supply chain and another 2% in the supporting activities.

Metals supply is responsible for 55% of the organizational water footprint (see following figure). Among metals, stainless steel plays a dominating role, contributing 74% of the freshwater consumption related to metals purchase (which equals 41% of Neoperl's total freshwater consumption), followed by brass (11% of total freshwater consumption). Inventory data on metals consider the market average content of secondary material.

In the chemicals/plastics category, polyoxymethylene granulate (POM) alone contributes around 50% of freshwater consumption, followed by polyethylene cross-linked (PEXa) (21%).

The fuels and energy category (12% of total freshwater consumption) is dominated by grid electricity due to cooling water evaporation. Other purchased materials (mainly cardboard, wooden pallets, silicone) account for 7% of total freshwater consumption.

Supporting activities have the lowest relative freshwater consumption (2% or total freshwater consumption) among the activity categories considered in this study. The main contributor (53%) is machinery (capital equipment), mainly due to the aluminum components, followed by canteen food (27%).

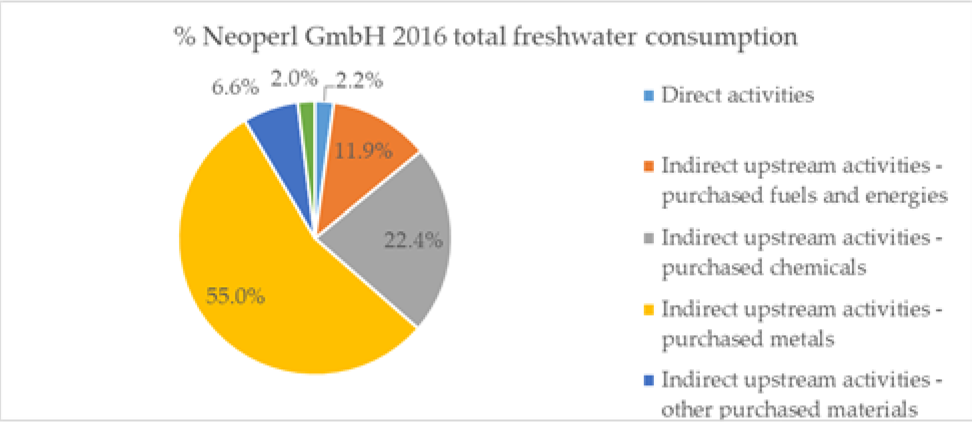


Figure 34: Activity contributions to Neoperl's blue freshwater consumption

Neoperl's direct and indirect freshwater consumption takes place in 34 countries throughout the supply chain. However, the picture is dominated by five countries accounting together for around 74% of Neoperl's supply chain freshwater consumption: China (28%), Germany (21% + 2% at the facility's location Müllheim), Italy (8%), Chile (8%) and Indonesia (7%) (Figure 35).

Figure 35: Total freshwater consumption by country/location

4.4.4.4 Impact Assessment

The resulting local consequences of freshwater consumption were calculated by means of the AWaRe method. Country-level characterization factors were used, according to the origin of materials recorded by the organization or to the import mix available in the WELLE database. The basin-level marginal AWaRe factor was chosen to characterize the freshwater consumption originating from the production site in Müllheim, Germany.

By activity category, the main contributors are purchased metals (78%), with stainless steel and brass dominating the picture with a contribution of 49% and 25%, respectively. Purchased chemicals potentially impact water scarcity as well (17% of Neoperl's water scarcity impacts in 2016).

Neoperl's activities and upstream operations' water scarcity impacts can be mainly localized in China (40%), Chile (23%), Italy (12%), and Indonesia (5%) (Figure 37).

A closer look at the major hotspots shows different distributions of local impacts. While 90% of impacts related to purchased brass are located in Chile (due to copper in the upstream chain), stainless steel shows a more diverse picture. More than half of the impacts are in fact located in China (53%), 11% in Indonesia, 15% in Italy and 4% in Australia. Further 7% are allocated to the "other/unspecified" category and mainly include Nickel production in New Caledonia. New Caledonia belongs to France, but, due to the distance to the French mainland, is not included in the calculations of the country-wide characterization factor. For this reason, the global average characterization factor was applied instead in the WELLE database for materials consuming freshwater in this region.

Besides metals and chemicals, water scarcity impacts could be identified also for further materials and activity types. Direct activities, responsible for ca. 2% of freshwater consumption, only contribute 0.1% when it comes to water scarcity impacts. This is due to the low AWaRe characterization factor for the Müllheim area, which equals 0.7 (*low water scarcity risk*) on a scale between 0.1 and 100.

The fuels and energy categories contribute 1.3% of water scarcity impacts, 98% thereof due to grid electricity.

Supporting activities are responsible for 2.5% of Neoperl's water scarcity impacts. The main contributor in this category (61%) is machinery (capital equipment), around two thirds thereof due to the aluminum components. The second largest contributor within this category is the organization's canteen (25%).

