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Review

Volumetric and Impact-Oriented Water Footprint of Agricultural Crops: A Review

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ABSTRACT

The Water Footprint (WFP) is an estimate of freshwater utilization in food production and its impacts on water resources by individuals, communities and industries. It is partitioned into green component that denotes rain water use, blue, ground and surface water, and grey, water used to assimilate the pollutant. In this study we try to review the current understanding of WFP concept from a volumetric and impact-oriented perspective. A *meta*-analysis was done from published peer reviewed literature related to the agricultural WFP of crops from google scholar database for the time frame 2006 to 2020. The results from the volumetric review shows the goal of nearly 60% of the studies is on the water consumption of crops, 62% of the studies focused on the three components of WFP and 80% of them used the WFP assessment methodology for its accounting. The progress of WFP research illustrates water scarcity or depletion is well explored compared to water degradation. However, after the emergence of ISO 14046, a stand-alone Life Cycle Assessment (LCA) method, scientific community started focusing on sustainability/impact assessment from a water degradation (eutrophication, ecotoxicity footprints) outlook. From the impact-oriented review on freshwater ecotoxicity, it is understood that majority of the studies use compartment models such us USEtox and ReCiPe methods for impact assessments using an egalitarian time frame. This review suggests the potential factors influencing the water impact indicators and guidance for comprehensive WFP assessment. Besides, future WFP assessments may consider the drivers of water, food and energy security for a complete understanding for water resource and environmental management decisions

1. Introduction

Water security is considered as a prominent theoretical framework for sustainability in environmental policy and resource management. United Nations identifies water availability, its sustainable management and access to all, as one of the seventeen Sustainable Development Goals (Goal 6: https://www.un.org/sustainabledevelopment/sustainable-development-goals/, last access: 14 July 2021). This involves water quality and quantity that faces multidimensional challenges from climate change, shift in water consumption patterns, economic and population growth. Global water consumption increased six times over the past 100 years (WWAP, 2020), agriculture being the major consumer. Agriculture is instrumental to water degradation through point and non-point pollution. Non-point pollution is a major water quality threat that arise from over use of agrochemicals and modern farming techniques (WWAP, 2018; FAO, 2011).

Food and Agricultural Organization statistics show that by 2050 about 60 percent excess food will be needed to feed humans (McGuire, 2015). This creates human water demand that exceeds water availability leading to water scarcity (Famiglietti and Rodell, 2013; Rushforth and Ruddell, 2016). Therefore, to understand the impact of excess water use and sustainable water resource utilization, the concept of WFP was introduced (Allan, 1997), which was subsequently developed by others (Hoekstra and Hung, 2002). The WFP concept acts a as a multi-faceted indicator of human water resource consumption. It serves as a platform

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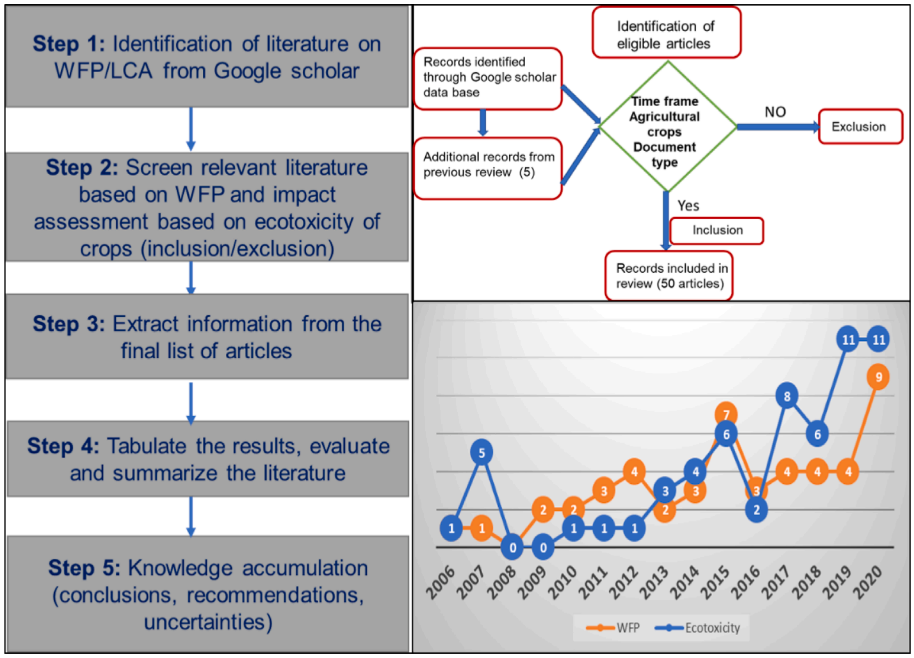

Fig. 1. Meta-analysis steps followed for review (left panel) and the inclusion/exclusion criteria, frequency of publications included in the review (right panel).

for decision-making for sustainable and equitable water use and provides a basis for the local environmental impact assessment from a social and economic viewpoint (Hoekstra et al., 2011). This later merged into Water Foot Print Network, an International Dutch-based Learning Community, that acts as a platform for serving communities interested in sustainability, equitability and efficiency in water storage. WFP focuses on the water resource management but excludes the potential impacts from water usage by anthropogenic activities (Boulay et al., 2013), in addition, it focuses more on products that lay the ground for specific water impact assessment (Finkbeiner, 2011). Basically, WFP evaluates water consumption based on different sources and water quality. Accordingly, there are three types of water footprints- green, blue (based on sources) and grey (based on the impacts to water quality). Green water refers to the water that is stored in the ground as a result of precipitation (Bocchiola et al., 2013; Dekamin et al., 2018). In other words, it is the water stored in the soil available to plants. Blue water is the water that flows into rivers and lakes or underground water, not directly from precipitation during the cropping season (Fader et al., 2011, Rost et al., 2008; Hoff et al., 2010). The grey water is defined as the polluted water due to production of goods (Hoekstra et al., 2011). This volumetric method has been used to assess the potential impacts of water consumption, water depletion or water scarcity based on the indicators green, blue and grey by the scientific community (Aldaya and Hoekstra, 2010; Chouchane et al., 2015; Palhares and Pezzopane, 2015). Subsequently, modified methods from the Life Cycle Assessment Community, termed as ISO 14046 was developed in 2014 (ISO 14046, 2014). The ISO 14046 uses the LCA method and gives the results in the impact category and can be used as a stand-alone study or part of a more comprehensive life cycle assessment. LCA method can be used to understand the potential impacts of pollutants by fate factor, exposure and the effect factor. As a result, various impact categories related to water such as eutrophication, acidification and ecotoxicity came into existence. These impact categories can be assessed for a product for its entire life cycle through ISO 14046. A few studies (Manzardo et al., 2016; Dekamin et al., 2018) considered eutrophication, acidification and ecotoxicity (in general) using impact-oriented ISO 14046. However, recent studies (Lovarelli et al., 2018; Esmaeilzadeh et al., 2020) focused specifically on the fresh water ecotoxicity realizing its effect on water quality for human consumption and biodiversity of ecosystem at different trophic levels (Marzullo et al., 2018).

Considering these aspects, in the present study, we try to understand the concept of WFP of agricultural crops in a volumetric and impact-oriented frame of reference from previously published literature. This review is not crop specific or location specific, making it different from previous reviews. In addition, an impact-oriented *meta*-analysis for freshwater ecotoxicity is portrayed. Accordingly, the main objectives are to explore the methodology adopted for volumetric and impact-oriented WFP assessment specifically the freshwater ecotoxicity impacts and the methods for quantifying the impacts, the main drivers of water consumption, depletion and degradation, and further research needs in the WFP sector. In terms of water footprint concept 'consumption' refers to water that is "lost" from the system, and that therefore cannot be used for other purposes at that particular time at that particular location" (Hogeboom, 2020). While 'depletion' is defined as the "reduced availability of freshwater as a resource for future generations" (Berger and Finkbeiner, 2010).

2. Methodology

2.1. Study selection and search methods

The present work aims to do a *meta*-analysis on the current understanding of WFP concept from a volumetric and impact-oriented perspective. Google scholar was the major scientific data base used for the *meta*-analysis.

2.1.1. Volumetric

The search used the keywords "Water footprint" and "LCA assessment". This gives the full list of literature that deals with the water footprint and LCA assessments. The articles obtained using the keyword

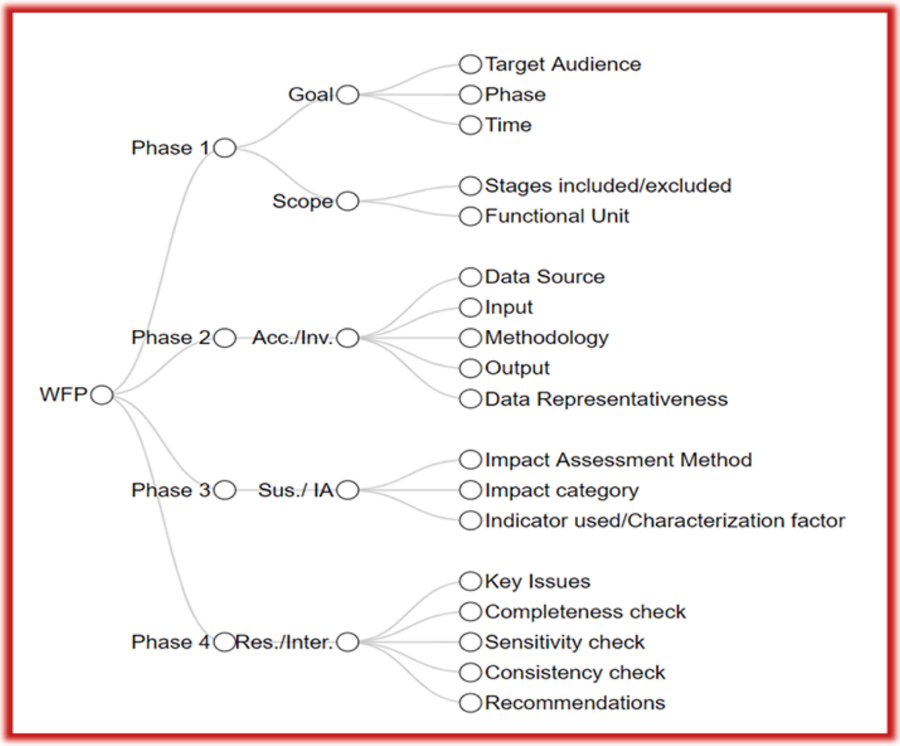

Fig. 2. Overview of Water Footprint (WFP) accounting phases obtained from literature. IA represents the impact assessment. Abbreviations: Acc./Inv. – Accounting/Inventory, Sus./IA – Sustainability/Impact Assessment, Res./Inter. – Response formulation/Interpretation.

