Water consumption throughout a car’s life cycle

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Abstract The freshwater consumption throughout a car’s life cycle is determined using the GaBi 4.3 software and internal LCA databases. In order to obtain a regionalized water inventory, which is a prerequisite for a meaningful impact assessment, the total water consumption is allocated to different cars’ material groups in a first step. Subsequently, the water consumption caused in these groups is assigned top down to the corresponding countries on base of import mixes, location of suppliers, production sites, etc. Based on this, country and watershed specific characterization factors are calculated and selected impact assessment methods for water use are applied to estimate consequences on different impact categories. The results of this study show, that – in contrast to other impact categories – the production phase is responsible for the majority of the total water consumption in a car’s life cycle. In detail, the use of water is mainly linked to the supply of resources and materials from more than 40 countries. Furthermore, it becomes clear that the results of the impact assessment are highly sensitive to the regional distribution, i.e. the balance of water consumption and the respective water supply.

1 Introduction

The consumption of freshwater along the lifespan of products has not been in the focus of life cycle assessment for a long time due to a lack of both awareness and appropriate methods analyzing its various impacts. However, since global water demand grows twice as fast as the world’s population and 1.8 billion people are expected to live in water scarce areas by 2025 [1], it is very likely that “water is the new carbon” as already claimed in 2008 [2]. Taking into account this relevance, attempts to measure and assess water consumption of products along their life cycles are important for a sustainable water management.

Starting from volumetric tools like e.g. virtual water [3], substantial methodological developments were undertaken recently. Modern impact based water footprinting methods characterize water consumption based on parameters like local scarcity or quality and model complex impact pathways to various safeguard subjects [4]. In this context it should be noted that water consumption denotes only the fraction of total water use that is not returned to the same river basin from which it was withdrawn due to evaporation, product integration, or discharge into other watersheds [5].
Volkswagen has been analyzing the environmental effects of its cars and components by means of life cycle assessment (LCA) [6, 7] since many years [8]. However, due to lack of data and appropriate impact assessment models, the consumption of freshwater has not been considered so far. Therefore, Volkswagen started a study to analyze the freshwater consumption of three specific models Polo, Golf and Passat along their product life cycles on both inventory and impact assessment levels. In order to allow for a comprehensive analysis of consequences resulting from water consumption seven impact assessment methods, which represent different levels of sophistication and model different impact pathways, are applied.

2 Materials and methods

2.1 Water inventory

The amount of water consumed along the life cycles of the three car models (Polo, Golf, Passat) was determined using GaBi 4.3 software and Volkswagen's LCA databases. The process of modeling a life cycle inventory (LCI) of a whole car is very complex due to the fact, that it involves registering thousands of components, together with any related upstream supply chains and processes. Therefore, Volkswagen developed the SlimLCI interface system [9], which enables a consistent data collection process based on specific vehicle parts lists, material and weight information stored in Volkswagen's material information system, technical datasheets and drawings. Hence, the LCI data used in this study were originally determined for the environmental commendations of the Polo, Golf, and Passat [10-12], that have been reviewed by independent experts according to [6, 7]. However, the quantification of the basic volume is not sufficient. Moreover, regionalized water inventories are needed which state the location where water consumption occurs to consider regional water scarcity conditions, the vulnerability of ecosystems, or socio-economic parameters [4].

As geographical differentiation is a prerequisite almost for all impact assessment methods [4], regionalized water inventories are determined in a top-down approach. This study comprises the first approach to break down the overall water consumption in car life cycles to specific regions based on general assumptions. In a first step the car's total water consumption is divided into the shares consumed by the life cycle stages production, use, and recycling. For further specification, the water consumed in the production phase is assigned to manufacturing steps and to 15 material groups (specified in the German material classification in motor vehicle construction standard [13]). Following this, the water consumption caused by the manufacturing steps and material groups is allocated to specific countries based on production mixes, location of suppliers, production sites, etc. Relevant assumptions that have to be made for the regionalization of the water inventory include e.g.