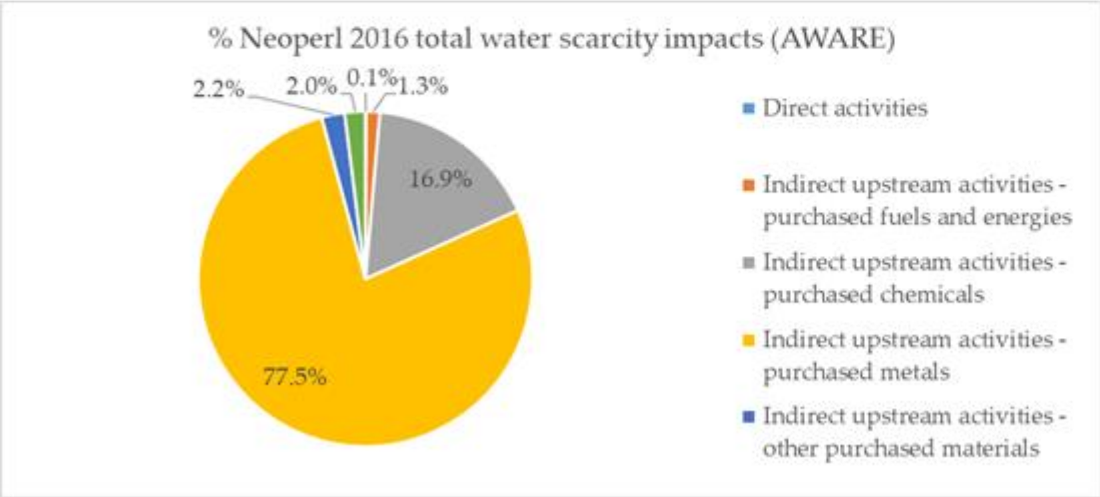


Figure 36: Total water scarcity impacts by activity category

Figure 37: Total water scarcity impacts by location/country

4.4.4.5 Interpretation

The case study allowed identifying Neoperl's material and geographical hotspots in terms of water consumption and resulting impacts. In addition, the study offered the possibility to gain insights in the supply chain and consider different impact mitigation options.

The main contributors emerging in the inventory analysis (brass and stainless steel in the indirect upstream activity purchased materials) turned out to be even more relevant after carrying out the impact assessment, due to the relatively high level of water scarcity in the countries where freshwater consumption takes place. The precision of results might be negatively influenced by temporal discrepancy between different data sources used in the calculation needs to be acknowledged: purchase data (mass) refers to the reporting period 2016, whereas freshwater consumption data retrieved from the WELLE database is partly older, thus possibly reflecting the corresponding technological state of the art. In addition, the AWaRe method used for characterization is based on freshwater consumption and availability data from the WaterGAP model (Flörke et al. 2013) dating back to 2010.

Discrepancies can be found also in the regional resolution of characterization factors. As described in section 4.4.4.3, inventory belonging to different activities was characterized at different geographical scales (basin level for direct activities, global level for unspecified flows, country level for most activities and materials). The scale was chosen by seeking the best possible precision. Therefore, direct freshwater consumption was characterized at the basin level (the location of the production site being known), while most purchased goods and services were attributed to the country of origin according to the companies purchase records or to worldwide production mixes.

A scenario analysis is conducted by taking into account the water saving potential of the flow regulators produced by the company and inserted in other devices during the use phase against a baseline that does not foresee the use of flow regulators. The aim of this exercise is to understand whether the water savings obtained in the use phase of sold products outbalances the company's cradle-to-gate water footprint. The analysis is conducted only at the inventory level, since no information on the location of water consumption is available, which would allow for assessing (avoided) water scarcity impacts. The reason is that Neoperl's products are mainly sold to faucet producers, which are in turn also possibly involved in business-to-business operations. Following the downstream value chain would require data from both first and second tier clients, which would go beyond the scope of this study.

The water saving potential of a flow regulator throughout its lifetime (assumed being 10 years) relies on the assumptions met in the product-related study by Berger et al. (2015) and is 166.2 m^3 of water use and 0.79 m^3 of water consumption. Multiplied by the amount of flow regulators sold by Neoperl in 2016 (30,000,000 pieces), 4,986,000,000 m^3 water use and 23,700,000 m^3 water consumption can be avoided against a baseline that does not foresee the use of water saving devices. In comparison, Neoperl's cradle-to-gate water consumption (109,667) represents 0.46% of water savings through product use. This can be seen as a conservative estimation, since it does not consider an additional amount (29,000,000) of flow regulators built in a wide range of aerators, for which an assumption on total water savings and water temperature can only be made after thorough investigation in the wide spread water usage behavior of consumers.

4.4.4.6 Analysis of the local water risk (WP5)

Analysis of the data with the WELLE tool revealed countries with the highest water risks and gave Neoperl a detailed understanding of possible impacts.

Initially, Neoperl planned to focus on assessing and mitigating the local water risks directly. However, as was discovered during investigation of the supply chain, Neoperl unfortunately has no direct influence on its suppliers mainly due to the multi-stage purchasing process.

In the case of brass, which is mainly sourced from Italy and Germany, an attempt was made to trace the specific upstream chains for the production of brass. Neoperl, in cooperation with the purchasing department, has contacted the respective suppliers. However, it turned out that on the one hand the suppliers of brass do not uniformly source the raw materials for brass production from one region and on the other hand do not want to reveal their sources of supply. In addition, a large part of the copper required for brass production is traded on the stock exchange where raw materials are traded without a certificate of origin.

