

Review

Water Resources for Sustainable Healthy Diets: State of the Art and Outlook

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Abstract: Sustainable healthy diets are high on the research and policy agendas. One of the crucial resources to provide such diets are water resources. This paper provides a brief overview of the current research state regarding this topic, with a focus on the water footprint concept, as latter quantifies water use along a supply chain. The water footprint (WF) quantifies blue and green water consumption, as both these water resources are essential for food and energy production as well as for the environment. Different kinds of information are embedded in a dietary WF and different data sources and modelling approaches exist, leading to WF dietary amounts that are not always directly comparable. A full sustainability assessment of a dietary WF encompasses three components: (1) an equity assessment of the total WF amount; (2) an efficiency assessment for each food item in the diet as well as (3) an impact assessment (blue water stress and green water scarcity) for each food item in the diet. The paper concludes with an outlook on future research on the topic, listing the following points: (1) future clarity in system boundary and modelling assumptions, with comparison of results between different approaches; (2) full sustainability assessments including all three components; (3) dietary footprint family assessments with the WF as one member; (4) WF assessments for multiple dietary regimes with support to the development of local dietary guidelines and (5) assessment of the synergies with LCA-based mid-point (scarcity-weighted WF) and end-point (especially human health) indicators and evaluation of the validity and empirical significance of these two indicators

Keywords: sustainable healthy diet; water resources; water; water footprint; food; diet

1. Introduction

Sustainable food systems and sustainable healthy diets are high on the policy agenda. The joint FAO and WHO report “Sustainable healthy diets—guiding principles” [1], launched on World Food Day 2019, includes the three pillars of sustainability (social, economic and environmental). It defines sustainable healthy diets as “*dietary patterns that promote all dimensions of individuals’ health and wellbeing; have low environmental pressure and impact; are accessible, affordable, safe and equitable; and are culturally acceptable*”. This document aims to support the efforts of countries as they work to transform food systems to deliver on sustainable healthy diets. In May 2020, the European Commission launched its “Farm to Fork Strategy”, which includes the aim of promoting sustainable food consumption and facilitating the shift to healthy, sustainable diets [2].

Water is an essential resource for delivering sustainable healthy diets. There is therefore a vast body of research on this topic with many substantial developments in recent years. This paper aims at providing a concise overview on the current research state as well as briefly discussing future research directions.

2. Current Research State

2.1. Blue and Green Water Resources Used in the Supply Chain of Food Products Providing a Healthy Diet

Due to human economic activities, both blue and green water resources are considered scarce [3,4]. Blue water refers to liquid water in rivers, lakes, wetlands and aquifers. Green water is the soil water held in the unsaturated zone, formed by precipitation, and it is available to plants. Irrigated agriculture receives blue water (from irrigation) as well as green water (from precipitation), while rainfed agriculture receives only green water. Both water resources are thus essential in providing a healthy diet [5–7]. Regarding blue water use, a differentiation needs to be made between water abstraction, also referred to as water withdrawal or gross water abstraction, and water consumption, also referred to as consumptive water use or net water abstraction (Figure 1a) [8]. Water consumption equals water abstraction minus return flows. Green water use only refers to green water consumption.