search “WFP/LCA assessment” were nearly 17000. Previous review articles (5) were used to identify additional articles. In order to refine the search articles based on the research question, the inclusion criteria were adopted. The criteria are to select the literature that deals with WFP of agricultural crops. The second criterion was to set the time frame of publication search from 2006 to 2020. The review articles and the WFP/LCA assessment manuals were not included in the publication list. Therefore, the document type forms the third criterion for the inclusion or exclusion of articles. Accordingly, nearly 50 articles were included, and the rest excluded. We selected the time frame from 2006 since the first study on crop cultivation based on water footprint concept emerged in 2006 by Chapagain et al., (2006) for cotton crop. The steps followed for *meta*-analysis and the criteria for inclusion of literature is given in Fig. 1. The included literature intends to answer the following research question: How do the selected studies go for assessing the WFP of crops? Do they adopt any stepwise procedure or methodology? Does it serve as a practical guide to the audience for WFP assessment over diverse regions across the globe?

2.1.2. Impact-oriented

The articles based on volumetric WFP focused on the sustainability/impact assessment from a water scarcity perspective. The sustainable use of water resources requires the view of WFP from an environmental, social and economic perspective. So, the degradation of water also must be taken in to account. Therefore, an additional list of articles is included to address the water degradation, fresh water ecotoxicity impact assessment. This is done using the keyword search “water footprint and ecotoxicity impact assessment”. This search yielded 16,400 articles. The next step was to refine the articles based on ecotoxicity impact assessment in agricultural processes to nearly 64. The major research questions considered were contribution of crops to freshwater ecotoxicity, how to quantify it and the characterization factors involved in impact assessments. The information obtained from literature are given in the results section.

2.2. Data extraction

The data extraction stage of the methodology consists of extracting information from eligible literature. Data includes the year of study, reference, the aim of the study and the different steps involved in WFP assessment. The spatio-temporal details, the different components, the methodologies in WFP estimation, the use of WFP concept in water scarcity and impact analysis, water degradation and the recommendations for the sustainable use of water resources. The analysis is done by tabulating the above details from literature. The information is then classified into different result sections as illustrations by means of collapsible tree, bar charts, histograms, word cloud, bubble plots and chord diagram according to the research questions provided in sections 2.1.1 and 2.1.2. Finally, the research needs or knowledge gap, conclusions from the study and recommendations are described in the results section.

Chord diagram (Gu et al., 2014) is used to visualize the relationship between different entities and compare their similarities within a data set. The input data set is represented in the form of a matrix with rows and columns. Each row and column are allocated in different sectors on either side of a circular lay out. The inter-relationship between each sector is represented by means of ribbon or nodes. The width of the nodes represents the strength of the relationship between the variables in the case of correlation plots. In general, it can typically be used to

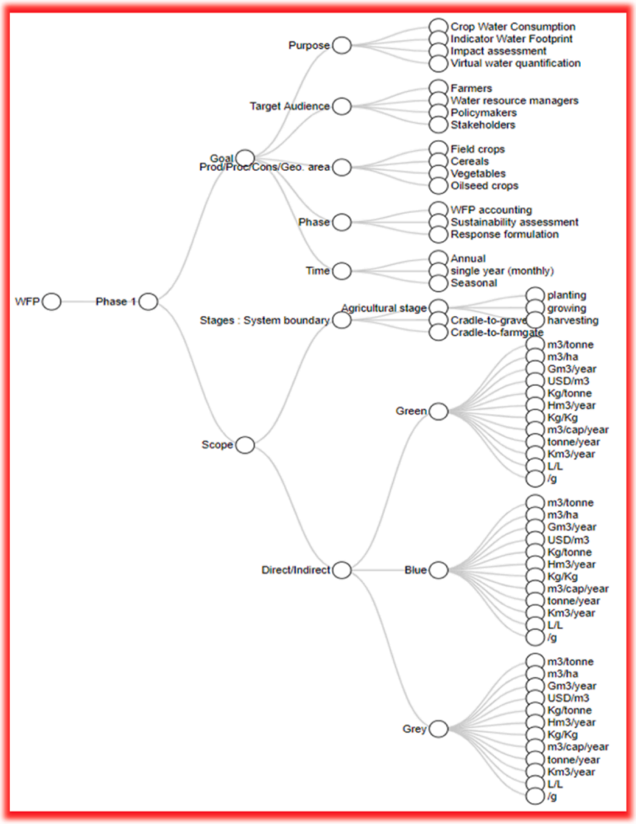

Fig. 3. Sub-stages involved in WFP accounting- phase 1 from literature review.

understand the relationship between different variables in a huge data set. In the present work, the chord diagram (Fig. 12) is used to denote the dependency of different indicator categories to its predictor variables in a qualitative way.

The frequency of publications is provided in Fig. 1(right panel). The number of publications related to WFP of crops have increased since 2009. This may be due to the introduction of base methods for WFP assessment by Chapagain and Hoekstra (2011), Chapagain and Orr (2009) and later by Hoekstra et al. (2011). The partition of water uses in to different 'colors' green–blue-grey was not done until 2009 as noted by Chenoweth et al. (2014). This classification revolutionized the quantification of agricultural crop water use. Accordingly, a lot of scientific studies have come addressing the components of water use and its impact assessment. The years between 2014 and 2016 have witnessed a sudden rise in the number of publications followed by the year 2020. A more detailed explanation on the different studies is provided in the subsequent sections.

3. Results

3.1. Overview of WFP assessment phases

Meta-analysis shows the WFP assessment methodology involves four phases- (i) defining goal and scope of the study (ii) WFP accounting, (iii) sustainability assessment phase and (iv) response formulation phase. Fig. 2 gives an overview of the phases involved in WFP assessment. Phase 1 deals with the ultimate target of the analysis, focus on which phase of the assessment, how to represent the output and the spatio-temporal scale of the analysis. Scope comprises the scope of interest, defining system boundary and the processes included or excluded in the study. The specifications of the data to be used as the input and the methodology that is going to be adopted for the analysis is given in phase 2. Phase 3 comprises of the sustainability assessment/impact assessment of water resources over a geographical region. It involves three steps namely impact assessment method, impact category and the indicator used for the impact assessment. The final stage is phase 4, that includes the recommendation to the audience by analyzing the key issues involved over the study region based on the impact assessments. The details of each phase are provided in the following sections.

3.2. Stages in WFP assessment - phase1

An in-depth analysis of the stages involved in phase 1 is represented in Fig. 3. The goal has two major components, (i) why one is interested in doing WFP/LCA assessment? and (ii) who will benefit from the assessment, i.e, the target audience. Literature review shows 60% of the studies (Fig. 4a) had water consumption (Dekamin et al., 2018 (oilseed crops), Jefferies et al., 2012 (tea and margarine), Lovarelli et al., 2018 (maize), Bocchiola et al., 2013, (crops); Huang et al., 2012 (maize); (Chapagain and Hoekstra, 2011; Marano and Filippi, 2015; Zheng et al., 2020); (rice); Lee, 2015; Liu et al., 2015; Sweet et al., 2017 (crops); Luan et al., 2018 (wheat, corn, sunflower); Li et al., 2020 (rice); Severo Santos

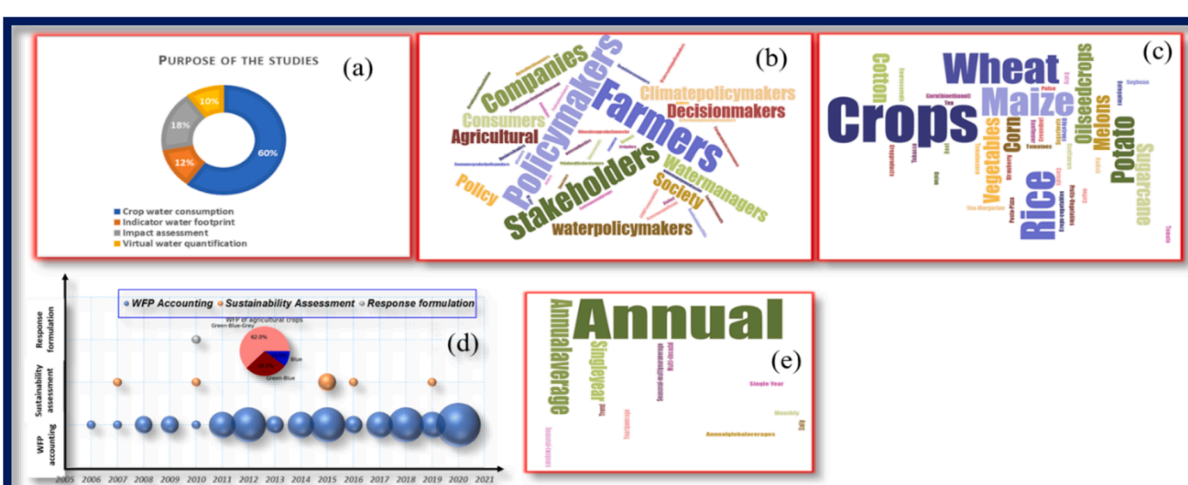

Fig. 4. Details of sub-stages involved in WFP accounting- phase 1 from literature review. (a) goals of the studies, (b) target audience, (c) product studied, (d) focus on which phase and (e) temporal selection.

