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purpose are located in areas without water-scarcity, i.e. in areas with more than 1000 m<sup>3</sup>/capita/year water available, thus being located in areas less problematic with respect to water losses from the reservoir surfaces. The 34 reservoirs in water-scarce areas are located in the countries United Arab Emirates, Saudi Arabia, Libya, Yemen, Jordan, Oman, Tunisia, Algeria and Singapore.

Figure 1. The location of the reservoirs with given functions, classified according to level of water scarcity and presented as portion of total number of reservoirs. The reservoirs with single and main purpose are combined.

Figure 1 tells us that 47 % of the reservoirs with irrigation as the single or main purpose are located in areas with less water than 1700 m<sup>3</sup>/capita/year than reservoirs with other types of functions, followed by water supply (approx. 21 %). In the other end, there are very few reservoirs with single or main purpose of flood control (4 %), navigation (< 3 %) and recreation (< 1 %) that are located in areas with less water than 1700 m<sup>3</sup>/capita/year. One interpretation of this picture might be that food from irrigated land and water supply are both basic services needed to the society, while water is a too scarce resource to be set aside for especially the purposes navigation and recreation.

### 3 DISCUSSION

### 3.1 CONSUMER OR COLLECTOR?

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3 The water footprint of a product is defined as the total volume of freshwater that is used directly or  
4 indirectly to produce the product. It is estimated by considering water consumption and pollution in all  
5 steps of the production chain (Hoekstra et al. 2011). The purpose of a water footprint study is to assess  
6 how a certain activity affects the downstream water users in the basin, including the ecosystem. A  
7 large water footprint would, as such, affect the downstream water users negatively and should be  
8 avoided, and activities with large water footprint would be undesirable in arid regions experiencing  
9 water-scarcity. It is then interesting to visit the study of Weichert (2013) that found the highest  
10 published water consumption values are typically in the regions with severe water-scarcity, such as the  
11 High Aswan Dam in Egypt. At the same time, there are indisputable huge economic benefit of this  
12 reservoir to Egypt (e.g. Strzepek et al., 2008), and it appears clear that the awareness of the high water  
13 footprint values would never disqualify this project from being built. The benefits of securing  
14 adequate water-services to the domestic users, agricultural sector and the power production is higher  
15 than the costs of the lost water due to increased evaporation. The importance of reservoirs in arid  
16 regions is also supported by Bates et al. (2008). Despite that the value of the evaporated/lost water  
17 might be very high in water-scarce regions (Maestre-Valero et al. 2013), we find it reasonable to claim  
18 that ‘the higher water-scarcity the more needed are the reservoirs’. The possibly biased picture given  
19 by the high water consumption values is that the methodology does not take into account the benefits  
20 of the reservoirs in providing water-services.  
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43 The downstream activities that are supposed to suffer from high water consumption rates from the  
44 reservoir are actually those that can benefit from the regulated flow provided by the reservoir. In the  
45 case of the High Aswan Dam in Egypt, the agricultural sector as well as the domestic supply of water  
46 from the Dam to the Mediterranean Sea benefit from the reservoir. Those supposed to be ‘the losers’  
47 of the high water footprint are actually ‘winners’ as they are provided more stable flows of water  
48 throughout the year.  
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### 3.2 SETTING THE RIGHT SPATIAL BOUNDARIES

1 Global hydrology tells us that the presence of water varies in time and space, but does not disappear  
2 nor is created. The definition of water consumption as well as water withdrawal hence involves  
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4 defining spatial and temporal boundaries of the problem of concern. The outcome of a study will  
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6 hence depend on how these boundaries are set. As the design of hydropower as well as other  
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8 infrastructure projects involving water might vary a lot due to its site-specific character, the water  
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10 might be transferred long distances within and between river basins, the spatial boundaries must be set  
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12 with great care (Fulton et al. 2014). In the majority of those studies concerning hydropower and water  
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14 consumption, the spatial boundaries are set to include only the nearby reservoir and the power plant,  
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16 even though the reservoir might serve as a regulating unit for several downstream hydropower plants  
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18 ('cascaded development') as well as serving other downstream purposes benefitting from a more even  
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20 flow pattern. As such, the spatial boundaries defined in the study will affect the outcome of the study a  
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22 lot. Exemplified, the High Aswan Dam in Egypt serves several purposes, and not only those purposes  
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24 taking water directly from the reservoirs benefitting from the storage of water, but also irrigated  
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26 agriculture and domestic drinking water supply located far downstream the reservoir.  
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### 34 **3.3 NET ASSESSMENT OF WATER LOSSES AND ALLOCATION**