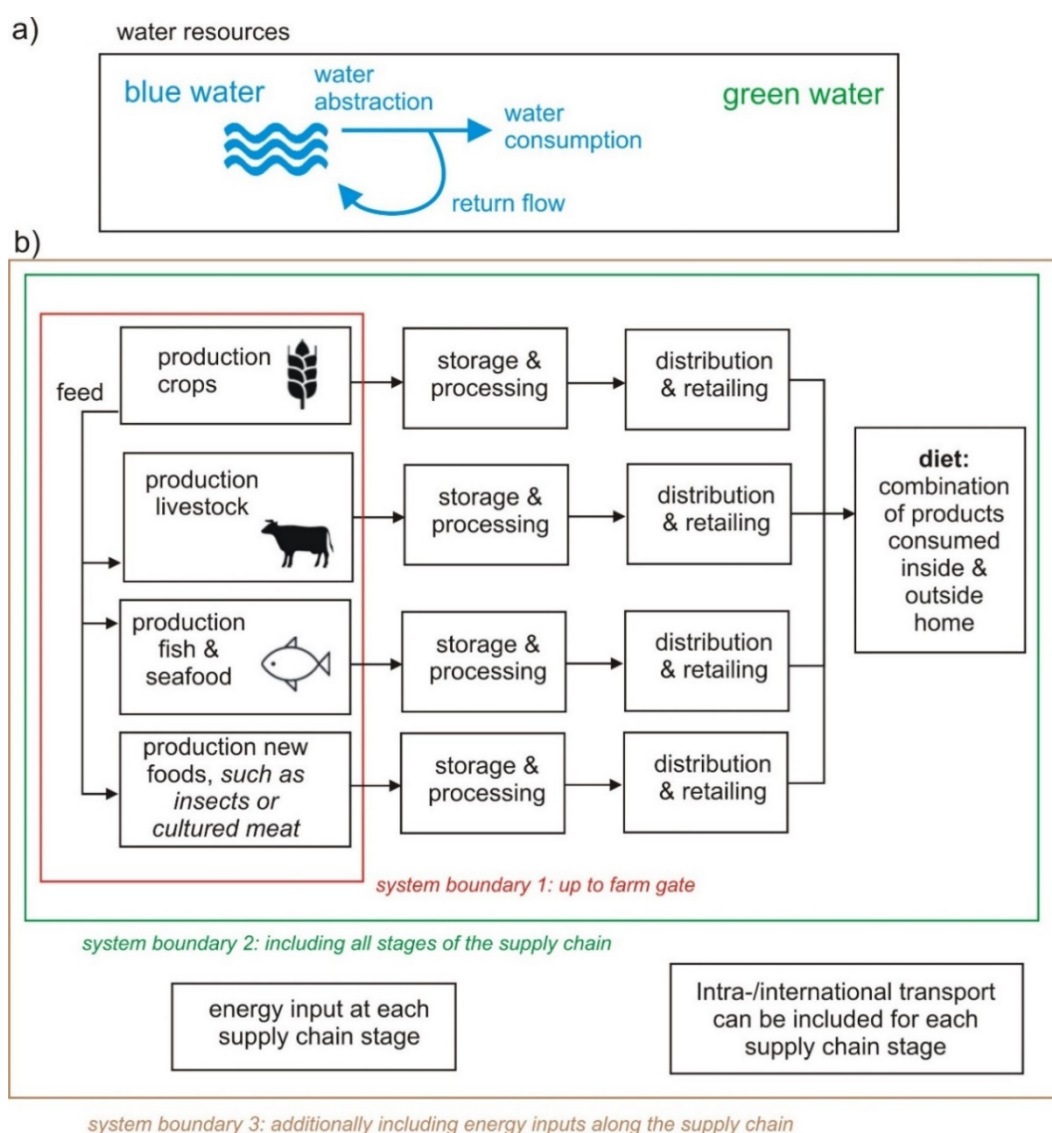


Figure 1. Representation of (a) water resources relevant for providing a healthy diet; (b) the supply chain of food products providing a healthy diet, with a selection of three relevant and common system boundaries used to quantify water resources required to produce a diet.

To assess the water use of food products, both blue water abstraction and consumption are relevant [9–11]. However, to assess the water use of a diet, it is generally accepted that blue water

consumption is the relevant indicator to quantify. This is to avoid the same resource being counted more than once, due to the potential multiple use of return flows in river basins as well as the complexity of supply chains [8,12]. The water footprint (WF) captures this supply chain thinking, by quantifying consumptive blue and green water resources along a supply chain [13,14].

According to Hoekstra [15], supply chains are extensive and complex, so that in praxis environmental footprint analyses of supply chains are truncated at some point. Figure 1b shows theoretical supply chains of product groups that can be part of a diet, i.e., crops [16], livestock products [17], fish and seafood [18] as well as new or future foods such as insects and cultured meat [19,20]. A selection of three commonly used system boundaries is also shown: system boundary 1 up to the farm-gate, system boundary 2 which includes following supply chain stages such as processing and distribution and system boundary 3 which additionally includes energy inputs along the supply chain. WF dietary assessments are in environmental footprint assessment (EFA) generally conducted for system boundary 1, neglecting the following steps of the supply chain. The reason for this is twofold. The first is because by far the largest proportion of blue and green water consumption of products occurs at this first supply chain stage, whereas further supply chain steps account for only small consumptive water uses [14,21]. The second is because including all steps requires more data and specifications on global supply chains. Bottom-up WF assessment approaches generally do not capture this information. Multi-regional input-output (MRIO) databases partially offer such information.

WF dietary assessments within system boundary 2 are therefore not abundant. For individual food products, WFs have been assessed along the whole supply chain. Within life cycle assessment (LCA), which is product- and impact-oriented, assessments for individual products are common [21], although not always based on detailed geospatial data [22].