Table 1
Expansion of abbreviations used in Fig. 12.

Acronym	Expansion	Acronym	Expansion	Acronym	Expansion
AEF	Aquatic Eutrophication Footprint	FI	Falkenmark Index	Papp	Phosphorous applictaion
BMP	Best Management Practices	GW	Groundwater	PC	Pesticides
Bwa	Blue water availability	Gwa	Green water availability	Po	Population
BWS	Blue Water Scarcity	GWS	Green Water Scarcity	PWI	Pollution Water Indicator
BWsus	Blue Water Sustainability	GWsus	Green Water Sustainability	Qact	Actual stream flow
Clim	Climate	HC	Herbicides	Reff	Effective rainfall
EF	Effect Factor	IC	Insecticides	Rf	Rainfed
EFR	Environmental Flow Requirement	Ir	Irrigation	RIS	Relative Irrigation Supply
ET	Evapotranspiration	LNP	Leaching of Nitrogen, Phosphorus	Rnat	Natural Runoff
ETenv	Actual evapotranspiration in protected areas	LU	Land Use	Sm	Soil Mobility
ETg	Green evapotranspiration	Mcr	Multiple cropping	Top	Topography
Etup	Actual evapotranspiration unprotected areas	ME	Marine Eutrophication	WDF	Water Degradation Footprint
EXF	Exposure Factor	Napp	Nitrogen application	WEF	Water Ecotoxicity Footprint
WFbl	Blue Water Footprint	WFgr	Green Water Footprint	WPL	Water Pollution Level Indicator
WFbl	Blue water footprint	WFgr	Green Water Footprint	Ws	Water solubility
Mcr	Multiple cropping	Cr.sp	Crop species		

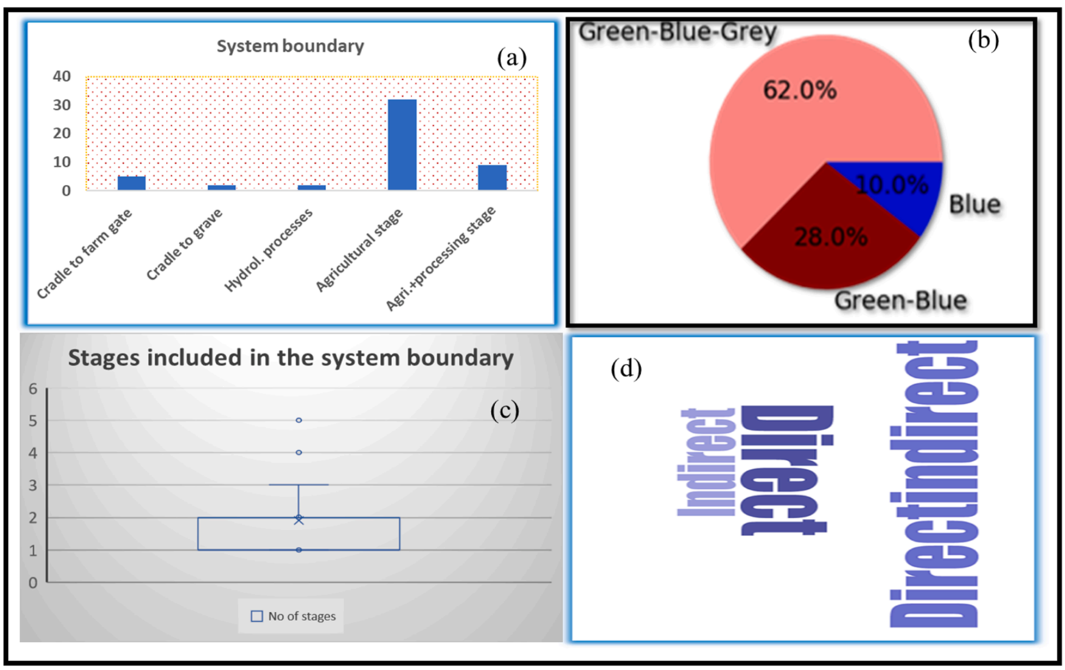

Fig. 5. Details of sub-stages involved in WFP accounting- phase 1 from literature review. (a) system boundary, (b) focus on which component of WFP, (c) frequency of stages included in the system boundary and (d) direct/indirect component of WFP.

and Naval, 2020 (soybean)) of diverse crops as the goal.

A few are based on the conventional cropping practices and its corresponding environmental impacts (Dekamin et al., 2018 (oil seed crops), Jefferies et al., 2012 (tea and margarine), Lovarelli et al., 2018 (maize); Rossi et al., 2020 (olive trees); Esmaeilzadeh et al., 2020 (onion); Cha et al., 2017 (radish); Morillo et al., 2015 (strawberry)) at a local, national and global level Chapagain and Hoekstra, 2007 (coffee and tea); Chiu et al., 2009 (corn, bioethanol); Fader et al., 2011 (crops); Hess et al., 2015 (potato); Mekonnen and Hoekstra, 2020 (crops and livestock); Palhares and Pezzopane, 2015 (dairy production); Garofalo et al., 2019 (wheat); Gobin et al., 2017; Mekonnen and Hoekstra, 2014 (crops)). The impact assessment of water resources from a consumer viewpoint using WFP as a tool was the major attention of 18% of the studies (Aldaya and Hoekstra, 2010; Fu et al., 2019; Chapagain et al., 2006; Chouchane et al., 2015; Chapagain and Orr, 2009; Cao et al., 2018; Xu et al., 2019; Leenes and Hoekstra, 2012; Manzardo et al., 2016).

About 12% of the studies aimed on indicator WFP for environmental sustainability of water resources (Segura river basin, Spain: Pellicer-Martínez and Martínez-Paz, 2016, Ercin et al., 2013; Novoa et al., 2019; Dianchi river basin: Zhang et al., 2018; United States major river basins: Veettil and Mishra, 2020) Savannah river basin, Veettil and Mishra, 2016) and the remaining 10% focused on virtual water consumption at an interprovincial (Bulsink et al., 2010), local or national level (Chapagain et al., 2006; Ercin and Hoekstra, 2014; Gerten et al., 2011).

Following identification of goals required for improving governmental policies toward water governance, the next step is to identify the target audience for these goals. Fig. 4b represents the target audience as obtained from literature. The major audience are the farmers (Herath

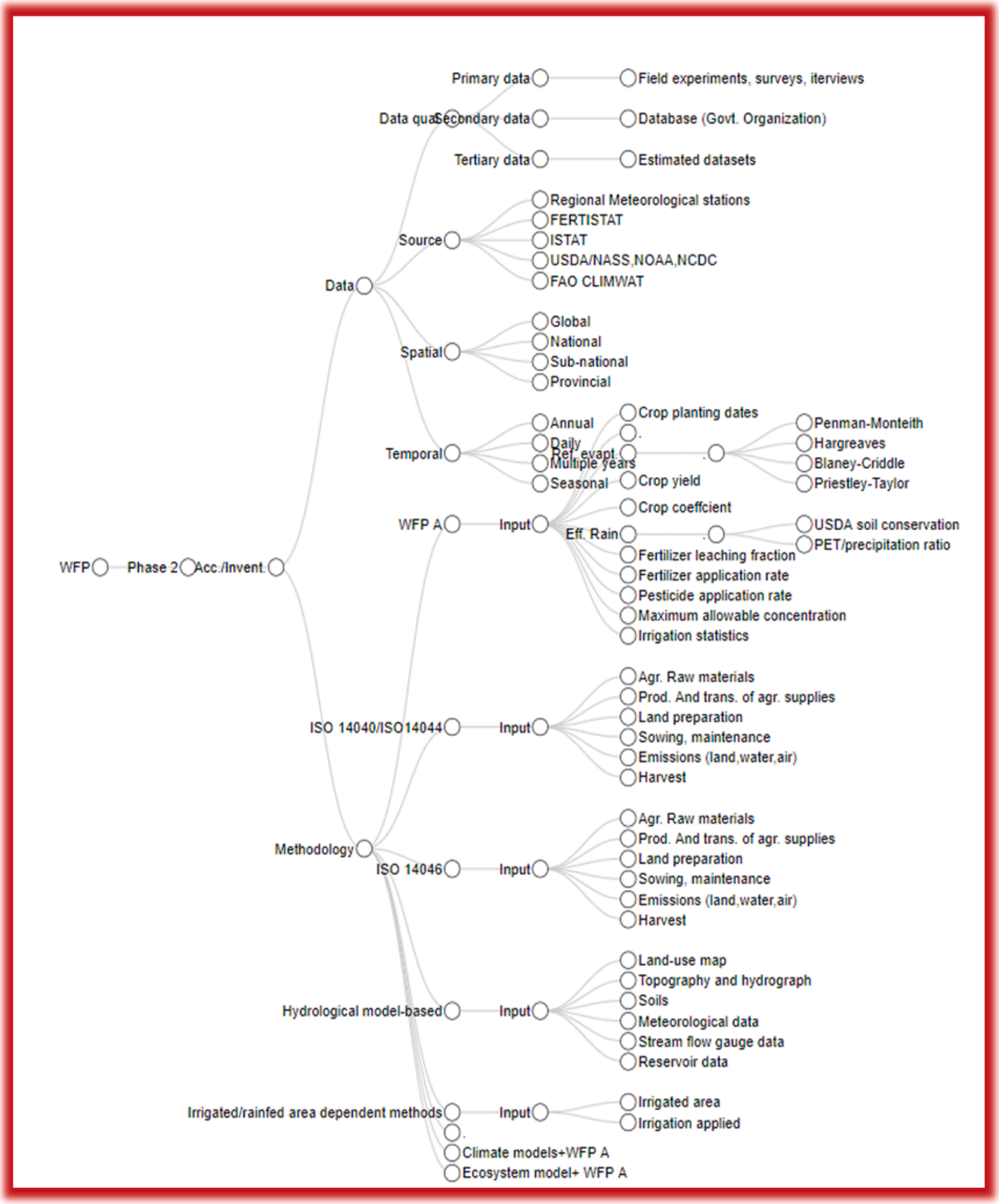

Fig. 6. Various stages involved in Phase 2 of WFP assessment.

