

Article

# Organizational Water Footprint to Support Decision Making: a Case Study for a German Technological Solutions Provider for the Plumbing Industry

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**Abstract:** With water scarcity representing an increasing threat to humans, the environment and the economy, companies are interested in exploring how their operations and supply chains affect water resources globally. To allow for systematically compiling the water footprint at the company level, the organizational water footprint method based on ISO 14046 and ISO/TS 14072 was developed. This paper presents the first complete organizational water scarcity footprint case study carried out for Neoperl GmbH, a German company that offers innovative solutions regarding drinking water for the plumbing industry. The cradle-to-gate assessment for one year includes, besides facility-based production activities, purchased materials, electricity and fuels, and supporting activities, such as company vehicles and infrastructure. Neoperl's total freshwater consumption amounts to approximately 110,000 m<sup>3</sup>, 96% thereof being attributable to the supply chain, with freshwater consumption through purchased metals playing the predominant role. Metals (mainly stainless steel and brass) are major hotspots, also when considering the water scarcity-related local impacts resulting from freshwater consumption, which mainly affect China and Chile. These results can be used to improve the company's supply chain water use in cooperation with internal and external stakeholders by means of, e.g., sustainable purchase strategies or eco-design options to substitute water intensive materials.

**Keywords:** organizational water footprint; corporate footprints; sustainable supply chain management; eco-design; water scarcity; water footprint; organizational life cycle assessment

## 1. Introduction

Given the challenges water scarcity poses on individuals, ecosystems and the economy, technological solutions to reduce freshwater consumption (as defined in [1], also referred to as blue water consumption in this paper and related documents) have been developed and implemented in the last decades. This also applies to households, responsible for 12% of worldwide water withdrawals [2], which can be substantially reduced even by 50% or more, by using water saving devices, such as low water flushing toilets, water-saving taps and showerheads, or water efficient appliances [3,4]. At the same time, companies producing such devices carry an environmental burden themselves, for example through material sourcing, energy consumption in the production phase, the transportation

of intermediate products, distribution, and company-wide activities not directly related to production, e.g., administration and research and development (R&D).

Viewed through the lens of sustainable life cycle management, two main questions arise. First, do the water savings through the products outbalance the water consumed during production, so that any net water savings in comparison to a baseline scenario (without water saving appliances) can be claimed for? Second, how does value-chain freshwater consumption affect water scarcity at the local level, and how can such impacts be mitigated?

Neoperl GmbH, a German company that offers innovative solutions regarding drinking water for the plumbing industry, addressed the first question in a water footprint case study at the product level for a flow regulator. The results show that estimated water savings through the product are approximately 26,000 times larger than the freshwater consumption originated by the product's life cycle (dominated by the production of components; the freshwater consumption for assembly at Neoperl's facility accounted for 0.4% of a regulator's life cycle freshwater consumption) [5]. Still, Neoperl's activities go beyond the flow regulators production line, and Neoperl GmbH came to the conclusion that a company-wide assessment would allow for tracking the company's water footprint, and enable better-informed decisions to address the company's water scarcity hotspots through mitigation measures.

For Neoperl GmbH, freshwater consumption and its effects represent not only a concern at the societal level, but are the backbone of production activities, focused on water saving devices. Neoperl GmbH joined the project "Water footprint of companies: local action in global supply chains" (WELLE), funded within the measure Global Resource Water (GRoW) by the German Federal Ministry for Education and Research (BMBF) [6]. The WELLE research partners developed solutions to measure and reduce water consumption at the production site and throughout the value chains of companies. This includes a method for the organizational water footprint (OWF) [7], a water footprint database for more than 100 materials and energy carriers [8], and an online tool assisting companies in determining their water footprint [9]. Additionally, four industry partners conducted water footprint case studies to test the methodological and software developments, and discussed different options to undertake mitigation measures addressing water scarcity hotspots identified in their global supply chains [6]. Neoperl GmbH contributed to the WELLE project by calculating the water scarcity footprint of their facility located in Müllheim, Germany.

The aim of this paper is to present the first organizational single-indicator water footprint focused on water scarcity impacts (the so-called organizational water scarcity footprint) following the WELLE approach, which includes testing the OWF method, the water inventory database and online assessment tool, and identifying pathways to reduce the company's water footprint. The work contributes to testing footprint metrics at the organizational level and diffusing footprint accounting among companies, and proposes and applies water scarcity mitigation pathways that depend on the location of hotspots within value chains.

The manuscript is structured as follows. Section 2 introduces the WELLE approach, which includes the organizational water footprint method (Section 2.1), the water inventory database (Section 2.2), the organizational water footprint online tool (Section 2.3), and impact mitigation options based on case study results (Section 2.4). Section 3 illustrates the organizational water footprint case study conducted by Neoperl GmbH to assess their impacts on water scarcity. The section follows the four-phase structure of life cycle assessment studies: goal and scope (Section 3.1), life cycle inventory analysis (Section 3.2), life cycle impact assessment (Section 3.3), and life cycle interpretation (Section 3.4). The water scarcity mitigation options derived from the Neoperl case study are described and discussed in Section 4. Concluding considerations and suggestions for future studies are included in Section 5.

