Water scarcity footprint of a Volkswagen car

Case study for the WULCA consensus midpoint impact assessment

model "Avaliable WAter REmaining"(AWARE)

Content

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1. Case study description

This study aims at testing the WULCA consensus midpoint impact assessment model “Avaliable WAter REmaining”(AWARE)[1] concerning practical applicability and scientific validity. It is based on an existing water footprint study that analysed water consumption and resulting impacts of three Volkswagen car models[2]. The water inventory of the Volkswagen Golf 1.6 TDI, which describes the water consumption along the car’s life cycle in a spatially explicit way (country level), is used as a basis for testing the AWARE characterization factors (CF):

- AWARE100, non-agricultural annual average (AWARE100, yr_non_agri)
- AWARE100, annual average (AWARE100, yr_avg)

In addition to these default CFs also modified CFs have been applied allowing for a sensitivity analysis of methodological choices:

- AWARE100+50%EWR, yr_non_agri with 50 % increased environmental water requirement
- AWARE10, yr_non_agri with an upper limit of 10 instead of 100
- AWARE1000, yr_non_agri with an upper limit of 1,000 instead of 100

In the following section results are presented and variations are explained considering the methodological differences between the CFs.

2. Results

2.1. Water inventory

Total water consumption along the life cycle of a VW Golf 1.6 TDI amounts to 62.4 m³. As shown in Figure 1, water consumption occurs mainly in Germany (ca. 13%), Indonesia and Thailand (ca. 10% each), Italy (ca. 9%) and South Africa (ca. 8%).

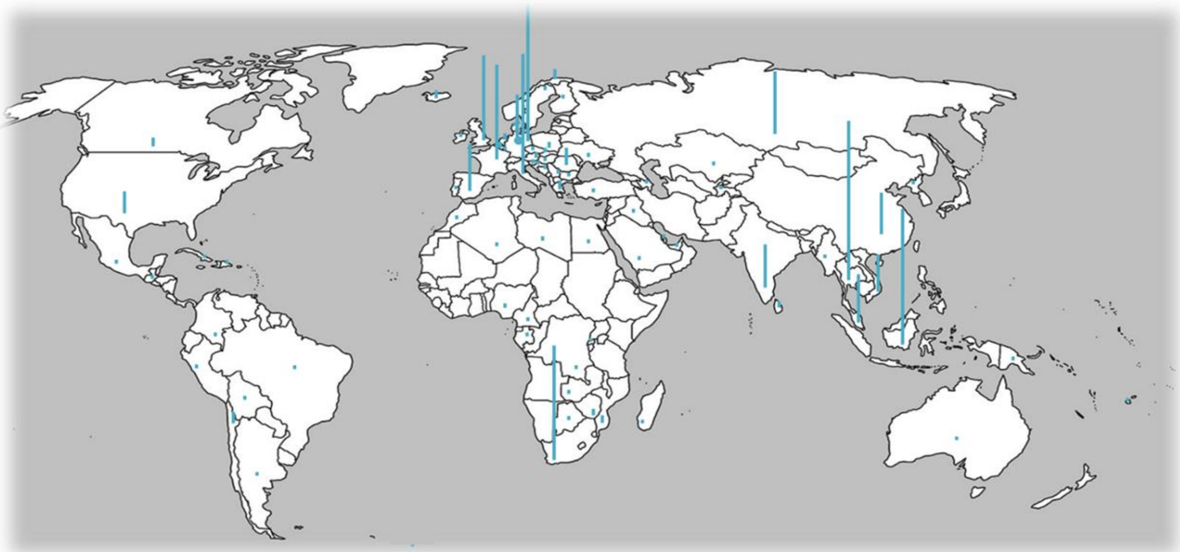

Figure 1 Relative spatially explicit water inventory of a VW Golf 1.6 TDI

[1] Boulay, A.-M., et al., The WULCA consensus characterization model for water scarcity footprints: Assessing impacts of water consumption based on available water remaining (AWARE). *Environmental Science and Technology* **2016,** *submitted.*

[2] Berger, M.; Warsen, J.; Krinke, S.; Bach, V.; Finkbeiner, M., Water Footprint of European Cars: Potential Impacts of Water Consumption along Automobile Life Cycles. *Environmental Science and Technology* **2012,** *46* (7), 4091-4099.