et al., 2014; Hess et al., 2015; Palhares and Pezzopane, 2015) Rossi et al., 2020; Esmaeilzadeh et al., 2020; Leenes and Hoekstra, 2012; Sweet et al., 2017; Morillo et al., 2015), water policy makers (Bulsink et al., 2010; Lovarelli et al., 2018; Galli et al., 2012; Cao et al., 2018; Garofalo et al., 2019; Zheng et al., 2020; Li et al., 2020) and local governments (Lee te al. 2015; Gobin et al., 2017; Fito et al., 2017; Zhang et al., 2018), companies (Manzardo et al., 2016), climate policy (Ercin and Hoekstra, 2014; Fader et al., 2011) and decision makers. Consumers too are included in the audience responsible for sustainable use of water resources (Ercin et al., 2013; Mekonnen and Hoekstra, 2014).

The major agricultural product (crops) used for the assessment in different studies are cotton, cereals such as wheat, maize, rice, followed by oilseed crops, melons, potato and sugarcane. Majority of the studies used a variety of 'crops' in their individual studies (Appendix A, Table A.1). The WFP assessment shows that the studies chose annual WFP in their analysis followed by the analysis based on annual average and a single year (Fig. 4e). This gives an indication that most of the studies dealt with crops that have their growing period mostly less than or equal to 12 months. Fig. 4d depict the yearly variability of studies that focus on different phases. The major phase that most of the studies

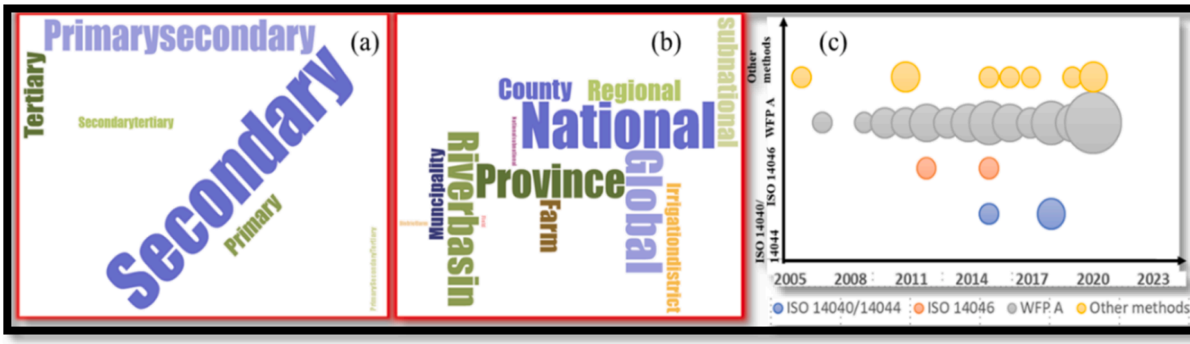

Fig. 7. Details of sub-stages involved in WFP accounting- phase 2 from literature review. (a) data representativeness, (b) Spatial scale of analysis, and (c) methodologies used in studies.

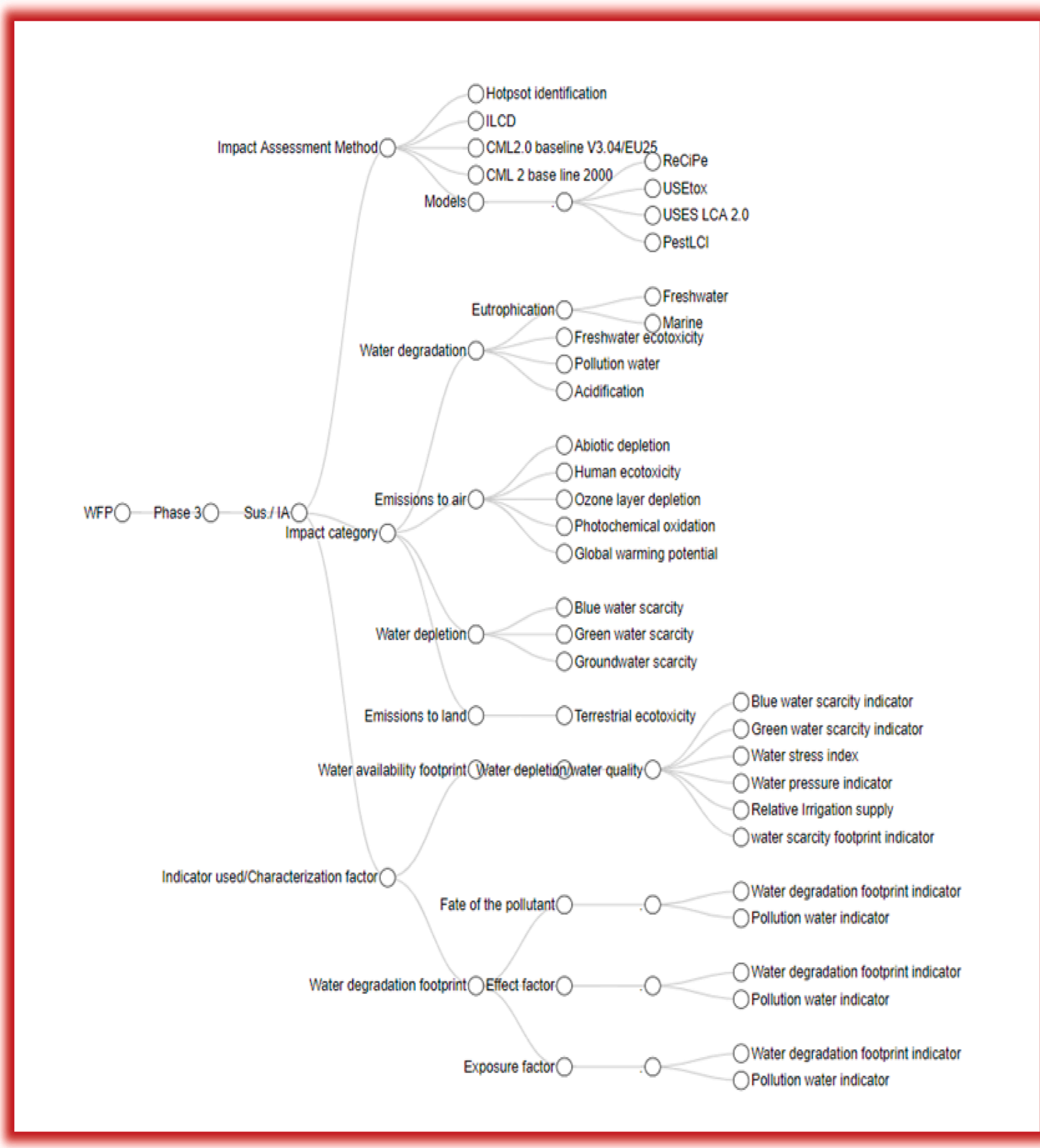

Fig. 8. Various stages involved in Phase 3 of WFP assessment.

Fig. 9. (a) Impact category indicators in sustainability phase of volumetric WFP accounting, (b) crops studied for ecotoxicity impact assessment from literature and (c) spatial domain used for the impact assessment.