## 2. Materials and Methods

### 2.1. The Organizational Water Footprint Method

This case study follows the methodological guidance to carry out OWF studies presented in [7]. The OWF method development is based on a criteria-based semi-quantitative evaluation of existing methods to assess the water-related environmental impacts of organizations [10], which identifies ISO 14046 [1] as the most suitable starting point for method development, complemented by organization-specific elements. On this basis, the method complements the requirements of ISO 14046 [1] (on water footprint, with a focus on products), with the peculiarities of organizational assessments described in detail in ISO/TS 14072 [11]. Thus, it enables practitioners to account for both the organizational scope and the specificities of water footprint in the inventory and impact assessment phase with only one document at hand. The organizational water footprint method also raises awareness on the conflicting or unclear requirements in the two standards (regarding comparisons, system boundaries and allocation), and provides recommendations on how to handle such cases. In addition, a data collection prioritization scheme specific to the indicator water scarcity (the impact category assessed in the Neoperl case study) is proposed to facilitate the resource intensive data collection step needed to compile the inventory.

### 2.2. The Water Inventory Database

The consumption of water in companies' value chains has different effects on local water scarcity in different regions (high in water scarce locations, low in water rich ones). For water inventory databases, this poses the challenge of capturing, not only the water consumption of various materials, but also their origin, and possibly region or country-specific water intensities. In order to obtain this information, the GaBi LCA database (version 8.7, service pack 36) was used as a starting point [12]. This database contains Life Cycle Inventories for a large variety of industrial processes and materials used in different industrial sectors. However, only water use in energy provision and agriculture is regionally specified in the GaBi database. While these processes will cover the largest fraction of water consumption in many production systems, potentially a significant fraction of water consumption remains unspecified, and is subject to large uncertainty regarding water scarcity.

Within the WELLE project, a method for calculating this missing information for regionalization was provided via two different regionalization approaches. First, the bottom-up approach, which relies on information available in the underlying background data, and accounts also for regionally variable water intensities (e.g., cause by the use of different technologies). Where bottom-up regionalization was not possible, due to data unavailability or to the confidential nature of background datasets, the top-down regionalization approach was applied. This makes it possible to determine the origin of materials and primary products through import data and worldwide production mixes, and thus to estimate the geographical location of water use.

On this basis, a comprehensive database of approximately 120 data sets based on the materials that occur in the value chains of the WELLE case study partners was developed. Besides regionalized freshwater inventory for materials and energy carriers, the database also contains aggregated datasets to calculate the water consumption of supporting activities, e.g., for office equipment, canteen meals, buildings and different transport modes, the latter being useful to assess the water footprint of business travels and employee commuting.

The regionalization approach being used, assumptions and underlying GaBi 8 datasets are described in detail in the WELLE water inventory database documentation available online [13].

### 2.3. The Organizational Water Footprint (OWF) Tool

To facilitate method application, an online tool based on thinkstep's Envision software [14] was developed within the WELLE project to allow for assessing companies' freshwater consumption and water scarcity impacts. The tool combines the database with the modeling approach provided by the OWF method. As illustrated in Figure 1, it leads users through six steps:

**Figure 1.** Organizational water footprint (OWF) tool screenshot. The six steps (on the top) and regionalization options for the purchased Crude Oil (indirect upstream activities) are exemplarily shown.

1. Indirect upstream activities: The amounts of purchased fuels and energies, purchased goods and materials, and purchased services, can be entered. If known, the country/countries of origin can be selected for regionalization by entering the corresponding import share. A global mix is delivered as the default setting for metals. Country (mixes) can be selected for all materials to indicate their origin, and allow for region-specific assessment. Additional materials can be assessed by entering freshwater consumption values and country of origin under “Other purchased materials → Generic Product/Others”. The same approach was chosen for the generic activity “purchased services”;

2. Direct activities: Different types of direct water input (deionized water, tap water, freshwater extraction) and output (freshwater release, wastewater) can be entered;

3. Indirect downstream activities: The freshwater consumption of the end-of-life of sold products, franchises, leased assets, processing of sold products, storage of sold products, use or consumption of sold products, can be entered and a country (mix) can be selected;

4. Supporting activities: In this category, data for the working environment and capital equipment-related activities, as well as business travels and employee commuting, can be entered. Underlying material data or product mixes are used for the calculation (e.g., for canteen meals, machinery and building materials, cars, travel modes).

Based on these data entries and the water inventory database, the tool determines the water consumption along the value chain in a geographically explicit way at the country level. This first result is used as the basis for an impact assessment step, in which the potential local consequences resulting from freshwater consumption are determined. For this, water consumption in a region is multiplied by a specific AWaRe (“Available Water Remaining”) characterization factor [15], which is an indicator for water scarcity, and denotes the potential to deprive other water users (human or ecosystems) when consuming water in a certain area. The AWaRe model was developed within a consensus-building process by the WULCA (Water Use in LCA) group [16], and characterization factors at the country and basin level are available and freely accessible online [17]. For direct activities,

indirect downstream activities and unspecific activities (like generic product or generic service), a specific AWaRe characterization factor can be entered to assess water scarcity impacts. Country-based location selection implies the use of country-level non sector-specific (so-called “unspecified”) AWaRe characterization factors.

In steps 5 and 6, the OWF tool displays the results for freshwater consumption and resulting local impacts (water scarcity footprint) in maps at a country scale, and in bar charts at the activity and material level. In this way, water footprint hotspots concerning an organization’s activities (e.g., materials or business travels), and the country in which they occur, can be identified. The tool can calculate two scenarios in parallel. This allows, among others, performance tracking, preliminary analysis on material or supplier substitution options, or the comparison between two different production lines. The tool can be used free of charge, and is available under <http://wf-tools.see.tu-berlin.de/wf-tools/owf/#/> [9].