2.2. UDP100, yr_non_agri

In order to obtain the user deprivation potential (UDP), the country specific water consumption shown in Figure 1 is multiplied by its corresponding characterization factor (AWARE100). Since an industrial product system is analysed, the AWARE100, yr_non_agri factors are used. The resulting user deprivation potential, non-agricultural annual average (UDP100, yr_non_agri) amounts to 767.6 m^3 world equivalents and its spatial distribution is shown in Figure 2.

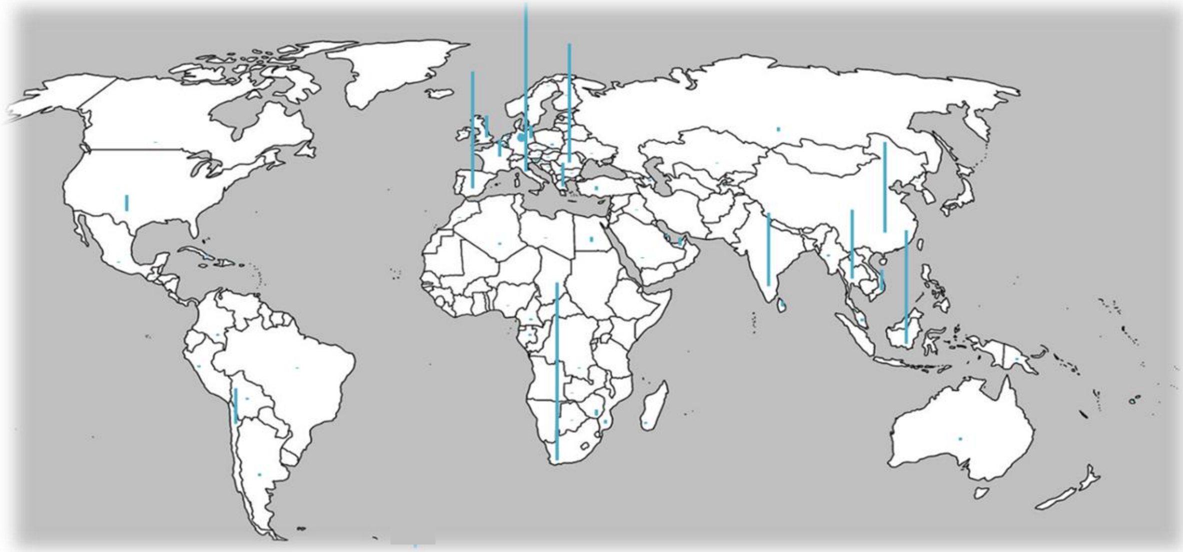

Figure 2 Relative spatially explicit user deprivation potential, non-agricultural annual average (UDP100, yr_non_agri) of a VW Golf 1.6 TDI

Results show that water consumption in regions with relatively low available water remaining causes a relatively high user deprivation potential. Compared to the inventory level results (Figure 1), countries like South Africa (ca. 17%), Italy (ca. 16%) or Spain (ca. 11%) show a higher contribution to the total results. Even relatively low amounts of water consumed in Chile (ca. 0.7 m^3) and Greece (ca. 0.6 m^3) result in a relatively strong UDP and shift these countries to the Top 10 relevant countries. Vice versa, relatively large amounts of water consumed in water abundant regions like Germany (ca. 8.0 m^3) or Russia (ca. 3.7 m^3) hardly contribute to the car's UDP.

2.3. UDP100, yr_avg

As a second step, the UDP is calculated again using the AWARE100, annual average (AWARE100, yr_avg) CFs. Compared to AWARE100, yr_non_agri, these factors are determined using the total (instead of only the non-agricultural) water consumption as a weighting factor when calculating annual country average CFs from the underlying monthly basin CFs.