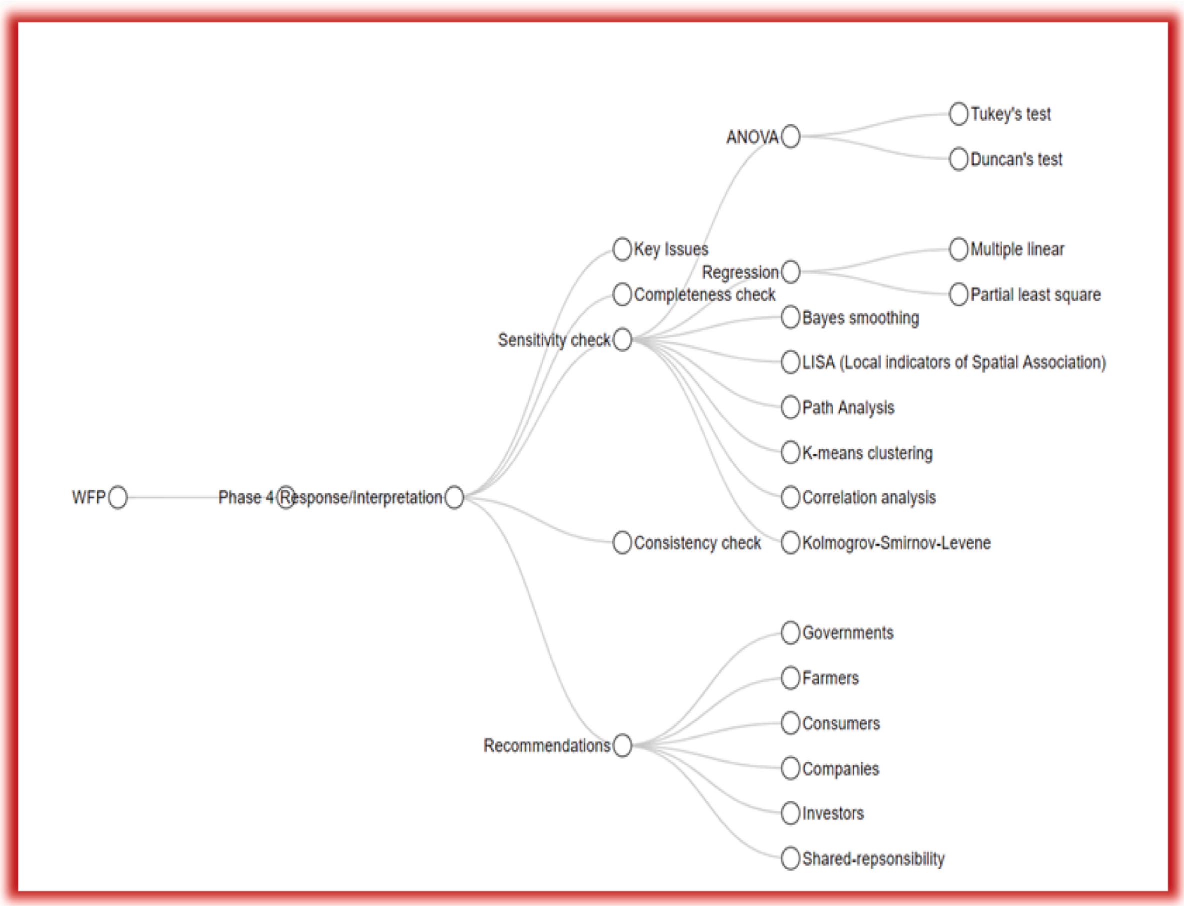

Fig. 10. Various stages involved in Phase 4 of WFP assessment.

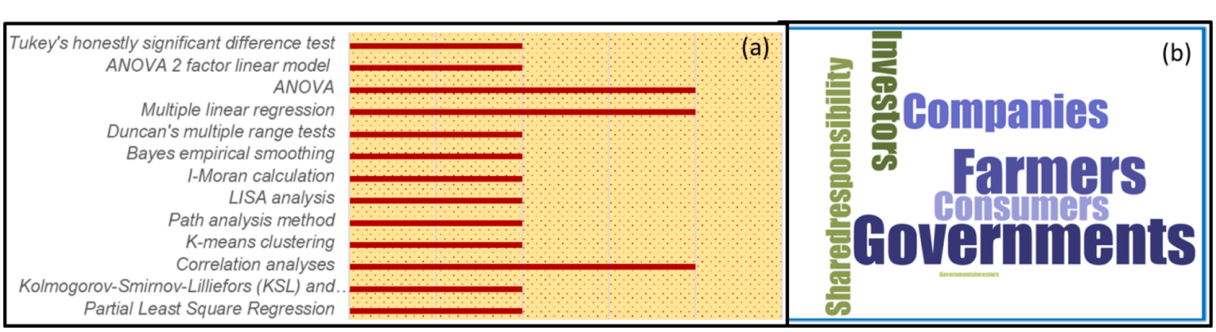

Fig. 11. (a) Consistency checks using statistical methods in WFP accounting and (b) word cloud showing the response formulation by the authorities.

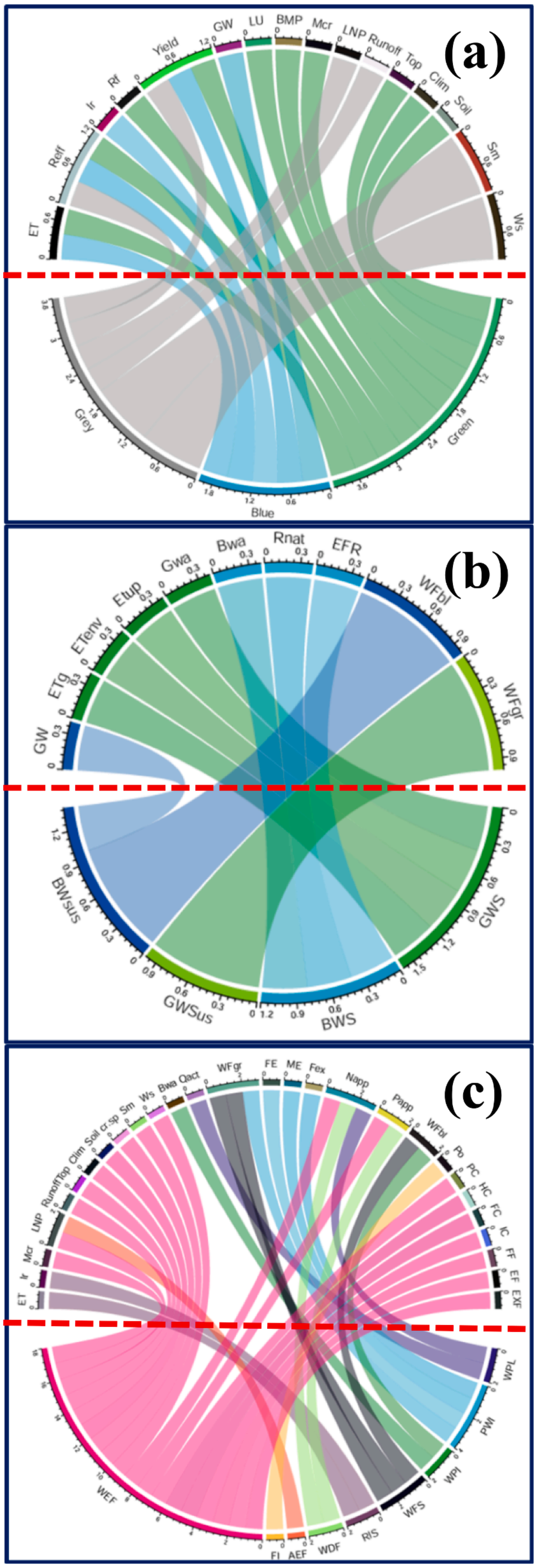

Fig. 12. The indicators for (a) consumption, (b) depletion and (c) degradation of water (south of the dotted line) and the factors influencing them (north of the dotted line) obtained from *meta*-analysis. The description of the variables in the figure are provided in Table 1. The green blue and grey color indicates the corresponding water footprints in (a) and (b), but not in (c). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

(Bocchiola et al., 2013; Bulsink et al., 2010; Fu et al., 2019; Chapagain and Hoekstra, 2007; Chapagain and Hoekstra, 2011; Chiu et al., 2009; Chouchane et al., 2015 and the references given in Table A.1) adopted is the WFP accounting specifically after 2009. Later, in 2014, the introduction of ISO 14046, a stand-alone methodology for impact assessment emerged. This led to an increase in the number of studies in 2015 that focused on sustainability assessment phase (Pellicer-Martínez and Martínez-Paz, 2016; Mekonnen and Hoekstra, 2020; D'Ambrosio et al., 2020; Morillo et al., 2015; Hess et al., 2015). Out of the 50 articles selected, only one article had all the 4 phases of WFP assessment (Aldaya and Hoekstra, 2010). Fig. 4e depict the temporal range of studies that vary from a single year (Dekamin et al., 2018; Manzardo et al., 2016; Cha et al., 2017), monthly (Jefferies et al., 2012), to annual average (Lovarelli et al., 2018; Pellicer-Martínez and Martínez-Paz, 2016; Aldaya and Hoekstra, 2010; Bocchiola et al., 2013; Bulsink et al., 2010; Fu et al., 2019; Chapagain et al., 2006; Chapagain and Hoekstra, 2007; Chiu et al., 2009; Chapagain and Orr, 2009; Fader et al., 2011; Gerten et al., 2011; Galli et al., 2012; Huang et al., 2012; Ercin et al., 2013; Ercin and Hoekstra, 2014; Herath et al., 2014; Chouchane et al., 2015; Hess et al., 2015; Palhares and Pezzopane, 2015; Cao et al., 2018; Garofalo et al., 2019; D'Ambrosio et al., 2020; Novoa et al., 2019; Xu et al., 2019; Bazrafshan et al., 2020; Li et al., 2020; Rossi et al., 2020). Some studies dealt with multiyear average, seasonal (Chapagain and Hoekstra, 2011; Mekonnen and Hoekstra, 2020; Severo Santos and Naval, 2020; Esmaeilzadeh et al., 2020; Lee, 2015; Gobin et al., 2017; Leenes and Hoekstra, 2012; Liu et al., 2015; Marano and Filippi, 2015; Fito et al., 2017; Sweet et al., 2017; Mekonnen and Hoekstra, 2014; Morillo et al., 2015; Luan et al., 2018; Veettil and Mishra, 2020) multi-decadal (Zheng et al., 2020) that focus on different phases.