#### 2.4. Water Scarcity Mitigation Options

Hotspots found: and now? The last step of the WELLE approach consists of suggesting different pathways to undertake mitigation measures to reduce the organization’s water scarcity footprint. Given the uniqueness of each organization’s activities, products, the proximity of relevant suppliers, and the degree of influence the organization can exert on other supply chain stakeholders, no universal solution can be provided. Instead, the WELLE project identified a set of measures and frameworks that could support companies in mitigation options, or inspire them in finding individual solutions.

The first step consists of understanding whether the hotspot activities are located between the company gates (direct activities), or at other stages at the value chain (indirect upstream or downstream activities). If the former is the case, widespread facility-focused improvement schemes and certifications, such as environmental management systems (EMS), according to ISO 14001 [18] or the Eco-Management and Audit Scheme (EMAS) [19], can be used, with particular attention to freshwater consumption as an environmental aspect. Besides these established tools, the newly developed Water Stewardship approach can be considered [20]. Next to the collection and evaluation of freshwater consumption (and pollution) data, water stewardship aims at involving other water users at the same catchment, such as businesses, local authorities, water providers and households, and take collective action to preserve water resources. The Alliance for Water Stewardship provides a certification scheme, which includes the evaluation of the water stewardship plan and the disclosure of water stewardship efforts [20].

However, as the review of a (limited) set of case studies in Forin et al. 2018 [7] has shown, the activities with the highest impact on water scarcity are often located in the upstream supply chain or in the use phase. In such cases, further tools like product eco-design or sustainable supply chain management can be explored.

Eco-design consists of integrating environmental criteria in product design and development. It can influence both the upstream supply chain (e.g., by reducing material use or through material substitution), the use phase (e.g., by increasing the energy or water use efficiency of products), as well as the end-of-life phase (e.g., by designing products in a way to support their recycling). The incorporation of eco-design into the EMS framework has been standardized in ISO 14006 [21], and strategies facilitating LCA-based eco-design in companies such as teaching methods for instructing (future) product developers, have been discussed in literature [22,23]. As water scarcity footprints are single-indicator assessments, eco-design options solely based on water scarcity impacts should be considered carefully in order to avoid burden shifting, e.g., reduced water footprint, but increased carbon footprint [24]. It is therefore recommendable to consider additional environmental indicators to test how alternative options perform in different impact categories in order to allow for better-informed decisions.

Sustainable supply chain management is defined as “the management of material, information and capital flows as well as cooperating among companies along the supply chains while taking goals of all three dimensions of sustainable development, i.e., economic, environmental and social, into account which are derived from customer and stakeholder requirements” [25]. While economic factors

are seldom neglected in purchase and logistics decisions, social and environmental criteria need to be defined, applied and evaluated within structured schemes, as suggested e.g., in the Step-by-step Guide by the German Federal Ministry of Environment [26]. Among the possible indicators, also the water footprint of supply chain materials (which are in most cases the water footprint hotspot) can be considered. Review literature shows the increasing use of life cycle assessment-based supply chain optimization approaches [27], whose focus goes beyond purchase management, and also involves also other supply chain stages, e.g., distribution [28,29], or addresses specific sectors [30,31], mainly with a focus on carbon emissions.

Also in the case of sustainable supply chain management, it is preferable to complement water scarcity indicators with additional environmental (and preferably social) indicators (see the social life cycle assessment framework [32]), in order to avoid burden shifting. As revealed by the definition reported above, sustainable supply chain management requires strong ties to suppliers and other value chain stakeholders, and their willingness to cooperate. These conditions might strongly vary depending, among others, on the size difference between supplier and client company, the dependence upon each other, and the stability of the customer relationship.

A further option requiring strong ties to supply chain stakeholders is carrying out water stewardship actions in cooperation with the hotspot supplier(s) and further stakeholders at the hotspot catchment(s) along the supply chain, i.e., applying, e.g., the Alliance for Water Stewardship certification scheme mentioned above to suppliers' sites instead of on-own activities. This requires a short distance to the hotspot within the supply chain (first or second tier supplier), as well as a strong willingness to cooperate on the supplier's side. Cooperation might be facilitated by strong problem perception at the local level (water shortages, droughts, etc.). Also a strong influence of the organization on its supply chain stakeholders (e.g., through dependence of the supplier on the client organization) might help prioritizing this action, similarly to the case of sustainable supply chain management.

### 3. Application of the OWF Method and Results

Neoperl GmbH applied the organizational water footprint method outlined in Section 2.1 via the WELLE organizational water footprint tool (Section 2.3). This section presents the complete case study following the four-phase approach.

#### 3.1. Goal and Scope

Many products provided by Neoperl aim to reduce water use in households. Following and expanding this approach, the study aimed at determining the company's freshwater consumption and the resulting potential impacts throughout the value chain.

Based on the study results, options to reduce water consumption should be 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 the availability and sustainable management of water and sanitation for all) within the company, and in external communication activities.

The organization under study is Neoperl GmbH, which has one production facility located in Müllheim, Germany. The reference period considered is the solar year 2016, the most recent period 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 company-own records.