WF dietary assessments within system boundary 3 have not been the focus of research but would be interesting within a wider water-energy-food-ecosystem (WEFE) perspective [23]. The food system requires a substantial input of energy at every supply chain stage [24], which can increase when much intra/international transport is included (Figure 1b). Consumptive water use to produce this energy is rather small for fossil fuels and nuclear energy but is substantial for biomass-based renewable energy as well as reservoir hydropower [25–28]. The renewables wind, solar and run-of-river hydropower have low unit WFs per amount of energy produced [25,29]. Decarbonisation of the energy system can thereby put extra pressure on water resources [29–32]. Including the WF of energy input in dietary assessments can thus substantially increase the total WF of a diet.

2.2. Embedded Information and Environmental Sustainability of a Dietary WF

A dietary WF encompasses different kinds of information (Figure 2):

- The inclusion of blue and/or a green WF component. Studies in the literature report on only the blue WF, the blue and green WF and the total WF (green plus blue) [33].
- The type and amount of singular food items within a diet, thereby identifying a healthy or unhealthy diet from a nutrition perspective (calories, protein, fats, macro- and micronutrients).
- The origin of these products (local and/or import) and associated WF of production. The latter is the result of production methods (irrigated versus rainfed, conservation agriculture, nutrient application etc.) and resulting yield, and agroclimatological conditions (soil, climate, etc.).
- The inclusion or exclusion of food losses and waste along the supply chain.
- The choice of system boundary (three selected choices are presented in Figure 1).