37 The establishment of a reservoir will change the natural runoff downstream the dam, which is also the  
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39 purpose of the reservoir. In some cases the reservoirs are established by damming a river creating an  
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41 artificial lake behind the dam, while in other cases the reservoir are based on a natural lake introducing  
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43 only small changes to the natural environment. The evaporation from the areas affected by the  
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45 reservoir might change due to the establishment of the reservoir, but the rate of this change is very  
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47 specific to the individual case and climatic region. It seems now that there is an agreement in that  
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49 future assessments of the water footprint shall be carried out based on the 'net'-approach, i.e.  
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51 subtracting the evaporation prior to the establishment of the reservoir (ref. most updated version of the  
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53 draft ISO Water Footprint Standard 14046, 2014). It should, however, be mentioned that the majority  
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55 of the published studies (Bakken et al. 2013), are based on the gross estimation, including those  
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57 presented in IPCC (2011). Only a few studies have calculated the net effect (Herath et al. 2011, Yesuf  
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2012; Tremblay et al. 2014), where Tremblay et al. (2014) even found negative numbers for water consumption. It should in relation to this be noted that calculation of the evapotranspiration with reasonable precision is a challenging hydrological task, from both reservoir surfaces as well as natural vegetation. As a large number of reservoirs are multi-purpose, allocation of the water losses between the various functions should be done, but a methodology to do this appears to be non-existing in published literature.

### 3.4 HANDLING THE IMPACT

Current methodological framework for the calculation of water footprint/consumption from reservoirs takes to a limited extent into account the positive effect of increased water availability from the reservoir (e.g. IPCC 2011; Bakken et al. 2013; ISO 14046 2014). The dominating approach simply calculates the water consumption dividing the evaporated water of on annual power production, while the latest version of ISO 14046 (2014) uses a different methodology acknowledging the increased availability. In ISO 14046 the impact is corrected based on a local/regional water scarcity-factor, which appears as a reasonable approach in order to assess the possible negative effect by the water footprint, but the positive effects of the regulation (increased water availability) might be higher the more water-scarce area the reservoir is in located in.

### 3.5 THE RISK OF GENERALISATION

We would like to draw the attention to the very site-specific character of hydropower projects compared to other energy technologies. This can for instance be seen in the water consumption values presented by IPCC (2011, Figure 9.6), confirmed by e.g. Olsson (2012) and Bakken et al. (2013), and a similar much higher variance for hydropower than the other technologies can be observed on emission on green-house gases (GHGs) in IPCC (2014, Figure 7.6). The site-specific character of hydropower can be explained by the fact that the location and design of the projects to a large extent is determined by local topography and climatic conditions. It is important to keep this in mind when

1 comparative studies across energy technologies are carried out. There is a risk of presenting a very  
2 biased picture when average values for hydropower are developed or even worse, when these values  
3 are applied to a new case without case-specific data, as the average values might be far out of range  
4 for the individual plants.  
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## 10 11 **4 CONCLUDING REMARKS**

12 We have in this study presented some basic statistics on the world's reservoirs and found that only  
13 very few reservoirs located in water-scarce areas are used exclusively for hydropower production or  
14 have power production as the main purpose (fewer than 0.1 %). As the purpose of the majority of the  
15 reservoirs located in water-scarce areas are to collect water in the wet season to secure adequate  
16 supply of water for irrigation and domestic water supply in the dry season (and flood control in the wet  
17 season), we find it fundamentally problematic to assign a water footprint to such an infrastructure,  
18 even though these reservoirs might also be used for power production. Rather opposite – the fact that  
19 reservoirs increase the availability of water in the dry season make reservoirs needed. The evaporative  
20 water losses is something we must accept in order to increase other and more important benefits of the  
21 reservoirs. If so, we would conclude that assigning water footprint/consumption values of reservoirs  
22 will convey the wrong message to decision-makers unless the reservoirs' effect on the availability of  
23 local water resources is fully accounted for.  
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