- Water consumption in the painting, final assembly, and recycling of the cars takes place at the Volkswagen production sites and recycling operators in Germany and Spain.
- Water consumed by the material group aluminum is assigned to countries contributing to the European aluminum import mix proportionally to their import shares [14].
- Water consumption for polymers is first divided into oil extraction, refinery, polymerization, and component fabrications based on generic data available in the GaBi database [15]. These shares are further allocated to countries on base of the European import mixes of crude oil [15], the location of refineries and polymerization plants [16], and on the location of plastic component productions conducted at suppliers and Volkswagen production sites.

2.2 Impact assessment

There are several impact assessment methods available to evaluate consequences for human health, ecosystems, and resources resulting from water consumption. Due to the high data requirements of some approaches only methods for which regionalized water inventories are sufficient were applied. In practice the following three methods, representing different levels of sophistication and assessing different consequences, have been selected:

1) Ecological scarcity method [17]

2) Motoshita et al. (2011) [18]
3) Pfister et al. (2009) [19]

In detail, the methodology according to Pfister et al comprises five different characterization models, namely: freshwater deprivation, damage to human health, damage to ecosystem quality, damage to resources, as well as overall damage aggregating three impacts to a single-score result. In equivalency to other 'well established' impact assessment methods (like e.g. global warming potential) the quantified figures of the water inventory also have to be allocated to specific characterization factors. Generally, in this study the impact assessment is based on country specific factors. For the methods of Motoshita et al (2010) and Pfister et al (2009) these are provided in the respective supporting information. However, for the ecological scarcity method only few characterization factors for OECD countries are provided [17]. Thus, factors for non-OECD countries were calculated according to [17] using hydrological data from AQUASTAT [20].

Furthermore, in order to specify the impacts of water consumed at the specific production sites in Pamplona (Spain), Wolfsburg and Emden (Germany), watershed specific characterization factors were applied. In the ecological scarcity method, characterization factors for the catchment areas Ebro (Spain), Weser and Ems (Germany) were determined using data from the WaterGAP 2 model [21]. For the five specific characterization models combined by Pfister and colleagues [19], watershed specific factors were derived from a GoogleTM Earth [22] layer provided by the authors [23]. For the method of Motoshita et al. (2011) no site specific characterization factors were determined as factors, which are influenced by parameters like house connection rate to water supply and sanitation, are negligibly low and similar throughout Europe.

2.3 Sensitivity analysis

The assessment of a water footprint as described so far is obviously based on several assumptions that have to be seen as potential sources of uncertainties:

1) Uncertainties of water data in the LCA databases
2) Uncertainties resulting from assumptions to establish regionalized water inventories
3) Uncertainties in the impact assessment models

As water data in generic LCA datasets is usually highly aggregated, it is hard to assess the quality of this data directly. The results of an internal consistency check [24] though revealed overall good quality for selected datasets at least. Equally, for 'simple users' it is very difficult to assess methodological uncertainties in complex impact assessment methods. Thus, a sensitivity analysis was accomplished in order to evaluate uncertainties that result from the regionalization of the water inventory, i.e. the following assumptions, specifically:

- Volkswagen purchases materials according to average import mix shares, i.e. specific information from the purchase department is disregarded.
- By assigning the water consumption of material groups to countries based on the import mix shares, it is presumed that water intensity of producing a certain material is equal in all countries.
- Material production is accomplished only in countries contributing to the import mix, i.e. it is neglected that water consuming background processes (e.g. production of ores, electricity, etc.) might also take place in other countries.

As several different possibilities concerning the geographical differentiation are feasible, a minimum and a maximum scarcity scenario were set up. In the minimum scarcity (min-s) scenario the individual water consumptions of the 15 material groups were assigned to the countries in the corresponding import and production mixes which show the lowest physical water scarcity. In contrast, in the maximum scarcity (max-s) scenario the material group specific water consumption was fully allocated to the water scarcest country in the respective import and production mixes. Physical water scarcity was measured by means of the withdrawal-to-availability (WTA) ratio which relates annual freshwater use to the renewable water supply in a specific country as shown in equation (1).

$$WTA = \frac{\text{annual water use}}{\text{renewable water supply}} \quad (1)$$

Water consumption in the foreground system such as manufacturing and recycling of Polo, Golf and Passat remain assigned to Germany and Spain in both scenarios. As it might be too optimistic or too pessimistic to assume that all materials are derived exclusively from the countries of lowest or highest water scarcity, the scenarios should be regarded as boundaries between which realistic options are possible.