The study was conducted cradle-to-gate, considering direct activities and indirect upstream activities (mainly material purchase). The assessment included also 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 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 (Section 3.4). The end-of-life phase was not included because Neoperl's products

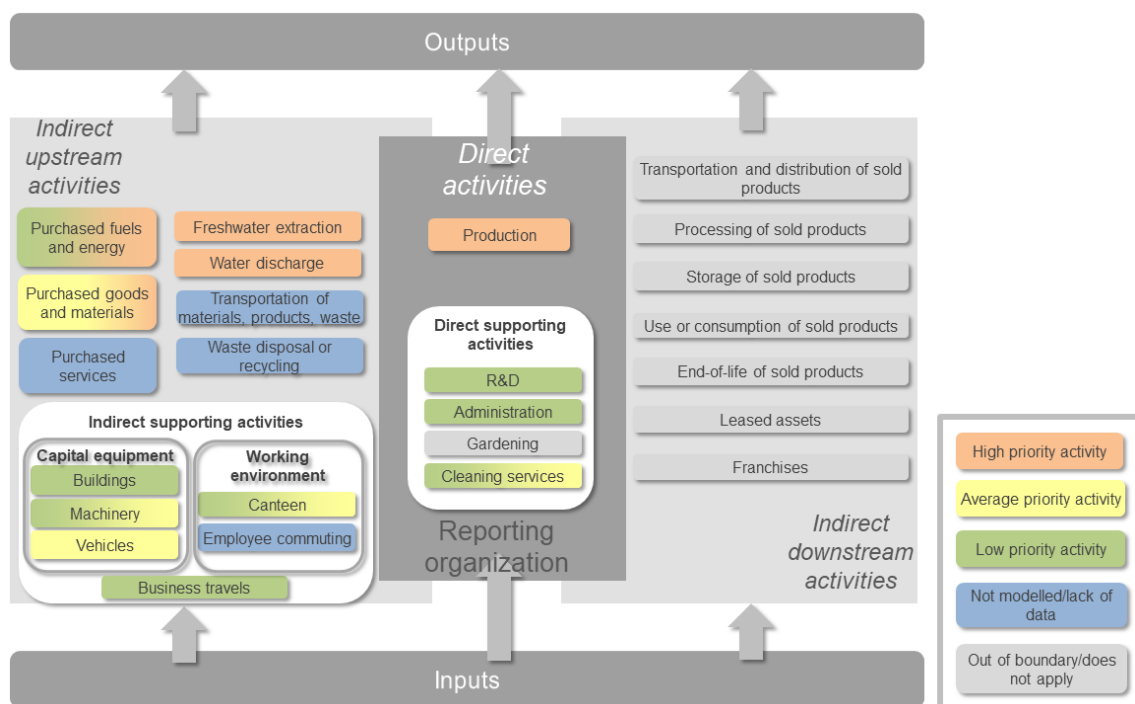
are mainly sold as intermediate products and embodied in final devices, distributed all around the world. It was not possible to track their final destination, nor to predict their end-of-life fate. However, the products are typically in use for at least 10 years.

In line with ISO/TS 14,072 [11] and following the recommendations for organizational water footprint [7], the case study is not intended for comparative assertions for public disclosure. That is, the results should not be compared to other companies as they have different reporting flows and different methodological settings may have been applied.

### 3.2. Life Cycle Inventory Analysis

#### 3.2.1. Activity Categorization, Data Collection Approach and Data Sources

The inventory data needed for the study is the freshwater consumption related to the company’s operations and upstream supply chain, and the location at which freshwater consumption takes place. In line with the organizational modeling introduced by the Guidance on Organizational LCA [33] adopted in 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 Figure 2.



**Figure 2.** Neoperl’s organization model for the organizational water scarcity footprint case study (own picture adapted from the general model in [7]). The highlighted (non-gray) activities are those carried out in the organization. Gray activities are out of the system boundary, or do not apply for the company. Blue activities take place at Neoperl, but were not modeled 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 [33]. Data sources and assumptions for indirect upstream activities (excluding supporting activities) are displayed in Table A1.

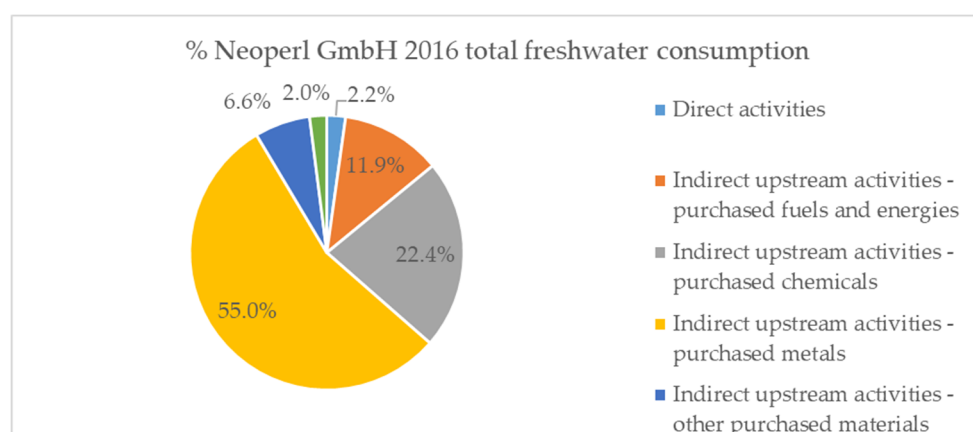
The freshwater consumption of supporting activities was estimated via proxy data sets available in the WELLE database. Freshwater consumption caused by business travels was estimated via the amount of purchased diesel. The estimation is limited to business travels by car, since no complete records of business travels by other means of transport (train, plane) were 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 [13], as well as one soft drink per person per meal, were assumed. The upstream freshwater consumption through work places (furniture and electronic devices) was assessed by using a proxy dataset [12], assuming each work place endowed with one table, one chair, one laptop and one screen.