In the case of stainless steel, Neoperl changed suppliers and it was not possible to contact the former Chinese suppliers from 2016 and to retrieve the information about their purchase channels supply. Therefore, no statement can be made about the complex conditions at the location of the suppliers. Consequently, the possible actions on reducing the local risk have been limited.

Under these circumstances, no site-specific water risk analyses are possible.

4.4.4.7 Mitigation measures (WP6)

The fourth and last step of the WELLE approach consists of transforming the knowledge gained from the OWF analysis into actions which can reduce water consumption and resulting impacts throughout the supply chain. Being water scarcity a local phenomenon, it is crucial to know where hotspots are located, i.e. to trace back, geographically, the purchased products through to the raw material stage, which is often the most relevant contributor to value chain water consumption. While trying to follow the provenience of materials throughout multiple tiers, Neoperl encountered two main obstacles.

First, inquiries to suppliers had a poor response rate and no useful information (e.g. exact location of second tier suppliers) could be obtained. Additionally, the main purchased goods are generic intermediate materials that are traded under high price pressure, which makes it difficult to establish long-term relationships and foster data exchange. This might be easier for companies purchasing more specific intermediate products subject to advanced technical requirements, which makes stable trade partnerships more likely.

Second, metals such as copper and nickel, detected as hotspot alloy elements for brass and stainless steel respectively, are traded at the stock exchange, which makes it even more difficult to trace back the actual supplier. To cope with these limitations, origin certification approaches such as those in place for conflict minerals might be adopted, since they proved to allow penetrating several supply chain tiers.

Due to these difficulties in tracing back materials to the exact supplier, generic import mix data provided in the WELLE database had to be used. While this allowed for determining local hotspots in a generic way, it affected the range of possibilities Neoperl had to mitigate their water scarcity impacts. In fact, options such as initiating water stewardship partnerships with suppliers or raw material providers could not be pursued since the exact hotspot suppliers (mainly second tier or beyond) could often not be identified, and due to limited leverage on first-tier suppliers, which did not deliver information on the origin of their materials.

As an alternative, options for sustainable purchase have been discussed in a workshop attended by Neoperl's owner, CTO, the purchase department and the environmental management department. In this workshop the company's top-management has decided to continuously track Neoperl's corporate water footprint. In order to reduce the organization's water consumption throughout the supply chain, eco-design measures at the level of material hotspots were explored. Specifically, it was considered how hotspot metals (stainless steel and brass) could be substituted by less critical alternatives. Neoperl already has, in its hoses production lines, stainless steel and plastics (PA6) reinforcement options, the latter currently produced in a lower number of pieces. The freshwater consumption and potential water scarcity impacts of these two materials are compared in Figure 38. While Figure 38a) and b) compare the freshwater consumption and water scarcity impacts for one ton of stainless steel and PA6 respectively; Figure 38c) and d) shows the impact for the specific substitution case, in which 125 tons of stainless-steel could be replaced by 27.5 tons of PA6 to reinforce the same amount of hoses. This results in a reduction of water consumption and potential water scarcity impacts of 96% and 97%, respectively.

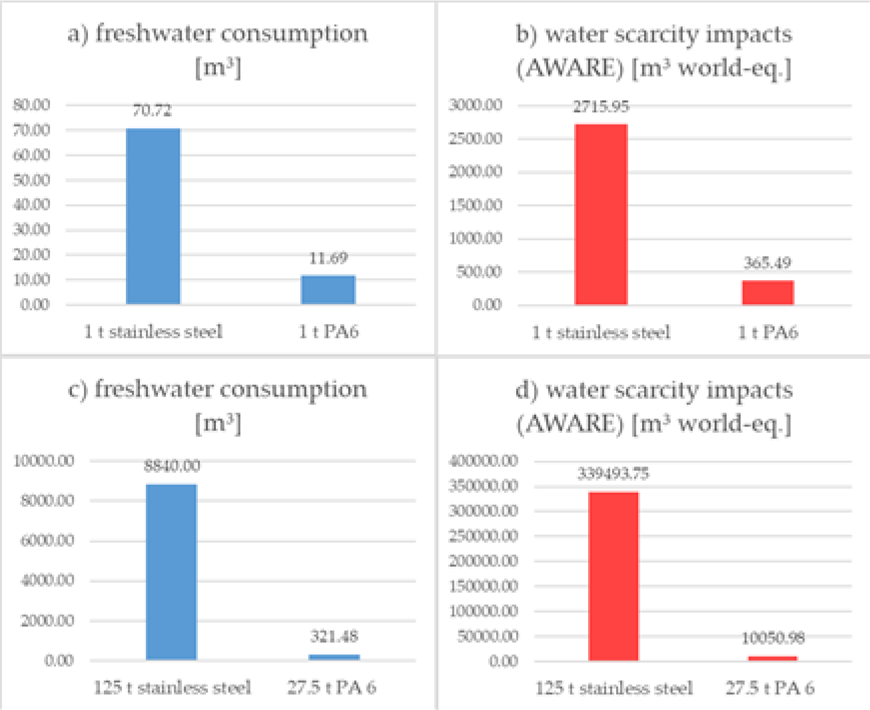


Figure 38: Comparison between the freshwater consumption and the potential water scarcity impacts of stainless steel and PA6. A comparison by mass is provided in a) and b); c) and d) compare the results for the respective amounts of stainless steel and PA6 needed to reinforce the same number of hoses. Calculations were realized via the WELLE tool.