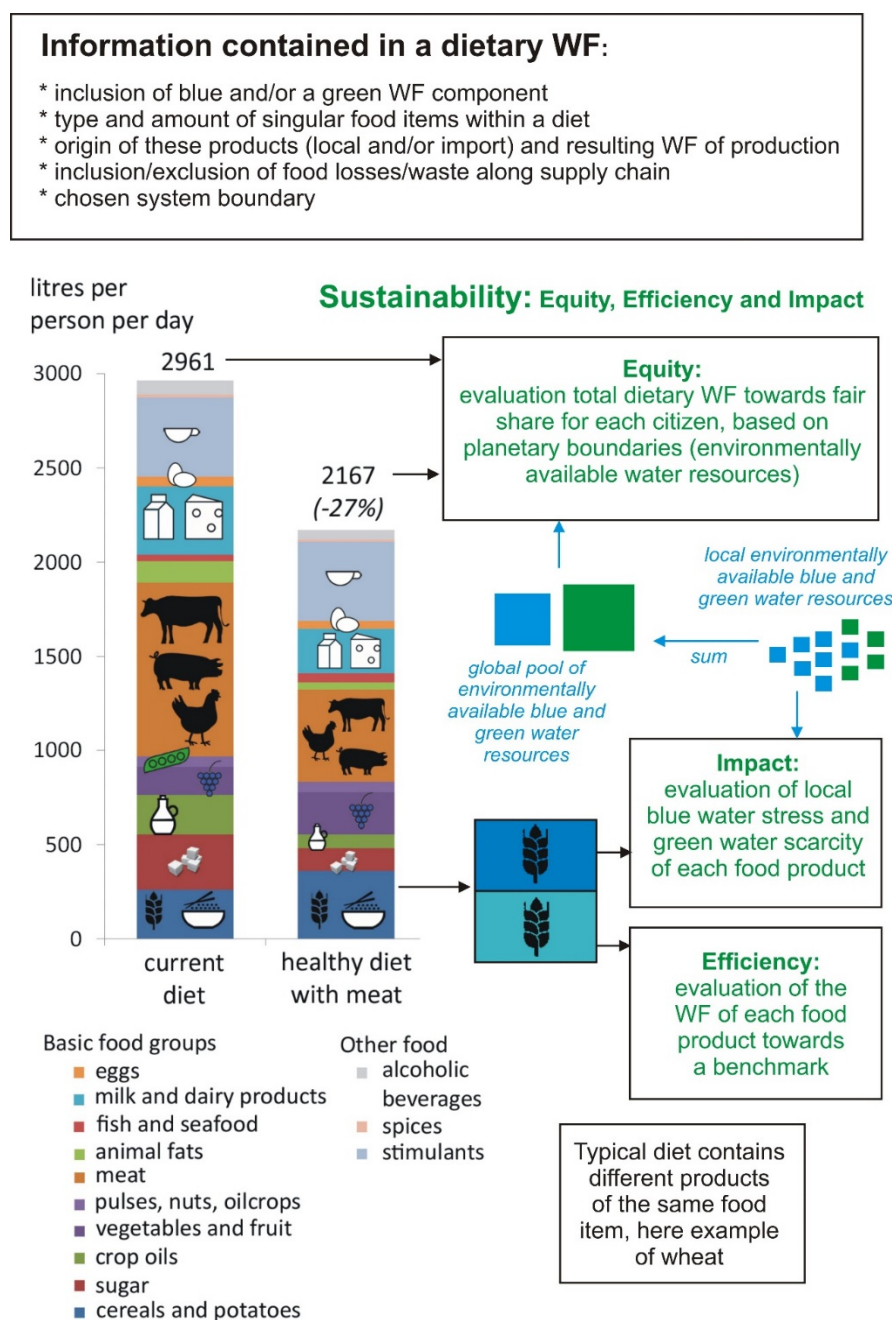


Figure 2. The green plus blue dietary water footprint (WF) of Berlin, for the current diet as well as a healthy diet including meat (data from Vanham et al. [34]). The figure also lists the different kinds of information contained in a dietary WF as well as the three aspects to evaluate the environmental sustainability (with respect to water quantity) of a dietary WF.

To evaluate the environmental sustainability of a dietary WF concerning water quantity, three aspects need to be addressed: equity, efficiency and impact (Figure 2). Hoekstra already defined sustainable, efficient and equitable water use as the three pillars for wise freshwater allocation [35], which basically overlap with the three aspects listed here. However, some terminologies are different. Hoekstra [35] refers to sustainability for what I call impact. I use the terminology sustainability as an umbrella for the three aspects. The latter definition is more in line with existing definitions by different institutions. The European Commission includes resource efficiency within the concept of sustainability: “Resource efficiency means using the Earth’s limited resources in a sustainable manner while minimising impacts on the environment [36]”. The FAO/WHO [1] defines sustainable healthy diets as

“dietary patterns that have low environmental pressure and impact”. In line with latter definition, Vanham and Leip [11] state that sustainable food systems need to address both pressures (water use/WF) and impacts (water stress/scarcity) [23,37]. The Sustainable Development Goal (SDG) target 6.4 on the reduction of water stress, incorporates an indicator 6.4.1 on water efficiency and 6.4.2 on water stress. Hence the justification for using sustainability as umbrella terminology.

Whether a dietary WF is sustainable thus needs to address:

- **Equity:** the evaluation of a total dietary WF towards a fair share of globally available blue and green water resources for each global citizen. WF amounts above this share are considered unsustainable. Local environmentally available blue water resources (available blue water resources minus environmental flows as well as sustainably available groundwater resources) [3,8,23,38] are scaled up to river basins [39] and ultimately a global pool/planetary boundary of blue water [23,40,41], as conceptually displayed in Figure 2. In addition, green water availability is scaled up to a planetary boundary [4,23]. Fair shares are generally defined as per capita equivalents to the global pool of water resources, although other distribution methods exist [42,43]. As already pointed out by Hoekstra [44], this per capita fair share will decrease due to population growth. In order for a diet to remain within such a fair share, substitution of water-intensive products such as animal products into less water-intensive products such as most vegetal products may be needed. Indeed, healthy diets with less or different animal products have lower total green plus blue WFs [34,45]. When only accounting for the blue or green component separately, this observation is more differentiated [33]. A more comprehensive discussion on this topic is included in Section 3.2.
- **Efficiency:** the evaluation of the WF of each food product within the diet towards a benchmark [10,11,46]. When the green plus blue WF is higher than the benchmark, the particular product is considered inefficient or in broader terms unsustainable.
- **Impact:** the evaluation of the local blue and green water stress/scarcity of each food product within the diet [10,47]. Impact should be low, otherwise the product is considered unsustainable.

Addressing all three aspects combined results in a sustainable dietary WF. For different countries, regions or socioeconomic groups, priorities in reaching these goals will be different. As an example, Niger and Bolivia have larger per capita WFs as compared to the USA. For the former, where the per capita consumption of animal products is low as compared to the USA, focus will have to be put on efficiency, whereas in the USA, much focus will have to be put on a shift to a healthy diet with less animal product consumption.

2.3. Geographical Coverage, Data Used and Modelling Approaches

Dietary WF assessments have been conducted at global level [48,49], at national level with global coverage [50,51], continental or regional scale [45,52], individual country level [53–63], river basin level [64], provincial level [61], city level up to inner-city/borough level [34,65–71] and for specific socioeconomic groups [65,72–74]. Harris et al. [33] also provide a selected overview of relevant studies. In theory, a dietary WF can be calculated up to the individual level.