Capital equipment was included and assessed through proxy values. For company-owned vehicles, a proxy freshwater consumption value for a vehicle and the vehicle lifetime were considered [13]. For machinery and buildings, the material composition was taken into account, divided by the estimated lifetime. The material data was retrieved from company-owned records. The assumptions for supporting activities can be found in Table A2.

### 3.2.2. Inventory Analysis Results

Neoperl’s total freshwater consumption in 2016 was approx. 109,667 m<sup>3</sup>, out of which only 2% occur at the production site. 96% of water consumption took place in the upstream supply chain, and another 2% in the supporting activities. Detailed inventory results disaggregated by activity category and activity/material are available in Table A3.

Metals supply is responsible for 55% of the company’s water footprint (Figure 3). 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.



**Figure 3.** Activity contributions to Neoperl’s blue freshwater consumption.

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% of 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%).

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 4).



**Figure 4.** Total freshwater consumption by country/location. Screenshot from <http://wf-tools.see.tu-berlin.de/wf-tools/owf/#/calculation>.

### 3.3. Life Cycle Impact Assessment

The resulting local consequences of freshwater consumption were calculated by means of the AWaRe method (see Section 2.3). Country-level characterization factors were used, according to the origin of materials recorded by the company, or to the import mix available in the WELLE database (see Tables A1 and A2). The basin-level marginal AWaRe factor was chosen to characterize the freshwater consumption originating from the production site in Müllheim, Germany.

By activity category (overview see Figure 5), 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 6).

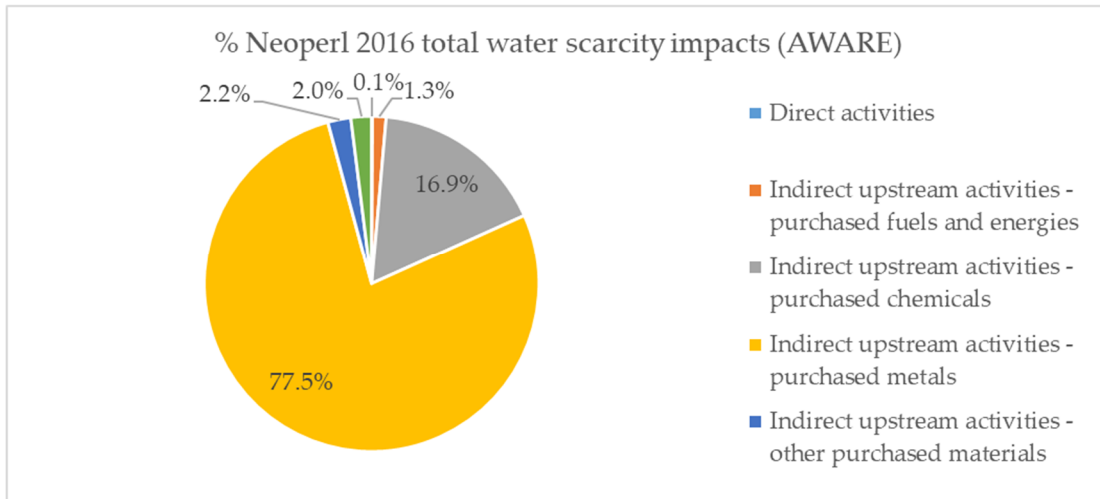


Figure 5. Total water scarcity impacts by activity category.



Figure 6. Total water scarcity impacts by location/country. Screenshot from <http://wf-tools.see.tu-berlin.de/wf-tools/owf/#/calculation>.

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. A 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 its distance to the French mainland, it 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 on a scale between 0.1 and 100.

The fuels and energy category contributes 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 company's canteen (25%). Table A4 provides further details on specific activity contributions.

The hotspot distribution along the value chain steps is in line with available studies for the producing industry. The predominant role of indirect upstream activities for organizations whose products do not consume water or energy in the use phase represents a common pattern, as can be observed in the short case study review provided in [7] (see particularly Table 6 in [7]). However, past organizational case studies mainly include, in the upstream chain, water-intensive agricultural materials, which dominate the picture, or plastics, thus not allowing for a comparison with the main (metal-related) hotspots detected at Neoperl.

### 3.4. Life Cycle Interpretation

The case study allowed identifying Neoperl's material and geographical hotspots in terms of water consumption and its resulting impacts. In addition, the study offered the possibility to gain insights in the supply chain, and consider different impact mitigation options, as explained in detail in Section 4.

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 which might be negatively influenced by the 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 [34], dating back to 2010.

Discrepancies can be found also in the regional resolution of characterization factors. As described in Section 3.3, 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 company 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 to be 10 years) relies on the assumptions met in the product-related study by Berger et al. [5], and is 166.2 m<sup>3</sup> of water use and 0.79 m<sup>3</sup> of water consumption. Multiplied by the amount of flow regulators sold by Neoperl in 2016 (30,000,000 pieces), 4,986,000,000 m<sup>3</sup> water use and 23,700,000 m<sup>3</sup> 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 behaviour of consumers.