3 Results

3.1 Water inventory

On the inventory level, the following results were obtained denoting the water consumption along the life cycles of the three cars:

- Polo: 51.7 m³
- Golf: 62.4 m³
- Passat: 82.9 m³

These figures explicitly undermatch the results of other publications that have been released in the past [25, 26]. When determining the water consumption of the main life cycle stages, it was revealed for all three cars that more than 90 % of the water is consumed in the production phase. Since results of other environmental interferences, like acidification or global warming [27], are usually dominated by the car's use phase [11], it can be seen that other processes than fuel consumption are relevant from a water perspective. After assigning the water consumption of materials and production steps to countries based on import mixes, location of production sites, etc., regionalized water inventories were established for the three cars. Fig. 1 shows the results of this regionalization for the Golf exemplarily.

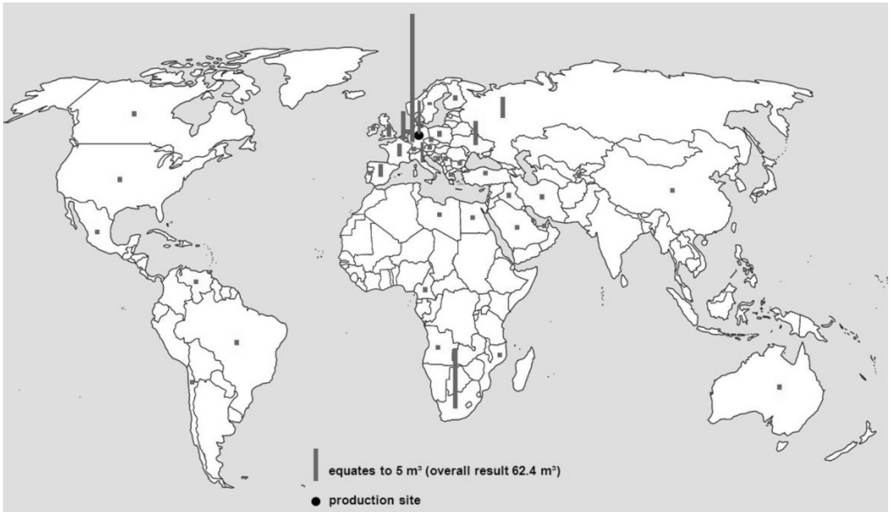

Fig. 1 Global water consumption throughout the life cycle of a Golf

The regionalized water inventories for Polo and Passat show comparable results. Water consumption takes place in 43 countries worldwide. Less than 10 % are consumed directly at the production site in Wolfsburg, Germany resulting mainly from painting and evaporation of cooling water. Hence, more than 90 % of the water consumption along the Golf's life cycle is caused by the material production in the global background system. In detail,

- steel and iron materials as well as polymers contribute equally strong to water consumption (more than 70 % in sum),
- special metals (gold, silver, and platinum group metals (PGM)) are responsible for about 20 % of the overall water consumption.

The significant figures in South Africa and Russia are supposed to result mainly from the production of special metals, i.e. the PGM particularly. These figures tend to overestimate the actual share of special metals, as their supply has been modeled with 100 % of primary material. Volkswagen actually runs an effective catalysts recycling program since years that helps to recover and recycle PGM in a closed loop system. However, due to methodological reasons this has not been considered in LCI so far.

3.2 Impact assessment

Based on the regionalized water inventories, the selected impact assessment models were applied in order to evaluate consequences resulting from water consumption in different countries. However, because of the incalculable influence of the uncertainties mentioned above the results of the impact assessment are not shown in absolute figures, but rather described as outcome of the sensitivity analysis.