The system boundary (Fig. 5a) for WFP assessment and ISO 14046/ ISO14044 is defined as the boundary for truncating the analysis. It consists of the stages included/excluded in the analysis. This can be cradle-to-farm-gate assessment, cradle-to-grave approach, agricultural stage, hydrological processes. The cradle-to-farm-gate is a boundary condition that takes in to account the processes that start with the processing of resources from the earth, their transportation, processing and production until the material is close to exit the factory gate.

Instead, the cradle to grave is related to both the cradle-to-farm-gate and transportation processes together, and also the emissions to air, water or land that is associated with the use of product and its annihilation (disposal, reuse or recycling). Hydrological process deals with the WFP accounting based on hydrological models. It involves precipitation, evaporation, soil moisture, percolation, runoff, etc. Agricultural stages implemented in the studies are planting, sowing and harvesting as displayed Fig. 5c.

Nearly 60 % of the studies focused on green–blue-grey components (Fig. 5b), 28% on green–blue and 10% studies considered only the irrigation water (blue component) alone for direct/indirect WFP assessment (Fig. 5d).

The functional unit or the reporting unit (Appendix A, Table A.1) needs to be defined according to the goal of the study. It can be expressed in different units such as tonne/year, Kg, Kg/ha, L/L etc. The cost also plays a role in WFP assessment in the form of functional unit. According to Hoekstra et al., 2011, the water footprint of crops can be represented by means of monetary unit per m3 of water consumed. This is called the economic water productivity denoted as the ratio of net benefit to the amount of water used to produce those benefits (Chouchane et al., 2015). Net benefit is the difference between selling price of a product and the cost of its cultivation until the harvesting stage. In other words, economic water productivities (USD/m3) are formulated as the product of physical water productivities (kg/m^3) and crop value (USD/kg). In other words, the reference unit is a comparable unit for WFP/LCA outputs for different geographically delineated areas on distinct time scales. The input data sets are accordingly defined in the accounting or inventory phase as given in the subsequent section.

3.3. Stages in WFP accounting – Phase 2

The second step in WFP assessment is accounting/inventory analysis stage (Fig. 6) that deals with the assembling the inputs and estimation of outputs. It accounts for the flow process, water balance and energy balance throughout the crop growth stages or the lifecycle of crops. There are three types of input datasets, one being primary data (Fig. 7a), coming from processes or installations controlled by a Government organization. The next category is called secondary data, that represents information from data bases created by governmental organizations, suppliers and upstream or downstream sources. The third being tertiary data, which are obtained from estimation. The data quality of the input data sets namely assumptions used, representativeness, accuracy, precision and uncertainty, is also considered relating to functional unit for a product water footprint. In some studies, assumptions are made in the analysis due to the difficulty in obtaining the rainfed and irrigation water amount (Aldaya and Hoekstra, 2010), that leads to wrong result interpretation. However, the obtained secondary data sets are checked and validated by experts (Dekamin et al., 2018) before being used for the assessments. A few studies have mentioned the technology coverage or precision in obtaining the primary data sets (Dekamin et al., 2018; Herath et al., 2014). The temporal details of the data consist of annual (daily, monthly) accumulated over the crop growing period and multi-year assessments over diverse range of spatial locations such as province, inter-provincial, river basin, municipality, county, national, sub-national levels.

The spatial details of the WFP accounting from the peer reviewed articles reveal the majority of the analysis were focused at a national level followed by provincial, global and river basin scale respectively (Appendix B, Table B.1). County level, farm level and regional scale assessment were also the topics for some studies. The bubble plot in Fig. 7c signify the WFP assessment (WFP A) as the base methodology for WFP accounting. These studies use the bottom-up approaches that use crop models (CROPWAT, Cropsyst, AQUACROP, Decision Support System for Agrotechnology Transfer, DSSAT) for estimating reference evapotranspiration using Penman-Monteith equation, Priestely-Taylor to estimate crop evapotranspiration.

Some studies focused on the environmental impact assessment of crops using ISO 14040/ISO 14044 or ISO 14046. ISO 14046 method accounts for the volume of water and quantify the scarcity and pollution and its accompanying impacts. Those studies having impact assessment as its goal use Life Cycle Inventory (LCI) data bases in combination with WFP assessment. The classification of water into different categories in these data bases are not consistent (Jeswani and Azapagic, 2011). Therefore, new approaches for categorizing the water flows in WFP life cycle inventory has been raised by Milà i Canals et al., 2009 (river basin) and Pfister et al., 2009 (watershed). In the WFP inventory phase, the distinction between input and output is adequate for assessing the impacts of water use. The outputs are the emissions to soil, water and air in the case of ISO 14040/14044/14046 and the corresponding WFP's in the case of WFP accounting. The 'other methods' on Y-axis (Fig. 7c) depict the studies using hydrological models such as SWAT, VIC that involves the surface soil moisture balance, water use estimation by Allan (1998) and the calculation from rainfed and irrigation-fed agricultural data sets (Chiu et al., 2009; Sweet et al., 2017). These methods are defined as 'hybrid' methods (Mubako, 2018), meaning a mix of methodologies, namely a combination of WFP assessment and ISO 14046/ISO 14044 (Jefferies et al., 2012; Lovarelli et al., 2018; Rossi et al., 2020, Esmaeilzadeh et al., 2020; Manzardo et al., 2016), hydrological model and WFP Assessment (Pellicer-Martínez and Martínez-Paz, 2016; Hess et al., 2015; D' Ambrosio et al., 2020; Marano and Filippi, 2015; Luan et al., 2018; Veettil and Mishra, 2020), climate models and WFP assessment (Bocchiola et al., 2013; Garofalo et al., 2019) and ecosystem model and WFP Assessment (Fader et al., 2011; Gerten et al., 2011).

3.4. Stages in WFP accounting – Phase 3

The sustainability assessment or impact assessment phase has environmental, social and economic components. Majority of the studies adopt environmental sustainability component for the impact assessment analysis. These are based on water depletion that characterizes the withdrawal to availability ratio for green water and blue water and water pollution for grey water in terms of indicators (Appendix C, Table C.1). The literature review based on volumetric WFP of agricultural crops bring about only a few literatures that focused on water degradation. Since water quality is also essential for sustainable and equitable use of water resources, it is necessary to consider the transport of toxic substances from the agricultural field to water and air. This prompted us to do an additional literature review for impact assessment based on ecotoxicity, specifically freshwater ecotoxicity. Literature review demonstrate the methods commonly used for impact assessment are International Reference Life Cycle Data (ILCD) System (Wolf et al., 2012), CML 2 baseline method, ReCiPe methods by (Raskin et al., 1997) and by means of models such as USEtox, USES LCA 2.0, and PestLCI (Fig. 8). While Hoekstra et al., 2011, Ercin et al., 2011, focused on the water availability assessment based on WFP A. The impact categories for water degradation consist of eutrophication, freshwater ecotoxicity, pollution water, acidification and those for water depletion - green water, blue water and ground water scarcity. The water depletion indicators quantify the impacts based on a defined water quality threshold. Lovarelli et al., 2018 and Ridoutt and Pfister, 2010 mentioned the grey WFP method by Hoekstra et al., 2011 is not enough to represent water contamination comprehensively. Ridoutt and Pfister (2010) pointed out there is a need for stand-alone water impact indicator considering water quantity and quality. They restated that grey WFP does not consider both consumptive and degradative water use, lacking broader acceptance. Also, Lovarelli et al., 2018 suggested that the method is based on the most penalizing pollutant even though other pollutants in small amount will affect the ecosystem. Therefore, they constituted an indicator based on both water quantity and quality, 'Pollution Water Indicator (PWI)' to represent the impacts. On the other hand, water degradation indicators compute the transport of pollutants to different environmental media, transformation and its effect on human beings and ecosystem biodiversity. While a few studies ((Pellicer-Martínez and Martínez-Paz, 2016); D'Ambrosio et al., 2020) consider the treated waste water from waste water discharge plants for irrigation at a river basin scale. These studies have used the impact/-sustainability assessment categories for each component of WFP, blue, green and grey. The indicators are water scarcity indicator for blue and green (defined as the ratio of blue/green WFP to the water availability) and water pollution level indicator for grey water footprint (defined as the ratio of grey water footprint to the actual stream flow for a river basin). Water pollution level indicator is calculated individually for surface and ground water. However, a few studies (Palhares and Pezzopane, 2015; Lee, 2015; Morillo et al., 2015) suggested the waste water treatment for reuse in irrigation and its impact on footprint values as a future research study. The next step in the sustainability assessment phase is the identification of hotspots using indicators. Hotspot identification is the method of identifying locations where the blue water consumption is large and water scarcity is high (Hoekstra et al., 2011).

The primary and secondary impacts in the hotspots are quantified using the indicators. The primary impacts refer to the effect of WFP in a catchment on water flows and water quality, whereas secondary impacts denote the impacts of WFP on human health, biodiversity welfare and security (Hoekstra et al., 2011).

Figure 9 shows 37% used all the three components of WFP indicator for delineating the sustainable water zones (water depletion) over a geographical area. Also, 31% of the studies used blue water scarcity as an indicator to explore the local impacts of water consumption. The combination of green–blue (19%) and blue-grey (13%) indicators were also the topic of studies. Even though the three components of WFP were considered for impact assessment in studies, the grey WFP is not much explored in terms of water quality. Impact-oriented *meta*-analysis reveals the most studied crops considered for ecotoxicity impacts are wheat, maize, grapes and rapeseed followed by corn, rice and soybean. Majority of the studies are from the European countries and China. Impact assessment of bio-energy crops were conspicuous feature of studies in the United States. Table C.2 represent the details of studies selected for freshwater ecotoxicity. Most of the studies use compartment models that determines the transport of contaminant to different environmental media namely air, water and land for assessing the impacts.