#### 4. Water Scarcity Mitigation Measures

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 that water scarcity is 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., the 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.

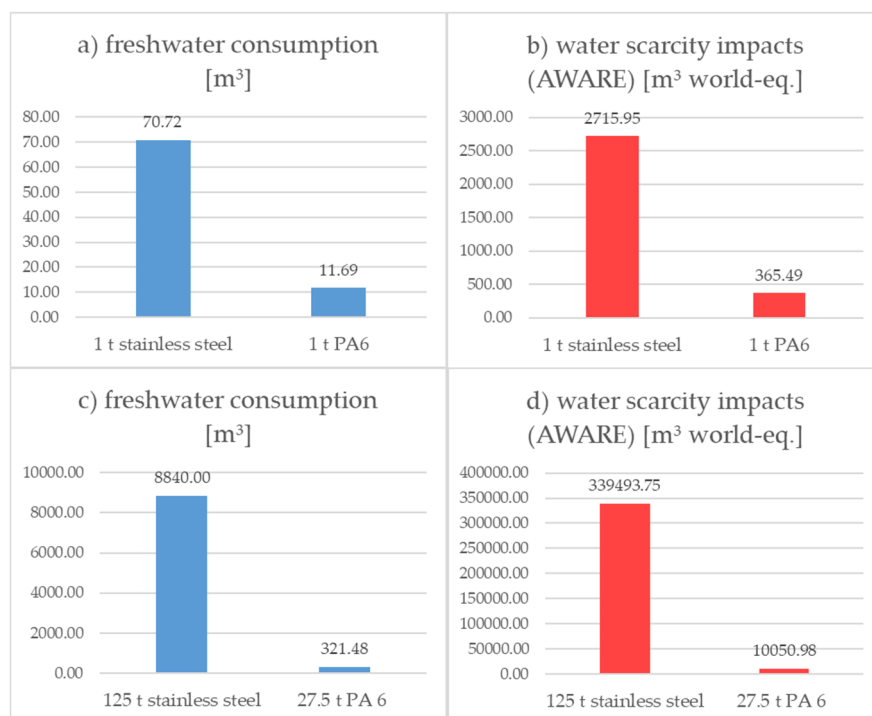
Second, metals such as copper and nickel, detected as hotspot alloy elements for brass and stainless steel, respectively, are traded at the stock exchange, which makes it even more difficult to trace back to the actual supplier.

To cope with these limitations, origin certification approaches, such as those in place for conflict minerals, might be adopted, since they are proven to allow penetrating several supply chain tiers [35].

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 this 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 company'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 7. While Figure 7a,b compare the freshwater consumption and water scarcity impacts for one ton of stainless steel and PA6, respectively; Figure 7c,d show the impact for the specific substitution case, in which 125 tons of stainless steel can 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. The assumptions listed in Table A1 apply for this analysis.



**Figure 7.** Comparison between the freshwater consumption and the potential water scarcity impacts of stainless steel and PA6. A comparison by mass is provided in (a) for freshwater consumption and (b) for water scarcity impacts; (c,d) compare the results for the respective amounts of stainless steel and PA6 needed to reinforce the same number of hoses with respect to freshwater consumption (c) and water scarcity impacts (d). Own figure base on calculations realized via the WELLE tool [36]. Own figure.

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, if 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.

## 5. Conclusions and Outlook

The OWF method developed in [7] 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 (Sections 2.2 and 2.3) proved easily applicable and useful for assessing the company's 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 company's purchase data (mass and origin) to estimate local water scarcity impacts. Assessing water scarcity requires a large amount of inventory data, regarding both the water consumption and the provenience of materials. Therefore, limited primary data availability risks impairing the study results. To cope with this limitation, the production mix data available in the OWF tool filled data gaps on the geographical location of second tier suppliers in the metals category, thus facilitating the estimation of the water scarcity impacts of raw materials. This shows the relevance of the availability of regionalized

water inventory datasets that might be extended in the future to a wider range of material within the framework of research projects or product development by database providers.

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 company's freshwater consumption by three orders of magnitude.

The choice of the most viable mitigation pathway is however a case-by-case decision that can be guided by the considerations of this paper. Future users are encouraged to assess individually, in cooperation with all relevant stakeholders, which measures might be useful. Reports evaluating such decision processes and their impact on the reduction of local water scarcity will deliver further examples and support future decisions.

In summary, the paper shows the applicability of the WELLE approach (OWF method, water inventory database, OWF tool and mitigation options) and its potential to support companies in identifying and reducing their value chain impacts on global water resources. The authors wish that Neoperl's work will inspire other companies to measure and tackle their water footprint.

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## Appendix A

Appendix A summarizes the data sources and regionalization assumptions for activities and materials. Table A1 refers to indirect upstream activities; Table A2 summarized data sources and assumptions for supporting activities.