However, decisions on material substitution, as well as changes in production processes or the selection of supplier, should not be based on a single-indicator assessment only to avoid burden shifting to other environmental impacts (e.g. reduce water scarcity impacts by increasing the global warming potential). For this reason, a comparison of the material alternatives according to other impact categories is planned to provide a meaningful ex-ante assessment of the material substitution option.

4.5 Water risk analysis (WP5)

The water footprint case studies conducted in WP4 revealed water related hotspots in the supply chains of the industry partners. However, sometimes several hotspots were identified and it is difficult to say whether a hotspot determined by a global analysis, really is a problem on the ground. In order to analyze the concrete situation at organizations' or suppliers' production sites, a more detailed water risk analysis was conducted in this work package.

The water risk assessment partly followed steps of the WWF water risk filter (WWF 2016) and addressed three dimensions namely physical water risk, regulative risk (possible legislative changes, compliance with legislation) and reputative risk (e.g. towards local stakeholders, consumers, customers or international media).

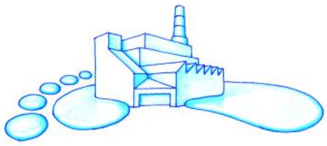
For the analysis a comprehensive questionnaire had been developed by TU Berlin which covers 37 questions addressing the three risk dimensions (Figure 39). Addressees of the questionnaire are the suppliers of the case study partners or other participants in their value chain who were classified as hotspots according to the Water Footprint assessment. The results of the water risk assessment of the individual industry case studies are presented in sections:

- 4.4.1.6 Evonik
- 4.4.2.6 Volkswagen
- 4.4.3.6 German Copper Institute
- 4.4.4.6 Neoperl

Those hotspots in the organizations' supply chains which had turned out as problematic in terms of water risk were chosen as starting point for the development of water stress mitigation measures presented in chapter 4.6

4.5 Water risk analysis

Please fill in this questionnaire to estimate your company's water-related Operational Risks and Responses.
The questionnaire is adapted from the WWF Water Risk Filter (http://waterriskfilter.panda.org) for the WELLE project.



Operational Risk

Physical Risk

Scarcity (Quantity)

O1. In which ways does the site use water?

Domestic purposes (drinking water & sanitation) only

O2. How important is the current and future use of water quantity and quality for operating/processing at this site?

O3. Has the site had problems withdrawing the required amount of water for its operations OR has the site experienced a significant flooding event affecting operations?

O4. What is the total annual amount of freshwater withdrawn (directly from any water source including municipal supply utilities) in m³/year?

.....

Regulatory Risk

Laws & Policy

O7. Relative to other water users in your local catchment (~ 50km radius), does this site face heavy water-related regulation and legal enforcement?

O8. Is the company exposed to planned or potential significant regulatory changes at this site?

Institutions & Governance

O9. Is the site always in compliance with legal waste water quality standards?

O10. Has this site been subject to any fines, enforcement orders, and/or other penalties for water-related regulatory violations in the last year?

O11. Does an official forum or platform exist in which the site and stakeholders come together to discuss water-related issues of the basin?

Reputational Risk

Media scrutiny

O12. Has there been any local/national media coverage that identifies this site (negatively) on a water issue in the past 5 years?

O13. Has there been any global media coverage that identifies this site or its parent company (negatively) on a water issue in the past 5 years?

Community conflict

O14. Relative to other water users in your local catchment (~ 50km radius), would you consider the site a large water user/polluter?

O15. Relative to other water users in your local catchment (~ 50km radius), is the company associated with the site a recognized brand (to the local public)?

O16. How would you describe this site's general water management/stewardship maturity?

O17. Has the company had involvement in any water-related disputes with other stakeholders in the basin within the last 5 years?

Other

O18. How important/material is this site to your company?

O19. What is the annual production volume for the site (primary or all products)?

O20. What is the number of full time equivalent employees (FTE) work at this site?

O21. If you have any final comments, please add them here:

Operational Responses

R1. How has this sites water-related capital expenditure changed (CAPEX) over the past 12 months compare to the previous 12 months?

R2. How has this sites water-related operating expenditure (OPEX) over the past 12 months compare to the previous 12 months?

R3. Please specify to which level this site discloses and reports against their water useage?

R4. Please specify to which level this site engages in developing awareness and capacities around local water issues?

R5. Please specify to which level this site builds water into its business planning and strategy processes?

R6. Please specify to which level this site engages in water-related collective action?

R7. Please specify to which level this site has developed its internal and external water governance efforts?

R8. Please specify the level of technology / infrastructure implemented at this site to address water challenges?

R9. Please specify to which level this site measures and manages it water use performance in operations?

R10. Please specify to which level this site has developed its internal water policies, standards and plans?