3.5. Stages in WFP assessment – Phase 4

The last phase in WFP assessment (Fig. 10) is the response formulation or the interpretation phase in which recommendations are being made for a sustainable future. Scientific studies identify Governments as the main authority for response formulation. Governments should strengthen macro-control and policy guidance on crop production to combat drought and water scarcity. Also, the requirement for farmer's participation in the activities of reducing water consumption and pollution is recommended by Huang et al., (2012). In addition, companies, investors also play a role in response formulation (Appendix D, Table D.1). Finally, there is a shared responsibility among different sectors.

The Life Cycle based (ISO 14046) interpretation phase defines consistency check as the process of verifying the assumptions, methods and data involved in the study, to make sure that they are consistent with the goal and scope definition. The various statistical methodologies identified from literature are provided in Fig. 11. The major statistical analysis method (Fig. 11, left panel)) is the ANOVA (Analysis of Variance), multiple linear regression and correlation analysis. In WFP analysis ANOVA test is used to compare the effective rainfall, evapotranspiration and crop water use for multiple years. Sometimes, the ANOVA is done for more than one independent variable or factor.

4. Discussion:

The present study focused on the *meta*-analysis of articles related to water footprint of agricultural crops from a volumetric and impact-oriented directive. One of the challenges in the literature review was to collect detailed information about each component involved in water consumption or water impact assessment. Majority of the literature follow the guidelines suggested by WFP Network, while others did it from an impact-oriented approach bringing the concept of WFP. It was difficult to obtain the information about WFP assessment stages from a single article. For example, identifying the target audience was not easy since some of the studies have implicitly mentioned in the article. Another significant feature noticed in the selected studies is that the third phase of WFP assessment, i.e, sustainability or impact assessment, is structured on the water scarcity and water stress. The degradation of water resource caused by emissions to water, a mid-point impact category is not considered in articles in the volumetric category. The completeness check, sensitivity check and consistency check are missing in majority of literatures. But, the key issues are understood and the recommendations are given based on the impact category analysis. Only two articles have discussed about the key issues and consistency checks, the remaining articles mentioned about the steps that need to be taken by the farmers, investors, companies and the policies by the Government.

The major agricultural crop category studied is found to be the cereal crops (wheat, maize and rice). Besides, a list of crops was also a choice for a few studies. Vegetables and fruits were the least studied category and field crops were the most common category as observed from literature. We found only one study that considered global assessment of water footprint benchmarks of crops by Mekonnen and Hoekstra (2014), using dynamic water balance and crop yield model. In our opinion, more regional studies that deal with WFP benchmarks are required for water resource management. Blue and green water WFP values are more susceptible to variation over different geographic regions due to climate and soil properties. However, the water use efficiency and nutrient uptake efficiency (crop rotation influence) thereby the water productivity depends on the crop type (legumes, cereals, oil seed crops, etc) and their cultivars. Grey water footprint in the literature considered only Nitrogen fertilizer leaving out the other chemicals. Besides, the natural concentration of chemicals in water bodies is considered as zero will over estimate or underestimate the grey water footprint values.

Since the focus of the study was on the review based only on agricultural WFP of crops, the major boundary processes identified from the literature are planting, sowing and harvesting. Consequently, scientific literature (60% of the studies) focused on the goal of accounting the crop water use from planting through harvesting. However, impact assessment studies using ISO standard methodologies use system boundary as multiple stages from the extraction of raw materials to the end of the lifecycle of a product making it a data-intensive process. Therefore, the availability of site-specific and crop specific reliable data sets for the system boundary processes need to be checked before starting the analysis for accurate results. Due to the lack of data sets for impact assessment phase, only 18% of the studies consider that phase in their analysis. The major constraints were on estimating the environmental flow requirements, especially for green water flows (For example, in differentiating the productive and unproductive evapotranspiration in green water scarcity assessments).

WFP assessment on the river basin scale is done utilizing hydrological models considering its ability to quantify the soil runoff and leaching rates ((Veettil and Mishra, 2016); (Pellicer-Martínez and Martínez-Paz, 2016)). WFP assessment has been criticized for its ability to enable meaningful comparison between the WFP of products that are produced in regions of differing water-resource availability. However, recent studies (D'Ambrosio et al., 2020; Novoa et al., 2019; Xu et al., 2019) have focused their attention on the regional water scarcity or water stress (water scarcity and degradation) from an impact category/indicator-based perspective. Impact categories can be water degradation, water depletion, emissions to air and land. The indicators include green/blue/ scarcity indicator, grey/pollution water indicator, water stress/pressure indicator, relative irrigation supply, water degradation/scarcity footprint indicator (Table C.1).

Ecotoxicity studies provided in Table C.2 suggest there are different methodical choices for estimating emissions and the characterization factors using different models in literature. This makes comparing the values between studies difficult. Also, Peña et al. (2018) noted majority of the studies did not reveal the quantification method for the plant protection products that cause ecotoxicity, thereby lacking transparency in their results. It is worth to be noted that there must be a spatial and temporal sync in the input flows and the characterization factors selected for impact assessments. Therefore, dynamic (time dependent) LCA assessments as proposed by Shimako et al., 2017 will be a likely option for impact-oriented assessments. A few studies that use 'hybrid' methods focused their attention on emissions to air and water in which they quantify the water use using WFP assessment and impact characterization using ISO 14046/ISO14044. The formulation/interpretation response process which involves discussing key issues, sensitivity control, completeness check, accuracy check, and finally offering suggestions for resource use that is renewable and efficient.

The water consumption, depletion and degradation indicators are of great help in addressing the global and regional water challenges, raising awareness and sharing responsibility (Hoekstra et al., 2011) between investors, producers, consumers, and the governments. The potential environmental impacts of consumption, depletion and degradation have a significant bearing on the stakeholders creating water - related business risks due to physical scarcity, regulation and reputation (Chapagain and Tickner, 2012). WFP can be used as a tool in policy and planning to support diverse stakeholders in achieving the Sustainable Development Goals (Berger et al., 2021). It can also serve and support producers to design their products in a way that reduces the indirect use of water along the supply chains, to devise more water efficient and environmental friendly strategies at local water hotspots for reducing water risks and promote sustainable agricultural practices for better use of water resources (specifically green water resources, (Nouri et al., 2020). Finally, WFP assessment tool can be used as an effective strategy to achieve energy security, food security and create realization among audiences 'outside the water box' (Chapagain and Tickner, 2012) considering water as a global resource.

Our review is not based on specific crop categories or over a spatial domain. This makes us difficult to provide a benchmark value for a crop over a climatic zone from the current review. Additionally, the literature included in the review that focus more on the impact assessment phase from both WFP and ISO 14,046 perspective are less, is another limitation. So, a comparison cannot be made between the two methodologies. We did not directly search for 'water quality impacts' while doing the literature review. Water quality impacts can be a potential search word for future studies that is beneficial for a comprehensive water quality assessment based on data availability. Besides, we did not consider the temporal scale effects on regional water footprints. The yield efficiency of crops, both irrigation or rainfed, different varieties of the same crop, the dependency of WFP on nutrient uptake, variability in crop water requirement according to the changes in daily maximum and minimum temperature is not addressed in the current review. This work did not consider the studies related to treated/semi-treated waste water reuse in irrigation while doing the literature review. However, the grey WFP in this case can throw light on the efficiency of grey WFP in differentiating the pollution by economic activities (dilution of treated/semi-treated waste water for reuse, Martínez-Alcalá et al., 2018) and domestic consumption.

The indicators of water consumption, water depletion and water degradation and their drivers are depicted in Fig. 12. Out of the consumption indicators, green water indicator is driven by the maximum number of factors compared to green and grey (Fig. 12a). Crop yield is the common predictor for the three consumption indicators. On the other hand, the depletion indicators in Fig. 12b have only green and blue components, water availability being the predictor common to both categories. Fig. 12c denotes the water degradation indicators that include freshwater ecotoxicity, eutrophication and water pollution level indicator.

4.1. Conclusions and future perspectives

Meta-analysis revealed the concept of water footprint has evolved as a tool for water management since its formulation by Hoekstra et al., 2011 and later by WFP Network. The introduction of ISO 14,046 in 2014 added more advantage to the concept bringing out different types of footprint associated with the impact category (eg:- water eutrophication footprint, water ecotoxicity footprint, etc). The partitioning of water resource into green, blue and grey and its virtual flow components has revolutionized the water-trade nexus. Future studies should explore WFP assessment from a water-food-energy nexus perspective. The drivers of water, food production and energy may be included in the analysis explicitly in the impact assessment stage. Also, the three footprint families, carbon footprint, ecological footprint and water footprint may be combined together for a complete understanding of the environmental impact assessments.

The observations from the review suggests potential future research needs in the field of WFP research. To be specific, (i) assessment must be done with higher spatial accuracy and regionalization of benchmark values using best management practices (crop rotation, tillage, cover crops) and technology, (ii) consider multiple cropping systems for WFP accounting, sensitivity of WFP to irrigation and rainfed systems (Zheng et al., 2020), (iii) ISO 14046 must be applied for more environmental water related issues regionally, (iv) Grey water indicator or pollution indicator must be applied to a broad number of crop varieties that use less pesticides and reduce nitrogen emission (Lovarelli et al., 2018), (v) improve performance of hydrological models during weather extremes (Veettil and Mishra, 2016). The present review could serve as a methodical guidance for WFP assessments. Considering the factors related to the different indicator categories outlined in Fig. 12 would improve water resource management decisions for a sustainable future.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A

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Table A1
Details of phase 1 obtained from literature.