Many of these dietary WF assessments have been conducted based upon different data sets as well as modelling approaches and resulting total amounts can therefore not always be directly compared. Essential data input are, e.g., food intake/food consumption data:

- Many studies use FAO Food Balance Sheet (FBS) data [14,45], which have the advantage that they are internationally standardized. These data are however food supply data, i.e., food reaching the consumer. They are on an “as purchased” basis, i.e., as the food leaves the retail shop or otherwise enters the household. The quantities are provided on the basis of “primary equivalents”. In order to convert them into actual food intake values, two correction factors are required. The first factor accounts for product equivalent conversions and the second for food waste (by households but also catering) and feed to domestic animals. Often FAO FBS dietary WF assessments therefore include a WF component of consumer food waste [45,75].

- National food supply data from national statistical offices can be used. These often differ in amount and/or food product specifications from FAO FBS data.
- Many dietary WF studies use dietary survey data directly. These are food intake data, often with additional information on socioeconomic factors. They thus provide the possibility to compute dietary WFs according to socioeconomic statistics [34,61]. Such surveys can be very detailed in the type of food item consumed. They can however also be biased due to under-reporting.

Study results can differ substantially based on which food intake/consumption data are used. For the USA, e.g., Hoekstra and Mekonnen [14] computed a blue plus green WF for the current diet (including food waste) of 5118 L/cap/day based on FAO FBS data, whereas Mekonnen and Fulton [56] computed a blue plus green WF for the current US diet (including food waste) of 2637 litres/cap/day based on a national nutrition survey.

Different modelling approaches can also result in different dietary WF amounts. The latter can be computed by bottom-up, top-down (e.g., MRIO) or hybrid approaches, including variations in attribution (mass, economic) methods. National dietary WF assessments can be simplified by assuming global WF averages for an imported food item instead of tracing imports from each country of origin. Sophisticated MRIO models/databases can actually solve the latter point, but some are limited by the amount of countries they include or the amount of individual years they cover. Specific MRIO models/databases do provide the possibility to quantify water over different economic sectors, thereby tracing processed food products better as compared to other approaches.

2.4. Scarcity-Weighted WF and Human Health Impact (Due to Malnutrition) from Water Stress in LCA

As described in Section 2.2, to evaluate the environmental sustainability of a dietary WF, three aspects need to be addressed: equity, efficiency and impact.

LCA, which is impact-oriented, uses mid-point and end-point indicators to assess the environmental impact of products and also diets. As mid-point indicator it uses the scarcity-weighted WF. Regarding end point indicators, the impact of water stress is quantified on human health as well as ecosystems. In an influential paper, Hoekstra [76] has already raised serious concerns on the validity of the scarcity-weighted WF and has argued that local physical water stress cannot be linked to local human health impacts. Although a general reply [77] was given to Hoekstra's criticism, both concerns remain valid and therefore relevant for dietary WFs. In the following, a concise justification is presented.

The scarcity-weighted WF has been developed by the LCA-community, using water stress as characterization factor, by multiplying the WF with water stress. It aims to capture both water use and water stress in one indicator, and is, e.g., used by Poore and Nemecek [9] to quantify the impact of different food products. It is measured in quantities of water equivalents. These are not real water volumes and should not be communicated as such.

Vanham and Leip [11] use the example of global irrigated maize to show that there is only a weak correlation between water use (WF) and blue water stress. They then present a water quantity sustainability scheme, which addresses both water use and water stress Equation (1), in line with the two sustainability aspects efficiency and impact discussed in Section 2.2. They also provide an example on consumer product choice, based on the indicators WF, water stress and scarcity-weighted WF. The scarcity-weighted WF results from multiplying the blue WF with blue water stress Equation (2). This example is here enhanced in Figure 3.