Results show a doubling of the UDP from 767.6 to 1,564.1 m^3 world equivalents, with Italy, South Africa and Spain being the main contributing countries. This increase of the UDP can be explained by the increase of the country specific CFs by a factor between 1.4 and 2.5. The reason for this is the inclusion of agricultural water consumption, which is usually much higher than the non-agricultural consumption and which varies strongly throughout the year. As agricultural consumption (irrigation) occurs mainly during the dry month with low available water remaining, the high CFs of these months dominate the annual average CFs.

However, we also identified countries like the United Arab Emirates, in which the total water consumption weighted average CF (18.56 m^3 world equivalents / m^3) is lower compared to the non-agricultural weighted CF (46.01 m^3 world equivalents / m^3). This is explained by the procedure of aggregating basin specific CFs to country average CFs based on consumption weighted averages. If a large share of agricultural water consumption occurs in a basin and/or month with relatively low water scarcity, this CF dominates the result of the country average.

2.4. UDP100+50%EWR, yr_non_agri

In order to test the influence of methodological settings in the characterization models underlying AWARE, the UDP was recalculated applying AWARE100, yr_non_agri CFs in which the environmental water requirement (EWR) has been increased by 50%.

As a result we observed an increase in the UDP from 767.6 to 1,191.2 m³ world equivalents. Next to Italy (ca. 16%) and South Africa (ca 14%), now Thailand contributes about 15% to the total UDP. This can be explained by a significant increase (factor 3.5) in the CF of Thailand when the EWR is increased by 50%. In the remaining countries a moderate increase between 1.2 and 1.9 has been detected.

It should be noted that there are also countries, like Sweden and Germany, which show a lower CF when increasing the EWR. This sounds contradictory at first sight but can be explained by the underlying characterization model of AWARE, in which the inverse of a region's available water remaining is normalized to the global average. Hence, even though the available water remaining is reduced in Sweden and Germany when the EWR is increased by 50%, a lower CF can be obtained if this reduction is lower than the reduction of the world average.

2.5. UDP10, yr_non_agri

In the AWARE characterization model it has been decided, to set the CFs to a maximum value of 100 if demand increases availability (representing 33% of world consumption at a monthly level) and if the available water remaining in a basin is smaller than 100 times the world average (representing 5% of the world consumption). As this represents an arbitrary value choice, its influence is analysed by recalculating the CFs with an upper limit of 10 in this section and 1,000 in the next section.