Figure 39: Questionaire to estimate an organization's water risk at different sites

4.6 Water stress mitigation (WP6)

Next to enabling organizations to determine and analyze their water footprints, it was a central goal of the WELLE project to identify options to mitigate water stress at hotspots along organizations' supply chains. The four WELLE case studies and other studies have shown that an organization's direct water consumption contributes to less than 5% of its total water footprint only. For this reason, optimization strategies need to consider an organization's entire value chain. Next to on-site focused environmental management systems (EMAS, ISO 14001), water stewardship measures, ecodesign approaches, and a sustainable procurement strategy are advocated (Figure 40). The concrete application of these measures in the case studies is presented in the sections above. In the following a general discussion of these strategies is presented.

While the leverage of reducing an organizational water footprint is usually larger in supply chains, the organization's control on water consumption patterns is decreasing along supply chain levels. Ideally, an organization's water scarcity mitigation strategy comprises the concurrent implementation of several measures tackling all water use hotspots regardless of the life cycle stage at which they occur. When trying to reduce an organizational water footprint, care should be taken to avoid shifting water-related environmental impacts to other environmental burdens (e.g. the carbon footprint).

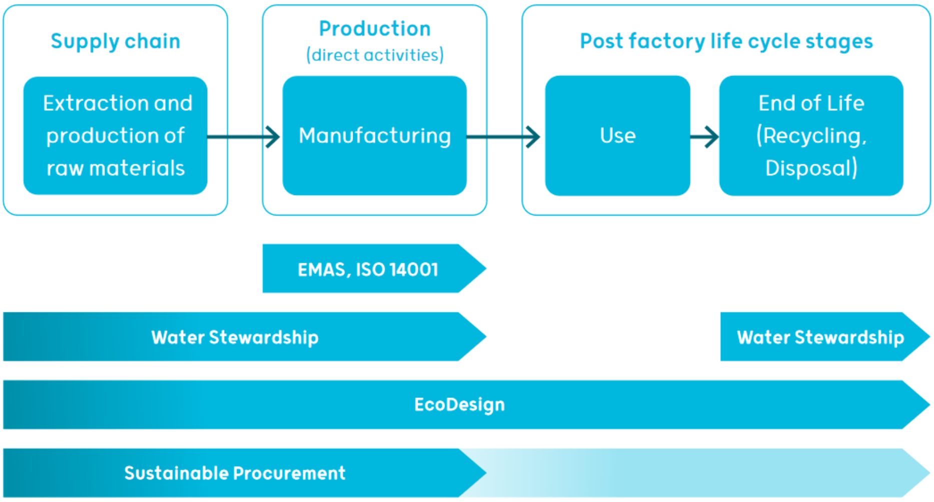


Figure 40: Measures for reducing an organizational water footprint and the life cycle stages which they target.

4.6.1 Water Stewardship measures

The International Water Stewardship Standard developed by the Alliance for Water Stewardship (AWS) focuses predominantly on sustainable development of local water resources and defines water stewardship as "the use of water that is socially and culturally equitable, environmentally sustainable and economically beneficial, achieved through a stakeholder-inclusive process that involves site- and catchment-based actions" (AWS 2019). Implementation of local water stewardship or comparable measures at an organization's premises can be useful, if an organization's direct water consumption contributes a relevant share to its total water footprint.

If the hotspots of an organization's water footprint have been identified in the supply chains, the organization can try to initiate water stewardship process together with suppliers operating in critical basins. In collective action involving the supplier, other water users in the basin, the local administration, the public, NGOs, and other relevant stakeholders, different measures can be pursued including:

- Increasing water use efficiencies
- Reducing losses in the local water system
- Establishing water allocation plans

4.6 Water stress mitigation

- Joint investments in water supply and waste water treatment technologies
- Improved water governance

If a direct involvement in water stewardship activities of suppliers seems not possible, organizations may request certificates from suppliers to prove responsible water management. If possible, organizations can support suppliers in receiving such certifications. Incentivizing suppliers to introduce sustainability measures may be an easy task for multi-national corporations but can turn out to be difficult for small companies purchasing from large companies. In such cases, companies may want to reconsider their procurement strategy or resort to ecodesign approaches.

4.6.2 Ecodesign

Ecodesign is defined by the European Commission as "a preventive approach, designed to optimize the environmental performance of products, while maintaining their functional qualities" (European Parliament and EU Council 2009) and may be applied under specific consideration of water. Organizations can apply ecodesign to decrease the water footprint of their products and services, and thus of the organization, by considering water use aspects along the life cycle of a product already in its design phase.

- **Supply chain:** Selection of less water intense materials or use of secondary materials (if associated with a lower water footprint)
- **Production:** Apply water efficient manufacturing process, reuse of process and waste water as well as reuse of material clippings during production
- **Post-factory life cycle stages:**
    - **Use:** Design for low water requirements during the use phase of a product or service or provision of consumer guidance for water efficient use
    - **End-of-Life:** Recycling or disposal without water intensive or water polluting processes

4.6.3 Sustainable procurement

As supply chain activities often cause the largest share of an organization's total water use and resulting impacts, the procurement is key in reducing an organizational water footprint. An organization's procurement strategy may be rendered more sustainable in terms of water use impacts by:

- Raising awareness of purchasing departments on the large water use of material production and the relevant influence of purchasing decisions on an organizational water footprint
- Close cooperation between an organization's purchasing- and environmental management department
- Incorporating environmental indicators and targets in purchasing decisions

5 Communication and dissemination

The dissemination of results was ensured by publications in scientific journals and reports, conference presentations, webinars as well as via the project homepage.