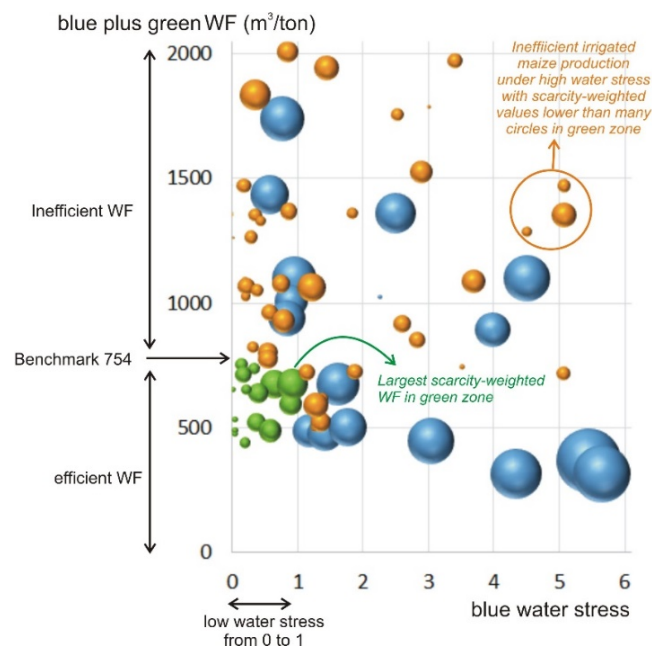


Figure 3. Relationship between (blue and green) WF of irrigated maize with blue water stress as well as a scarcity-weighted WF (relative amounts in circle size). Green circles indicate sustainable situations (low water stress and WF below a threshold/benchmark). The benchmark is chosen at 754 m³/t. Blue and orange circles indicate unsustainable situations (water stress is larger than 1 and/or WF above the benchmark). Orange circles identify lower scarcity-weighted WF amounts in the unsustainable zone as compared to the highest scarcity-weighted WF amount in the sustainable zone (green circles). Blue circles identify higher scarcity-weighted WF amounts.

Blue water stress in Vanham and Leip [11] is defined as:

$$\text{blue water stress} = \frac{\text{blue WF}}{(\text{WA} - \text{EFR})} \quad (1)$$

with WA = total blue water availability, EFR = environmental flow requirements and WA-EFR = environmentally available blue water resources. Blue water stress values up to 1 are defined as “low water stress”. Values exceeding 1 indicate blue water stress.

$$\text{scarcity weighted WF} = \text{blue WF} \times \text{blue water stress} \quad (2)$$

Figure 3 shows for a sample of irrigated maize locations, scattered worldwide, the relationship between the WF (blue plus green, Y-axis), water stress (X-axis) and the scarcity-weighted WF (relative amounts in circle size, from small circles for small amounts to large circles for large amounts). The so-called sustainable zone (with green circles) encompasses maize locations with low water stress (value 0 to 1) where maize has a WF up to a certain benchmark [11], set at the 50th production percentile of 754 m³/t [16,46]. Blue and orange points are in the unsustainable zones, where water stress is larger than 1 and/or the WF above the benchmark. Orange circles identify lower scarcity-weighted WF amounts in the unsustainable zone as compared to the highest scarcity-weighted WF amount in the sustainable zone (green circles).

A substantial amount of orange circles is observed under high water stress conditions as well as above the WF threshold value. These represent maize production locations that would be favoured over some of the green zone maize production locations, when using the scarcity-weighted WF as sustainability indicator. The blue circles represent maize production locations that are unsustainable and which are not scored better by the scarcity-weighted WF as compared to the locations in the green zone. In other words, the maize of some farmers producing their crop in a low-impact and efficient

manner, would be scored less sustainable as compared to some farmers producing in an unsustainable way. This is a conflicting information.

Here it was chosen to use the blue plus green WF, as to have a meaningful benchmark amount, as also used in the water quantity sustainability scheme of Vanham and Leip [11]. When only the blue WF would be used, benchmarks should be set according to climatological zones [78].

The conflicting observations of Figure 3 confirm the concerns of Hoekstra [76]. In addition, by combining water use and water stress into one scarcity-weighted WF indicator, the possibility to compare water use to a benchmark is lost. Not only products are assessed by the mid-point indicator scarcity-weighted WF but also whole diets [79–81], sometimes referred to as water-scarcity (dietary) footprint. Such amounts are expressed in m³ water equivalent or litre water equivalent per time unit, e.g., litre water equivalent per person per day [80]. These amounts are not real water volumes and should not be regarded or communicated as such.

Regarding endpoint indicators, LCA aims to quantify the impact of water stress on human health [22]. There are indeed relations between water and human health. The access to water sanitation and hygiene (WASH) is essential for human health and therefore captured in SDG targets 6.1 and 6.2 [82]. Clean drinking water is part of any healthy diet, and therefore relevant for sustainable healthy diets. However, it is especially economic and not physical water scarcity that is responsible for the lack of sufficient clean water access to humans, as infrastructure is key for clean water supply. This aspect is however not included in the LCA endpoint indicator [22,83]. The latter attempts to quantify the damage of local water stress to local human health based on malnutrition, as described by different authors [22,83,84]. A threshold for required water resources to provide a healthy diet is set at 1300 m³/(year and capita), which equals 3562 L/(day and capita). This amount quantifies green and blue water resources required for a standard diet as first proposed by Falkenmark and Rockstrom [5]. Pfister et al. [83] and Verones et al. [22] propose a global map of human health impacts of water consumption (in DALY/m³), for 11,050 watersheds. This approach and the resulting map are problematic in many ways:

- The value of Falkenmark and Rockstrom [5,7] incorporates green and blue water resources. The approach of Pfister et al. [83] and Verones et al. [22] only address blue water scarcity, by assuming a lack of available food due to water stressed irrigation. It is not clear how green water is addressed. Green water is the dominant resource in global food production [14,85]. River basins may be blue water stressed; they can still provide enough rainfed food for a healthy diet.
- The value of Falkenmark and Rockstrom is a rough global average high estimate for producing a balanced diet of 3000 kcal per person per day, with 20% calories from animal products and 80% from vegetal products. Many countries require much less green and blue water resources for a healthy diet [45,52–54]. Healthy diets also include pescatarian and vegetarian diets, which are even less water demanding.
- International food trade partly compensates for national food shortages. Water stressed countries can import food. Many river basins cross international borders.
- Trade within countries between river basins can compensate for regional food shortages. As an example, inhabitants in China's northern water stressed region, coloured yellow to red (high DALY/m³) on the map of Verones et al. [22], can very well still have access to a healthy diet with food items produced in China's wet non water stressed southern region, coloured green (low DALY/m³) on the same map.
- This approach ignores socioeconomic differences within a country/river basin. Local water resources may be relevant for the local human health of a small-scale farmer depending on his/her own food, most other inhabitants will purchase their food from the regional, national or international market. Especially middle class or wealthy inhabitants will be able to do this. In many transition and developing countries, proportions of the population now overconsume particular products such as sugar and fats.

- Some river basins are specialized in producing particular food items. The diversity of food items within a river basin can be not enough for a healthy diet.
- Countries or people within river basins can to a large extent depend on marine fish and seafood, for which wild catch does not depend on available water resources.
- Malnutrition has many forms, including overconsumption of specific products.

These facts show that the food system is highly complex. An empirical relation between local water stress and its effect on local malnutrition (human health) seems highly questionable, probably impossible. This confirms the concern of Hoekstra [76], who states that there are too many pathways between water stress and human health, with too many other variables in between, to find a single equation that relates both factors.

3. Outlook

3.1. Future Clarity in System Boundary and Modelling Assumptions, with Comparison of Results between Different Approaches

This paper has described that many system boundaries, data sources as well as modelling approaches exist to compute a dietary WF. Future dietary WF assessments should therefore provide clarity on the details of their approach, to make them comparable with other approaches.

Full food supply chain assessments are a topic of future research, including energy input to give full credit to all green and blue water resources to provide diets (Figure 1). Such assessments would be valuable within a wider WEFE/WEF/FEW nexus [24,86–88].

A research topic to explore is the assessment of multimodel approaches based on the same data, such as physical bottom-up approaches and top-down MRIO-models, in order to determine and evaluate differences in results. Similarly, combined assessments using different data sets (e.g., FAO FBS data, national food supply data as well as different nutrition surveys) are of interest.

3.2. Full Comprehensive Sustainability Assessments

A sustainability assessment regarding water quantity of a dietary WF assessments requires three aspects to be addressed: equity, efficiency and impact (Figure 2).

Regarding equity, several assessments of total dietary WFs for different diets exist in the literature, which generally show that plant-based diets require less water resources as compared to diets containing many animal products [45,50,57,58,69]. Including high quantities of pond-raised aquatic animals, which are very blue water-intensive foods [50], or specific nuts [47], can however again increase the total dietary WFs. In addition, existing dietary WFs in western countries as well as richer socioeconomic classes in transition and developing countries are generally higher than dietary WFs of recommended healthy diets and should therefore be reduced [45,65,69]. On the other hand, dietary WFs of poorer sections of the population in transition and developing countries will increase when they opt for healthy diets containing more animal products [50]. A comparison of these total amounts with a fair share of available water resources has however not been the focus of much research. The EAT-Lancet reference diet [48] is a scientifically constructed diet based on a planetary boundary for blue water, but it does not include green water.

An assessment of the efficiency and impact of each food item has not been the topic of much research. A first analysis for the UK has used this approach [89]. In addition, Vanham et al. [69] assess the blue water stress of food items consumed in Hong Kong.

3.3. Dietary Footprint Family Assessments with the WF as One Member

Sustainable healthy diets have low environmental pressure and impact [1], and trade-offs between different environmental concerns exist [23,37]. A much-required research gap is therefore environmental footprint family assessments of different diets, recognizing overlaps between different existing footprints [23]. Several dietary WF studies have included additional members of this family [48–50],

many of them the carbon, ecological and/or land footprints, but also nitrogen, phosphorus and grey water footprints. Such assessments can be extended with other relevant environmental indicators for the food system, such as the chemical and biodiversity footprints, animal welfare, antibiotics use and the fisheries maximum sustainable yield [90,91]

3.4. *WF Assessment for Multiple Dietary Regimes with Support to the Development of Local FBDG*