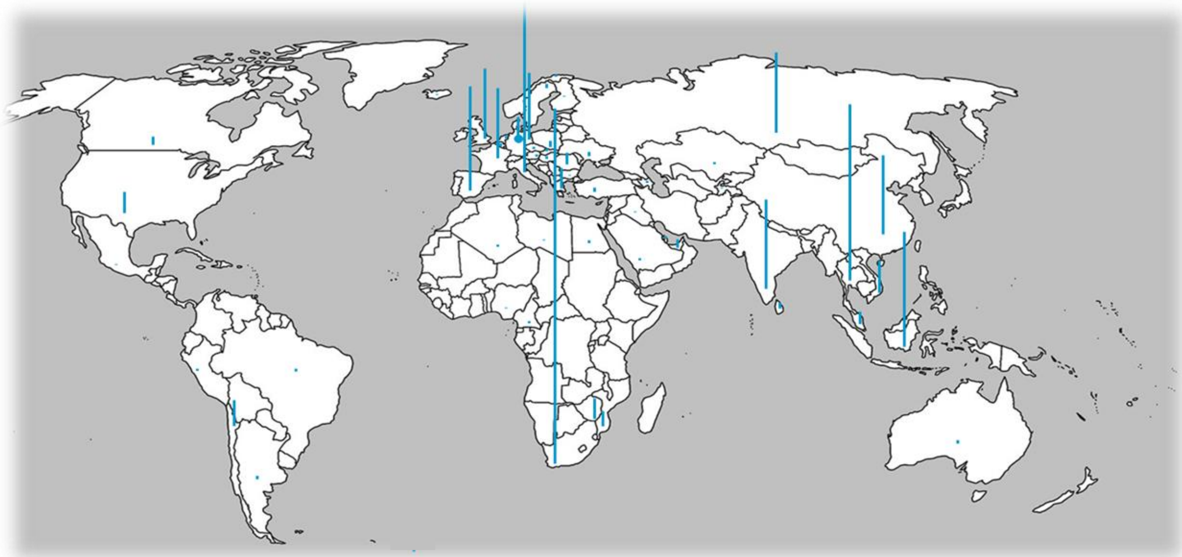

Figure 3 Relative spatially explicit user deprivation potential, non-agricultural annual average (UDP10, yr_non_agri) of a VW Golf 1.6 TDI

As shown in Figure 3, the UDP10, yr_non_agri shows similar results than the water inventory (Figure 1). With small changes in ranking, South Africa, Thailand, Italy and Indonesia dominate the total result. Countries like Chile or Greece, which are irrelevant on the inventory level but which popped up in the UDP100, again disappeared from the Top 10 list. Hence, the results are mainly influenced by the volumes of water consumed since the CFs (ranging from 0.1 to 10) are not able to provide a sufficient discriminative power.

2.6. UDP1000, yr_non_agri

Repeating this analysis with an upper limit of 1,000 leads to opposite findings. As shown in Figure 4, the UDP1000 is mainly influenced by the location of water consumption – the actual volume is of relatively low relevance.

Figure 4 Relative spatially explicit user deprivation potential, non-agricultural annual average (UDP1000, yr_non_agri) of a VW Golf 1.6 TDI

3. Comparison between AWARE and WAVE

A comparison between AWARE (UDP100, yr_non_agri, Figure 2) and the Water Accounting and Vulnerability Evaluation model (WAVE, Figure 5)[3] shows similar results concerning the contributions of individual countries and the identification of hot spots. Also in WAVE South Africa (ca. 20.7%), Italy (ca. 16.9%) and Spain (ca. 7.3%) are identified as the Top 3 countries contributing most to the total environmental impact.

Figure 5 Relative spatially explicit freshwater deprivation potential of a VW Golf 1.6 TDI according to WAVE

[3] Berger, M.; van der Ent, R.; Eisner, S.; Bach, V.; Finkbeiner, M., Water accounting and vulnerability evaluation (WAVE) – considering atmospheric evaporation recycling and the risk of freshwater depletion in water footprinting. *Environmental Science and Technology* **2014,** *48* (8), 4521-4528.

However, water consumption in Indonesia and Thailand is considered less relevant than in AWARE. A possible explanation might be the consideration of EWR in AWARE, which adds relevance to countries in which a relatively low share of availability is consumed by human activities. As another difference, water consumption in Germany, France and the UK causes visible impacts in WAVE which is not the case in AWARE. This can be explained by the range of characterization factors, which spreads by a factor of 100 only in WAVE. Hence, similar as in UDP10, the water inventory has a relatively strong influence on the results. Still the results obtained by WAVE are more similar to UPD100 than to UDP 10. The reason for this is a setting in WAVE which sets the CFs to the highest value (1.00) in arid and semi-arid regions and, thus, increases the range in CFs. Moreover, it should be kept in mind that in WAVE the aggregation from monthly basin CFs to annual country CFs is accomplished based on total water consumption only.

4. Lessons learned

This case study provided inside into the AWARE characterization model and identified significant methodological settings which should be kept in mind when interpreting results of a water scarcity footprint using AWARE.

First, the provision of annual country CFs based on agricultural, non-agricultural, and total consumption weighted averages of the underlying monthly basin CFs is a relevant support for practitioners. Even if the exact basin and the month of water consumption is unknown, it is usually known whether the product comprises an agricultural or non-agricultural system. A comparison of the UDPs obtained by means of AWARE,yr_non_agri and AWARE,yr_avg has shown a doubling of the category indicator result. This can be explained by the fact that agricultural consumption (irrigation) occurs mainly during the dry month with low available water remaining. Hence, in a consumption weighted average the high CFs of these months dominate the annual average CF. Even though the absolute UDP changed significantly, the contribution of individual countries to the total UDP remained rather constant.