5.1 Peer reviewed journals and book chapters

- Silvia Forin, Markus Berger, and Matthias Finkbeiner. 2018. 'Measuring Water-Related Environmental Impacts of Organizations: Existing Methods and Research Gaps'. *Advanced Sustainable Systems,* 2 (10): 1700157. https://doi.org/10.1002/adsu.201700157.
- Silvia Forin, Natalia Mikosch, Markus Berger, and Matthias Finkbeiner. 2020. 'Organizational Water Footprint: A Methodological Guidance'. *The International Journal of Life Cycle Assessment*, 25: 403–422. https://doi.org/10.1007/s11367-019-01670-2.
- Silvia Forin, Markus Berger, and Matthias Finkbeiner. 2020. 'Comment to "Marginal and Non-Marginal Approaches in Characterization: How Context and Scale Affect the Selection of an Adequate Characterization Factor. The AWARE Model Example"'. *The International Journal of Life Cycle Assessment*, 25: 663–666. https://doi.org/10.1007/s11367-019-01726-3.
- Silvia Forin, Jutta Gossmann, Christoph Weis, Daniel Thylmann, Jonas Bunsen, Markus Berger, and Matthias Finkbeiner. 2020. 'Organizational Water Footprint to Support Decision Making: A Case Study for a German Technological Solutions Provider for the Plumbing Industry'. *Water*, 12(3): 847; https://doi.org/10.3390/w12030847
- Aurélie Wojciechowski, Silvia Forin, Markus Berger, Michael Binder, Matthias Finkbeiner. 2020. 'Combined Organizational and Product Water Scarcity Footprint: a case study on the use of amino acids for chicken production'. submitted.

5.2 Expert and public audience

- Interview on Springer Professional: https://www.springerprofessional.de/en/nachhaltigkeit/wasserwirtschaft/-erste-wasserfussabdruecke-ganzer-unternehmen-erstellt-/14959268
- Silvia Forin, Markus Berger, Jonas Bunsen and Matthias Finkbeiner, Organizational Water Footprint - Analyzing Water Use and Mitigating Water Scarcity along Global Supply Chains. TU Berlin Chair of Sustainable Engineering, 2020. https://welle.see.tu-berlin.de/Organizational_Water_Footprint_(OWF)_Practitioners_Guidance.pdf.
- Daniel Thylmann. 2020. 'Organizational Water Footprint Tool - Database Documentation'. Sphera. http://welle.see.tu-berlin.de/#database.
- Silvia Forin, Markus Berger, Matthias Finkbeiner, Ladji Tikana, Klaus Ockenfeld, Lisa-Marie Bischer, Michael Binder, et al. 2019. '**WELLE: Water Footprints in Companies: Organizational Water Footprint - Local Measures in Global Value Chains**'. In *Proceedings of the GRoW Midterm Conference – Global Analyses and Local Solutions for Sustainable Water Resources Management*, edited by Annika Kramer, Sabine Blumstein, Theresa Lorenz, and Elsa Semmling. Frankfurt am Main. https://bmbf-grow.de/sites/bmbf-grow.de/files/documents/welle.pdf. ISBN: 978-3-942664-00-4.
- Markus Berger. 2020. 'Module 3.5 Water Footprint' eLearning Sustainable Procurement, JARO Institute

5.3 Presentations

- Forin, Silvia, Markus Berger, Jonas Bunsen, and Matthias Finkbeiner. 2019. "**Water Footprint of Organizations Local Actions in Global Supply Chains (WELLE).**" presented at the World Water Week, Stockholm. https://programme.worldwaterweek.org/Content/ProposalResources/PDF/2019/pdf-2019-8523-5-Forin%20et%20al._Water%20Footprint%20of%20Organizations.pdf.

- Tikana, Ladji, Klaus Ockenfeld, Markus Berger, Silvia Forin, and Jonas Bunsen. 2019. "**Wasserfußabdruck Für Unternehmen Lokale Maßnahmen in Globalen Wertschöpfungsketten (WELLE) - Die Wertschöpfungskette von Kupfer betrachtet.**" presented at the Kupfer-Symposium 2019, Dresden.
- Wojciechowski, Aurélie. 2019. "**WELLE: Insights on Assessing the Organisational Water Scarcity Footprint of the Production of Amino Acids.**" presented at the World Water Week, Stockholm. https://programme.worldwaterweek.org/Content/ProposalResources/PDF/2019/pdf-2019-8523-5-Forin%20et%20al._Water%20Footprint%20of%20Organizations.pdf.
- Forin, Silvia, Markus Berger, and Matthias Finkbeiner. 2018. "**The Water Scarcity Characterization Algorithm for Macroscale Assessments Informing Policy and Management Decisions.**" presented at the 18th ACLCA Conference, Fort Collins.
- Berger, Markus, Silvia Forin, and Matthias Finkbeiner. 2017. "**Wasserfußabdruck Für Unternehmen: Lokale Maßnahmen in Globalen Wertschöpfungsketten (WELLE).**" presented at the GRoW-Auftaktveranstaltung, Karlsruhe. https://bmbf-grow.de/sites/bmbf-grow.de/files/documents/07_berger_welle.pd.
- Forin, Silvia, Markus Berger, and Matthias Finkbeiner. 2017. "**Water Footprint of Organizations – How to Measure a Company's Water Use Impacts beyond the Gates.**" presented at the ISIE-ISSST 2017: Science in Support of Sustainable and Resilient Communities, Chicago. http://programme.exordo.com/isie2017/delegates/presentation/56/.