Many studies have conducted dietary WF assessments based upon existing national or regional dietary guidelines [34,53,54]. Other studies assessed the dietary WFs of theoretical dietary variations. Most notably, the EAT-Lancet Commission has created a reference diet in such way, based upon planetary boundaries, including the boundary for blue water [48]. For green water this has not been done. Kim et al. [50] conducted national dietary WF assessments in 140 countries for nine increasingly plant-forward diets, aligned with criteria for a healthy diet. These studies are indeed important advancements and can be used as input to adapt national Food-Based-Dietary-Guidelines (FBDG), as they bring in the component environmental sustainability. Recommended diets should be based upon planetary boundaries [40,92] and should leave it open as to whether a person prefers to eat animal products or not.

More research is needed to translate general sustainability recommendations to the local conditions of countries. The EAT-Lancet reference diet is a global reference diet, which recommends food intake ranges for specific food groups. However, national FBDG should also account for the specific agroclimatological, historic and sociocultural setting of a country. Which specific food items to promote within a food group should acknowledge this. National FBDG can, e.g., be anchored within territorial or regional diets such as the Mediterranean Diet [93,94] and the New Nordic Diet, which can ensure a greater appropriation of the FBDGs by the targeted population [91]. Research should confirm that such territorial diets respect the equity principle of sustainability (Figure 2), i.e., whether they respect the planetary boundary for water [95].

Future dietary WF assessments also need to account for the water-intensity of new or future foods [19] and adapted food production techniques. It can make sense from socioeconomic perspectives or the perspective of other environmental concerns to promote certain food items, but their water-sustainability should also be addressed. Relevant examples are treenuts [47] or brackish and freshwater pond aquaculture [50].

3.5. *Assessment of the Synergies with and Validity of Lca-Based Indicators*

Hoekstra [76] already expressed his concern on the LCA mid-point indicator scarcity-weighted WF and the endpoint indicator human health impacts of water consumption. These are in LCA assessments used for products as well as for dietary assessments. The scarcity-weighted WF is recommended in an ISO document [96]. However, the analysis conducted in Section 2.4 confirms the concerns of Hoekstra [76]. An analysis of global irrigated maize production shows that, when using the scarcity-weighted WF as sustainability indicator, the maize of some farmers producing their crop in a low-impact and efficient manner, scores less sustainable as compared to some farmers producing in an unsustainable way (Figure 3). The products of some unsustainably producing farmers would be favoured over some sustainably producing farmers. There is thus an urgent need to evaluate the physical meaning of this indicator and whether it conflicts with established indicators on water sustainability. Regarding the indicator on human health, it seems highly questionable, probably impossible, to prove an empirical relation between local blue water stress and its effect on local malnutrition (human health).

4. Conclusions

Regarding the sustainable use of water resources for food products and drinking water, both part of a healthy diet, blue water abstraction and consumption are relevant. The SDG indicators 6.4.1 on water efficiency and 6.4.2 on water stress only account for blue water abstraction, not consumption [8,82,97].

It is now generally recognized that water consumption and not abstraction is the indicator of choice to account for water along the supply chain [44]. The water footprint concept quantifies blue and green water resources along supply chains up to a total dietary assessment and is therefore the focus of this paper.

This paper describes under the section “2. current research state” that many different modelling approaches, data sources as well as boundary conditions and assumptions exist. Resulting studies are abundant but not always directly comparable in their results because of this.

Many significant advances on this topic have been made in the past. With increasing data availability and model sophistication, studies have become more sophisticated and landmark results have been published, such as [34,48–50].

The paper concludes with a future research outlook, listing the five main following points:

- (1). Future studies on dietary WFs should provide clarity in system boundary and modelling assumptions. Full food supply chain assessments are a topic of future research as well as studies comparing results between different approaches.
- (2). Studies addressing all three sustainability components (equity, efficiency and impact) are currently not abundant in the literature.
- (3). To address trade-offs between different environmental concerns, dietary footprint family assessments with the WF as one member are to be conducted.
- (4). A key research topic is WF assessments for multiple dietary regimes including with the aim to support the development of local dietary guidelines, which account for local agroclimatological, historic and sociocultural conditions.
- (5). This paper confirms previous concerns about the validity of the LCA mid-point indicator scarcity-weighted WF, stressing the need to evaluate the physical meaning of this indicator and whether it conflicts with established indicators on water sustainability. In addition, this paper argues that it is probably impossible to prove an empirical relation between local blue water stress and its effect on local malnutrition (LCA end-point indicator human health impact). Further research should evaluate the validity of these indicators.

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Conflicts of Interest: The author declares no conflict of interest.

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