**Table A1.** Data sources and assumptions for indirect upstream activities, by material (type).

Activity Specification	Material	Collected Data	Data Source	Freshwater Consumption and Regionalization Sources/Assumptions
Purchased Fuels and Energies	Diesel	Purchased mass [t]	Company's purchase records	WELLE database for Germany
Purchased Fuels and Energies	Natural Gas	Purchased mass [t]	Company's purchase records	WELLE database for Germany
Purchased Fuels and Energy	Electricity	Purchased quantity [MWh]	Electricity bill	WELLE database for Germany; German grid mix
Purchased Goods and Materials Chemicals/Plastics	ABS, PVC, PET, PBT, LDPE, POM, PA6, PP, NBR, PSU, PEX, EPDM	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption assumed in the country of provenience according to company's purchase records (material shares for Taiwan ( $\leq 1.5\%$ ) were allocated to China).
Purchased Goods and Materials Metals	Cast Iron; Lead	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption assumed in the country of provenience according to company's purchase records
Purchased Goods and Materials Metals	Steel alloyed	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption for the steel production process assumed in the country of provenience according to company's purchase records, freshwater consumption for iron ore according to WELLE tool mix <sup>1</sup>
Purchased Goods and Materials Metals	Stainless steel	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption for the steel production process assumed in the country of provenience according to company's purchase records, freshwater consumption for nickel (background process) regionalized as follows: nickel producing countries assumed to use local nickel for steel production, nickel for remaining steel production regionalized according to WELLE tool mix <sup>2</sup>
Purchased Goods and Materials Metals	Brass	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption for the brass production process assumed in the country of provenience according to company's purchase records, freshwater consumption for copper (background process) regionalized according to the WELLE tool global dataset <sup>3</sup>
Purchased Goods and Materials Other purchased materials	Wooden pallets	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption assumed in the country of provenience according to company's purchase records
Purchased Goods and Materials Other purchased materials	Silicone	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption assumed in the country of provenience according to company's purchase records
Purchased Goods and Materials Other purchased materials	Cardboard	Purchased mass [t]	Company's purchase records	WELLE database; Freshwater consumption assumed in the country of provenience according to company's purchase records
Purchased Goods and Materials Other purchased materials	Auxiliary materials, e.g., acids (low tonnage)	Purchased mass [t]	Company's purchase records	Own estimations; Freshwater consumption assumed in Germany

<sup>1</sup>. Australia: 44.3%; Brazil: 21.5%; China: 20.3%; India: 8.5%; Russia: 5.5%. <sup>2</sup>. Australia: 7%; Canada: 7%; China: 5%; Other countries: 33%; Indonesia: 24%; Philippines: 15%; Russia: 9%. <sup>3</sup>. Australia: 3%, Brazil: 11%; Canada: 1%; Chile: 69%; Canada: 1%; Germany: 1%; Spain: 1%; France: 1%; Indonesia: 2%; India: 2%; US: 2%; others: 2%.

**Table A2.** Data sources and assumptions for supporting activities.

<b>Activity</b>	<b>Specification</b>	<b>Collected Data</b>	<b>Data Source</b>	<b>Freshwater Consumption and Regionalization Sources/Assumptions</b>
Supporting Activities Business Travels	Travel by car (diesel purchase)	Purchased quantity [l]	Company's purchase records	WELLE database for Germany
Supporting activities Canteen		Average amount of consumed meals per day	Company canteen for canteen clients	WELLE database for Germany; 230 meals/canteen client; meal including meat assumed
Supporting activities Capital equipment	Buildings	Building area and material composition	Company records	WELLE database for Germany, assumed building lifetime: 50 years
Supporting activities Capital equipment	Machinery	Material composition	Company records/BOMs	WELLE database for Germany, assumed machinery lifetime: 25 years
Supporting activities Capital equipment	Company cars	Number of vehicles	Company records	WELLE database; assumed vehicle lifetime: 15 years
Supporting activities Working environment	Work places	Number of work places	Company records	WELLE database: each workplace assumes 1 table, 1 chair, 1 laptop, 1 display



## Appendix B

Appendix B shows the inventory and water scarcity footprint results by activity category and activity/material.

**Table A3.** Life cycle inventory results by activity category and activity/material.

Activity Category	Activity	Freshwater Consumption [m <sup>3</sup> ]	% Total Freshwater Consumption	% Activity Category Freshwater Consumption
<b>Direct activities</b>		<b>2418.78</b>	<b>2.2%</b>	<b>100.0%</b>
<b>Indirect upstream activities; purchased fuels and energies</b>		<b>13,008.95</b>	<b>11.9%</b>	<b>100.0%</b>
	Diesel	154.30	0.1%	1.2%
	Natural Gas	1.65	0.0%	0.0%
	Electricity from grid	12,853.00	11.7%	98.8%
<b>Indirect upstream activities- purchased chemicals</b>		<b>24,533.76</b>	<b>22.4%</b>	<b>100.0%</b>
	Ethylene propylene diene elastomer (EPDM)	347.41	0.3%	1.4%
	Acrylonitrile Butadiene Styrene Granulate (ABS)	36.18	0.0%	0.1%
	Nitrile butadiene rubber (NBR)	435.31	0.4%	1.8%
	Polyamide 6 Granulate (PA 6)	1307.40	1.2%	5.3%
	Polybutylene Terephthalate Granulate (PBT)	63.58	0.1%	0.3%
	Polyethylene Cross-Linked (PEXa)	5250.60	4.8%	21.4%
	Polyethylene high density granulate (HDPE/PE-HD)	599.52	0.5%	2.4%
	Polyethylene Low Density Granulate (LDPE/PE-LD)	1207.50	1.1%	4.9%
	Polyethylene Terephthalate Fibres (PET)	1937.00	1.8%	7.9%
	Polyoxymethylene Granulate (POM)	12,178.00	11.1%	49.6%
	Polypropylene Granulate (PP)	543.31	0.5%	2.2%
	Polysulfone (PSU)	367.02	0.3%	1.5%
	Polyvinyl Chloride Granulate (S-PVC)	260.93	0.2%	1.1%
<b>Indirect upstream activities- purchased metals</b>		<b>60,295.84</b>	<b>55.0%</b>	<b>100.0%</b>
	Brass	12,463.00	11.4%	20.7%
	Cast iron part	3041.60	2.8%	5.0%
	Lead	40.69	0.0%	0.1%
	Stainless steel	44732.00	40.8%	74.2%
	Steel alloyed	18.55	0.0%	0.0%

Table A3. Cont.