Thus, Fig. 2 shows the results in a relative scale for the default, min-s, and max-s scenarios. In each scenario and in each impact category, the results of Golf and Passat are shown normalized to the Polo (100 %). In the default scenario it can be seen that the increased water consumption of Golf and Passat is reflected to a similar extend by the ecological scarcity method. In contrast to this, the other impacts categories show rather similar results for Polo and Golf. This can be explained by two reasons:

1) Water consumption at the Polo's production site in Spain is weighted higher than the similar water consumption at the Golf's production site in Germany.
2) Some impact categories, especially those measuring damages to human health, are dominated by water consumption of the PGM production in South Africa.

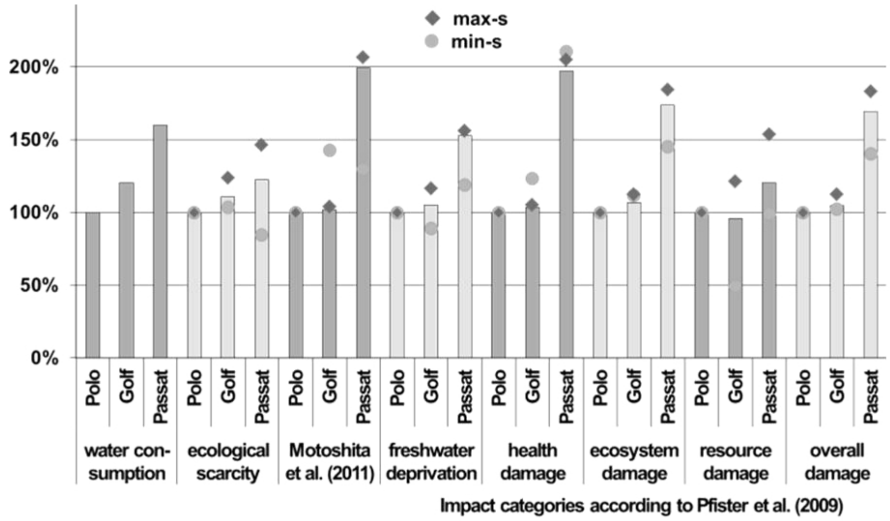

Fig. 2: Relative comparison of water footprints

As the PGM contents of Polo and Golf are comparable, the results of these impact categories are similar, too. Since the Passat contains more PGM as Polo and Golf higher impacts in the human health categories are reasonable. On the other hand, water consumption in South Africa does hardly affect the damage to resources since the WTA ratio is close to 1. For that reason the Passat scores only slightly worse in this impact category due to the larger water consumption of the larger material production. When accomplishing this relative comparison for the max-s scenario, a similar ranking of Polo, Golf, and Passat is obtained in most impact categories. Only in the ecological scarcity method and in the category assessing damage to resources different results were determined which are similar to those obtained by the simple water inventory. In contrast, large differences to the ranking of cars based on water consumption and between the impact categories are obtained in the min-s scenario, as water consumption is allocated to countries which are differently assessed by diverse methods.

4 Conclusion

This study analyzes the water consumption and the resulting impacts on the life cycle of a car. It represents the first known application of volumetric and impact based water footprint methods on such complex products. Using to the Volkswagen SlimLCI interface system, the calculation of the absolute water inventory figures can be done on the basis of a thorough and consistent methodology. However, the regionalization of this inventory data, which is a necessary and inevitable step, still has to be based on assumptions such as the manual disaggregation of import mixes. Additional to the - almost unknown - inherent uncertainties from impact assessment methods and generic datasets for background systems, this must be seen as a notable source for uncertainties. The reliability and usability of water inventories could be enhanced, if spatially differentiated water flows were available in the LCA databases (bottom-up approach) as it is already common practice for fossil energy carriers [15].

We therefore recommend focusing on regionalization of water inventories at first. Particularly for complex products the application of additional - maybe even more sophisticated - impact assessment methods should be avoided, until a procedure has been developed that allows a regional disaggregation in a sound, robust and reliable manner.

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