5.4 Video and film

Two webinars were conducted to disseminate results of the WELLE research project. The webinars are available for download via https://welle.see.tu-berlin.de/data/webinar/.

5.5 Doctoral theses

Silvia Forin: Organizational water footprint: method and application. In preparation, to be submitted in 2020.

5.6 WELLE Homepage

The WELLE homepage serves as the central dissemination platform and contains information regarding the WELLE approach, project partners case studies, the WELLE tool, publications and the WELLE database.

https://welle.see.tu-berlin.de/

5.7 WELLE Organizational Water Footprint tool

The WELLE organizational Water Footprint tool (http://wf-tools.see.tu-berlin.de/wf-tools/owf/#/) not only enables non-expert users to perform an Organizational Water Footprint study. Its global accessibility and ease of use also turns it into a powerful tool to communicate and disseminate the Organizational Water Footprint methodology.

6 Conclusion and outlook

In the following sections, the WELLE project partners share their thoughts on the outcome and main findings of the WELLE project and how they plan to use these insights in their future work. Subsequently the general project conclusions are presented.

6.1 Project partners' reflections on the WELLE project

6.1.1 German Copper Alliance (Deutsches Kupferinstitut Berufsverband e.V.)

The Organizational Water Footprint of the copper production chain shows how important a detailed inventory of water flows along a supply chain is. The calculation of the water footprint based on regionalized water stress factors support also to best identify important hotspots. In our case study even if the blue water consumption was well balanced between inside Europe activities and those outside of Europe, the water footprint with the method AWaRe shows a clear shift to the outside Europe activities. The hotspot is indeed linked to the concentrate supply from outside Europe produced is a dry region of America. South-America and particularly Chile is an important source of concentrate imported to Europe. However, options for direct mitigation measures from Europe are limited. But with the information gained from WELLE, a fair discussion leading to support for local mitigation actions is possible as based on facts and can enable a significant and sustainable change. Nevertheless, high impact mitigation measures are also linked to technological improvement.

6.1.2 Evonik Industries AG

The WELLE project has allowed us to get a deeper understanding on the Water Footprint methodology and on the WF of two of our major products thanks to the expertise brought by the other partners of the project. The goal is now to implement the method to other products of our portfolio. The project also allowed us to assess for the first time the Water Footprint of some supporting activities based on data and tools already used for assessing the Evonik Carbon Footprint. The feasibility and the value added to assess the Water Footprint at a bigger scale (e.g. for a whole production site or for the whole organization) will be checked in the next months and internally discussed.

Finally, the first approach for developing Water Stewardships measures with one of our suppliers has initiated a bigger process by our Procurement Department, that has developed a questionnaire on the sustainability performance of our purchased raw materials, destinated to our main suppliers. Finally, the Water Stewardships measures initiated at the Blair site will be continued, as this process could only be started in the scope of the project.

6.1.3 Neoperl GmbH

The OWF method developed was successfully applied in this case study, including the activity prioritization scheme, whose suggestion to prioritize metal-related inventory data in water scarcity assessments was confirmed by the results of the study. The water inventory database and the OWF tool proved easily applicable and useful for assessing the organizational water footprint. In particular, the range of material-specific freshwater consumption data available as well as the opportunity to select the country of origin of purchased materials allowed making use of the organization's purchase data (mass and origin) to estimate local water scarcity impacts. At the same time, the production mix data available in the OWF tool filled data gaps on the geographical location of second tier suppliers in the category of metals, thus facilitating the estimation of the water scarcity impacts of raw materials. For stainless steel, one of the material hotspots identified in the study, options for water footprint reduction for eco-design via material substitution were explored. Different management stakeholders and OWF method developers were involved in this process. After considering also additional life cycle assessment based environmental indicators, the option of partly substituting stainless steel through PA6 in hoses reinforcements was discussed. Additionally, Neoperl plans to periodically calculate their OWF and track performance development. This helps monitoring the effects of mitigation measures and promptly responding to eventual hotspot shifts caused by changes in production and supply. In addition, Neoperl found out that water savings through flow regulators and flow regulated aerators outbalance the total organization's freshwater consumption by three orders of magnitude. In summary, the study shows the applicability of the WELLE approach (OWF method, water inventory database, OWF tool and mitigation options) and its potential to support organizations in identifying and reduce their value chain impacts on global water resources. It remains to be seen if Neoperl's work will inspire other organizations to measure and tackle their water footprint.