A methodological sensitivity analysis in which the EWR has been increased by 50% revealed an increase of 56% in the UDP and changed the ranking of countries' contributions to the total UDP significantly. This can be explained by the different default EWR in different basins (30-60%) which are increased to 45-90%, respectively. Especially in basins with rather high EWRs a situation in which demand exceeds availability is easily reached leading to a setting of the CF to 100, which also influences the annual average. Hence, the setting of EWR has shown to be a significant methodological parameter which should be focused on in future research.

A difficulty in interpreting the CFs, especially in the methodological sensitivity analysis, is the normalization of the inverse of the available water remaining in a basin to the global average. This leads to the situation that a methodological setting cannot be analysed independently. It always needs to be seen in relation to the (also changed) world average. For instance, an increase in EWR of 50% (which decreases the available water remaining), a counter-intuitive decrease in CFs of Sweden and Germany was identified. Considering the normalization to the world average, this result expresses that the reduction in the available water remaining in Sweden and Germany is lower than the reduction on global average. Hence, even though the normalization to the world average increases the physical interpretation of CFs and allows for an easy to understand unit (m^3 world-equivalents/m^3), it represents a challenge for methodological sensitivity analyses.

Changing the upper limit of the CFs (10; 100; 1,000) leads to an increased discriminative power of the CFs. Comparing the annual country CFs of countries has shown that this setting does not only influence the relative difference between the countries but also the ranking of countries. This can be explained by two facts. First, monthly basin CFs are more likely to become equal if the upper limit is 10 only. Second, if the upper limit of CFs for water scarce months is 100 or even 1,000, the relative weighting of these CFs in the annual average is much higher.

In general, the setting of the upper threshold of the CFs to 100 (in basins in which demand increases availability or in which the available water remaining is smaller than 100 times the world average) has shown to be a good compromise. This setting balances the influence of the inventory (overrepresented in UDP10) and the CF (overrepresented in UDP1000). Nevertheless it should be kept in mind that there is no scientific justification that a range of three orders of magnitudes (0.1-100) is the "correct" setting.

5. Potential problems

As for any other water characterization model, the main hindrance for the application of AWARE in industrial product systems is the absence of spatially explicit inventory data. This case study was only possible because the inventory data had been regionalized in a top-down regionalization approach discussed in the underlying publication[4].

Even though we did not identify obvious mistakes in the CFs or obviously wrong conclusions drawn from the application of AWARE, the interpretation of the results was not always straightforward and some CFs appeared counter-intuitive.

For instance, it seems illogical that CFs based on total water consumption weighted average are lower than non-agricultural weighted CFs in some countries (like UAE). Also a comparison of CFs between countries can lead to strange findings. For instance, strong differences are detected between countries in the MENA region, ranging from 29 m^3 world equivalent/m^3 in Saudi Arabia, over 43 in Libya to 98 in Egypt. Obviously, each of the three countries are dominated by desserts and suffer from extreme water scarcity. Thus, it is hard to explain that, according to AWARE, there are significant differences between them. It also hard to justify why Saudi Arabia is considered less water stressed than Spain or Greece (31 m^3 world equivalent/m^3).

The reasons for these counter-intuitive CFs, which might reduce the acceptance of AWARE among practitioners, can be explained by the methodology of aggregating basin specific CFs to country CFs based on consumption weighted averages. If a large share of water consumption occurs in a small basin with relatively low water scarcity (as it is the case in many dessert countries), this CF dominates the result of the country average. However, this aggregation procedure seems justified from a scientific point of view as it is most likely that the (spatially unknown) water consumption occurred in the basin with the highest share of the country's water consumption.

[4] Berger, M.; Warsen, J.; Krinke, S.; Bach, V.; Finkbeiner, M., Water Footprint of European Cars: Potential Impacts of Water Consumption along Automobile Life Cycles. *Environmental Science and Technology* **2012,** *46* (7), 4091-4099.