Activity Category	Activity	Freshwater Consumption [m <sup>3</sup> ]	% Total Freshwater Consumption	% Activity Category Freshwater Consumption
<b>Indirect upstream activities- other purchased materials</b>		<b>7192.70</b>	<b>6.6%</b>	<b>100.0%</b>
	Cardboard	2700.20	2.5%	37.5%
	Generic product/others	137.00	0.1%	1.9%
	Silicone	1935.10	1.8%	26.9%
	Wooden pallet	2420.40	2.2%	33.7%
<b>Supporting Activities</b>		<b>2217.25</b>	<b>2.0%</b>	<b>100.0%</b>
	Canteen	593.71	0.5%	26.8%
	Capital Equipment - Building	283.29	0.3%	12.8%
	Capital equipment - Cars	27.76	0.0%	1.3%
	Capital Equipment - Machines	1170.6	1.1%	52.8%
	Working Environment	141.89	0.1%	6.4%
<b>Total</b>		<b>109,667.28</b>	<b>100%</b>	

Table A4. Water scarcity footprint results by activity category and activity/material.

Activity Category	Activity	Water Scarcity Impacts (AWARE) [m <sup>3</sup> world-eq.]	% Total Water Scarcity Impacts (AWARE)	% Activity Category Water Scarcity Impacts (AWARE)
<b>Direct activities</b>		<b>2418.78</b>	<b>0.1%</b>	<b>100.0%</b>
<b>Indirect upstream activities; purchased fuels and energies</b>		<b>41,515.44</b>	<b>1.3%</b>	<b>100.0%</b>
	Diesel	1140.60	0.0%	2.7%
	Natural Gas	7.84	0.0%	0.0%
	Electricity from grid	40,367.00	1.3%	97.2%
<b>Indirect upstream activities; purchased chemicals</b>		<b>531,475.56</b>	<b>16.9%</b>	<b>100.0%</b>
	Ethylene propylene diene elastomer (EPDM)	12,373.00	0.4%	2.3%
	Acrylonitrile Butadiene Styrene Granulate (ABS)	967.16	0.0%	0.2%
	Nitrile butadiene rubber (NBR)	14,662.00	0.5%	2.8%
	Polyamide 6 Granulate (PA 6)	40,862.00	1.3%	7.7%

Table A4. Cont.

Activity Category	Activity	Water Scarcity Impacts (AWARE) [m <sup>3</sup> world-eq.]	% Total Water Scarcity Impacts (AWARE)	% Activity Category Water Scarcity Impacts (AWARE)
	Polybutylene Terephthalate Granulate (PBT)	1613.50	0.1%	0.3%
	Polyethylene Cross-Linked (PEXa)	78,772.00	2.5%	14.8%
	Polyethylene high density granulate (HDPE/PE-HD)	14,822.00	0.5%	2.8%
	Polyethylene Low Density Granulate (LDPE/PE-LD)	32,492.00	1.0%	6.1%
	Polyethylene Terephthalate Fibres (PET)	63,473.00	2.0%	11.9%
	Polyoxymethylene Granulate (POM)	241,570.00	7.7%	45.5%
	Polypropylene Granulate (PP)	13,242.00	0.4%	2.5%
	Polysulfone (PSU)	10,109.00	0.3%	1.9%
	Polyvinyl Chloride Granulate (S-PVC)	6517.90	0.2%	1.2%
<b>Indirect upstream activities; purchased metals</b>		<b>2,439,615.74</b>	<b>77.5%</b>	<b>100.0%</b>
	Brass	783,400.00	24.9%	32.1%
	Cast iron part	110,700.00	3.5%	4.5%
	Lead	1726.70	0.1%	0.1%
	Stainless steel	1,543,300.00	49.0%	63.3%
	Steel alloyed	489.04	0.0%	0.0%
<b>Indirect upstream activities; other purchased materials</b>		<b>69,957.45</b>	<b>2.2%</b>	<b>100.0%</b>
	Cardboard	4152.70	0.1%	5.9%
	Generic product/others	186.85	0.0%	0.3%
	Silicone	60,917.00	1.9%	87.1%
	Wooden pallet	4700.90	0.1%	6.7%
<b>Supporting Activities</b>		<b>62,786.80</b>	<b>2.0%</b>	<b>100.0%</b>
	Canteen	15,902	0.5%	25.3%
	Capital Equipment - Building	4007.4	0.1%	6.4%
	Capital equipment - Cars	426.3	0.0%	0.7%
	Capital Equipment - Machines	38315	1.2%	61.0%
	Working Environment	4136.1	0.1%	6.6%
<b>Total</b>		<b>3,147,769.77</b>	<b>100%</b>	

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