6.1.4 Thinkstep AG

The project is a large advance in extending the established water footprint method for products to organizations. The project demonstrated that such an extension is feasible and yields valuable results for strategic decision making in organizations. It helps to focus on the real hotspots of water consumption, which lay outside the direct access of organizations in most cases (Tier 3 instead of Tier 1), a phenomenon also observed in other environmental impact categories such as climate change. The project demonstrated the need for reliable data to cover the upstream supply chains. The existing data from LCI databases serve as a good starting point for such assessments, and some datasets were improved significantly in the course of the project to even better represent global supply chains. However, it also became evident that the availability of data is limited, and large "manual" research effort is required to compile additional information such as water use on sub-country level or on water shed level (instead of country-level). To make the water footprint (both of products or organizations) a useful and reliable decision-making tool, data users, data compilers and data provider should continue and strengthen their efforts to improve data availability and accessibility.

6.1.5 TU Berlin

The development of a water footprinting method for organizations and linking it to mitigation measures were two long-envisaged research goals of the Chair of Sustainable Engineering at TU Berlin. The achievement of both goals strengthens the chair's competitiveness on environmental impact assessment with a focus on water. All WELLE publications and the graduation of a doctorate candidate highlight the success of the WELLE research project for the TU Berlin. The gained knowledge has been made publicly available within several scientific publications as well as within a practitioners' guidance. All results have already been integrated into courses being taught at TU Berlin. The WELLE practitioners' guide and WELLE online tool are two additional outputs which are expected to pose a particularly lasting contribution for reducing an organizational water footprint.

6.1.6 Volkswagen AG

Applying the organizational water-footprint method as developed within this research project led to a deeper understanding of the water consumption evident within the supply chains of Uitenhage plant's products as well as their use phase. Hotspots of water consumption and causation of water stress were identified on a material level and country level. However, the hotspot originally identified due to erroneous data (platinum-group metals in South Africa) did not prove to be correct.

This shows that water consumption data—even on a country level—should be of high quality in order to make the proper first step in analyzing water risks. Additionally, the country level can only be the first step toward a deeper analysis of supply chains in order to identify water stress on a water basin level. This can then lead to appropriate mitigation measures and subsequently a reduction of water risks.

The bulk of data for this organizational water footprint study came from product water footprints (bottom-up approach). This approach turned out to be very feasible since the majority of water consumption happens within the supply chain and use phase of the products. Thus, future organizational water-footprint studies at Volkswagen—in particular for plants with a more diverse product structure—should adapt the Organizational

Water Footprint methodology developed within the WELLE research project. Alternatively, and depending on the focus, product water footprints could be used, especially for vehicles that are built in several plants. This project has also shown that the water footprint method is able to support decision-making processes with regard to the sourcing of materials or even to the kinds of materials that should be preferably used, which holds promise for using it in the future.

6.2 Overall conclusion & outlook

Freshwater is a vital resource for humans and ecosystems but is scarce in many regions around the world. Organizations measure and manage direct water use at their premises but usually neglect the indirect water use associated with global supply chains – even though the latter can be higher by several orders of magnitude.

As of 2015, there was no standardized life-cycle-based approach for analyzing the water consumption of an organization. Against this background, the BMBF funded research project "Water Footprint for Organizations – Local Measures in Global Supply Chains (WELLE)" has been launched by TU Berlin, Evonik, German Copper Institute, Neoperl, thinkstep and Volkswagen. The project aims to support organizations in determining their complete Organizational Water Footprint, identifying local hotspots in global supply chains and taking action to reduce their water use and mitigate water stress at critical basins.

Within the WELLE project a method for analyzing an Organizational Water Footprint has been developed (Forin et al. 2018, 2019b, c). To support stakeholders in conducting Organizational Water Footprint studies, a Practitioners' Guidance has been published, which presents the method in a clear and concise way by illustrating each step with a practical example. Further, the WELLE database was introduced which provides water consumption data of an organization's indirect activities (material and energy purchase, business trips, canteens, etc.) in a spatially explicit way. In order to facilitate the application of the method and the database, a WELLE online tool has been developed which allows for determining an organization's water footprint by entering direct water use data at production sites, purchased goods and energy as well as supporting activities such as business trips or buildings. In order to test their validity and applicability, the previously developed method, database and online tool have been tested in four case studies conducted by industry partners representing different sectors and scopes. Evonik examined two production lines for the chemical and biotechnological production of amino acids. Volkswagen conducted an organizational water footprint for the production site in Uitenhage, South Africa. The German Copper Institute prepared a water footprint for the entire European copper production and Neoperl analyzed the water footprint of the whole company. Based on the results, options to reduce an organization's water use and to mitigate local water stress by means of water stewardship approaches, sustainable purchase strategies and ecodesign measures have been discussed and recommended.

In future research, the scope of organizational water footprints should be extended from the currently considered blue water consumption (ground and surface water) to the consumption of green water (soil moisture) resulting from plant evapotranspiration and to water pollution aspects. From an application perspective, the number of spatially explicit water inventory datasets should be increased by implementing the regionalization approach developed in this project into large LCA databases. Finally, the implementation of measures to mitigate water stress throughout supply chains was hindered by the fact that companies solely face pressure to reduce direct water consumption at production sites. Hence, the awareness that it can be environmentally preferable and economically more efficient to reduce water consumption at local hotspots in global supply chains needs to be increased throughout all stakeholder groups.

By analyzing their Water Footprints, organizations can determine water use and resulting local impacts at premises and "beyond the fence" along global supply chains. In this way they can reduce water risks and contribute to a more sustainable use of the world's limited freshwater resources.

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