No.	Reference	Ultimate Target Why WFP/LCA assessment	Target Audience	Is there a focus on particular phase?	Scope of Interest Product/Process/ Consumer or Community/ Geographically delineated area/ National/Business	Stages included/not includedSystem boundary	Direct/Indirect, Green/Blue/Grey	Time frame	Functional Unit
1	Dekamin et al., 2018	WFP and LCA of oilseed crops.	Oil seed crop production sector	WFP accountingLCA Impact assessment	Oilseed crops	Cradle-to-farm-gate assessment	Direct and IndirectGreen, Blue and Grey	single year	Kg/tonne
2	Jefferies et al., 2012	WFP and LCA of margarine	LCA and WFP communities	WFP accountingLCA impact assessment	Tea and Margarine	Cradle to grave	Direct and indirectGreen, Blue	Monthly	m^3/tonne, L/ g, L-ecosystem-eq
3	Lovarelli et al., 2018	LCA of maize grain cultivation	Policy makers and stakeholders	WFP accountingLCA impact assessment	Maize	Cradle to farm gate	Direct and indirectGreen, blue and grey	Annual	m^3/tonne
4	Pellicer-Martínez and Martínez-Paz, 2016	WFP and environmental sustainability	Sustainable water management planners	WFP accountingSustainability assessment	Production of goods	Hydrological processes	DirectGreen, blue and grey	Annual	Hm^3/year
5	Aldaya and Hoekstra, 2010	WFP and impact assessment	Consumers	WFP accountingSustainability assessmentResponse formulation	Pasta and Pizza	Agricultural stageProcessing stage	Direct and indirectGreen, blue and grey	Annual	m^3/tonne
6	Bocchiola et al., 2013	Indicator WFP	Water resourcemanagers	WFP accounting	Crops	Agricultural stage	DirectGreen and Blue	Daily	Kg/Kg
7	Bulsink et al., 2010	WFP and virtual water flows	Water policy makers	WFP accounting	Crop products	Agricultural stageVirtual water flows	Direct and indirectGreen, blue and grey	Annual	m^3/cap/year
8	Fu et al., 2019	WFP and impact assessment	Sustainable water management planners	WFP accounting	Wheat, Maize, cotton and groundnut	Cultivation	DirectGreen, blue and grey	Annual	m^3/year
9	Chapagain et al., 2006	WFP of worldwide cotton consumption	Product exporting and importing countries	WFP accounting and impact assessment	Cotton	Field-to-end	Direct and indirectGreen, blue, dilution waterVirtual water content	Annual	m^3/tonne
10	Chapagain and Hoekstra, 2007	WFP of tea and coffee	Society	WFP accounting	CoffeeTea	Cultivation	Direct and indirectCrop water requirementVirtual water content	Annual	tonne/year
11	Chapagain and Hoekstra, 2011	WFP of rice	Society	WFP accounting	Rice	Cultivation	Direct and indirectGreen, blue and greyVirtual water flows	Annual average	Km^3/year
12	Chiu et al., 2009	WFP of bioethanol	Bio fuel mandates	Embodied water accounting	Corn (bioethanol)	Field to pump	Process waterIrrigation water	Annual	L/L
13	Chouchane et al., 2015	WFP and water scarcity	water resources managers	WFP accounting	CropsNational/sub-national	Agricultural stage	Direct and indirectGreen, blue and grey	Annual	Gm^3/year
14	Chapagain and Orr, 2009	WFP of horticulture industry	Policy actors, business leaders, regulatorsand managers	WFP accounting	Tomato	Open systemsPlastic covered houses	IndirectGreen, blue and greyVirtual water content	Annual	Mm^3/year
15	Ercin et al., 2013	WFP of production in a river basin	Consumer product policy makers	WFP accounting	Crops	Agricultural stageProcessing stage	Direct and indirectGreen, blue and greyVirtual water flows	Annual	Gm^3/year
16	Ercin and Hoekstra, 2014	Future WFP of production and consumption	Climate policy makers	WFP accounting	Crops	Agricultural stageClimate Scenarios	Direct and indirectGreen, blue and greyConsumptionProductionVirtual water flows	Annual	Gm^3/year
17	Fader et al., 2011	Internal and external agricultural WFP	Climate policy makers	WFP accounting	Crops	Cultivation stage	Direct and indirectGreen, blue	Annual global averages	m^3/cap/year
18	Galli et al., 2012	Integrate WFP of production and consumption	Policy makers academicians	WFP accounting		Agricultural stage	Direct and indirectGreen, blue and diluted water	Annual	

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Table A1 (*continued*)

No.	Reference	Ultimate Target Why WFP/LCA assessment	Target Audience	Is there a focus on particular phase?	Scope of Interest Product/Process/ Consumer or Community/ Geographically delineated area/ National/Business	Stages included/not includedSystem boundary	Direct/Indirect, Green/Blue/Grey	Time frame	Functional Unit
19	Gerten et al., 2011	Water availability and FP for future	Growing world population.	WFP accounting	crops	Hydrological processes	Direct and indirectGreen, blue	Annual	m^3/year
20	Herath et al., 2014	WFP of potato using primary data	Potato cultivators (farmers)	WFP accounting	Potato	Cultivation stage	DirectGreen, blueGrey for impact studies	Annual	m^3/m^3
21	Hess et al., 2015	WFP of potato and risk assessment	Growers	WFP accountingSustainability assessment	Potato	Cultivation stage	DirectBlue water	Annual average	m^3/tonne
22	Mekonnen and Hoekstra, 2020	Blue WFP of global crop production	Governments, companies and investors	WFP accountingSustainability	Crops and livestock	Agricultural and production stage	DirectBlue water	Seasonal, multiyear average	m^3/month
23	Huang et al., 2012	WFP of local crops	Farmers	WFP accounting	Crops	Farming stageProcessing stage	DirectGreen, blue and grey	Annual	m^3/ha
24	Palhares and Pezzopane, 2015	WFP of both a conventional and an organic dairy production system	Farmers	WFP accounting	Dairy production system	Farm stage	Direct and indirectGreen, blue and greyVirtual water	Annual	/m^3year
25	Cao et al., 2018	Blue scarcity WFP	Policy makers	WFP accounting(Scarcity)	CropsIndustry	Cultivation	DirectGreen, blue	Annual	Gm^3
26	Garofalo et al., 2019	WFP and climate change impacts on yield	Stakeholders and policy makers	WFP accounting	Wheat	Cultivation	DirectGreen and blue	Annual	m^3/tonne
27	D`Ambrosio et al., 2020	WF of crop production and sustainability assessment	Sustainable water resources policy makers	WFP accountingSustainability assessment	Crops	Cultivation	DirectGreen, blue and grey	Annual	mm
28	Novoa et al., 2019	Evaluation of agricultural WFP from WFP scarcity indicators	Water resources managers	WFP accountingSustainability assessment	Crops and vegetables	Cultivation	DirectGreen, blue and grey	Annual	m^3
29	Xu et al., 2019	County level WFP and water scarcity	Agricultural managers	WFP accounting	WheatMaize	Farm stage	DirectGreen, blue and grey	Annual	Bm^3
30	Bazrafshan et al., 2020	WFP of date palms	Water resource managers	WFP accounting	Date palms	Cultivation	Direct and indirectGreen, blue and grey	Annual	m^3/Kg, USD/ m^3
31	Zheng et al., 2020	Yield assessment and water resource utilization	Policy makers, stake holders	WFP accounting	Rice	Farm stage	DirectGreen, blue	Multi decadal	m^3/tonne
32	Li et al., 2020	Path analysis of rice WFP	Agriculturalwater management policy makers	WFP accounting	Rice	Field stage	DirectGreen, blue and grey	Annual	Gm^3
33	Rossi et al., 2020	WFP impact of Olive production	Farmers	WFP accounting	Olive trees	Cradle to farm gate	Direct and indirectGreen, blue and grey	Annual	m^3/tonne
34	Severo Santos and Naval, 2020	WF of soybean in the agricultural frontier	Decision makers about resource allocation for sustainable projects	WFP accounting	Soybean	Agricultural frontier	DirectGreen, blue and grey	Annual average	m^3/tonne
35	Esmaeilzadeh et al., 2020	Environmental impacts of onion production	Farmers	WFP accountingLCA assessment	OnionProduction	Cradle-to-gate approach	Direct and indirectGreen, blue	Annual	MJ/tonne

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Table A1 (*continued*)

No.	Reference	Ultimate Target Why WFP/LCA assessment	Target Audience	Is there a focus on particular phase?	Scope of Interest Product/Process/ Consumer or Community/ Geographically delineated area/ National/Business	Stages included/not includedSystem boundary	Direct/Indirect, Green/Blue/Grey	Time frame	Functional Unit
36	Lee, 2015	Regional water scarcity index using WFP framework	Local governments	WFPLand FPCarbon FP	Crops	AgriculturalProcessing stage	Direct and indirectGreen, blue and grey	Annual	m^3
37	Gobin et al., 2017	WFP of arable crops	European water governance.Stake holders	WFP accounting	Crops	Cultivation	DirectGreen, blue	Annual	m^3, Mg^{-1}
38		WFP of sweeteners and bio-ethanol	Farmers	WFP accountingSustainability assessment	Sugarcane BeetMaize National	Agricultural stageProcessing stage	Direct and indirectGreen, blue and grey	Annual	m^3/tonne
39	Liu et al., 2015	WFs of crop production and consumption	Water resource managers	WFP accounting	Rice, wheat, corn, coarse cereals, sunflowers, melons, vegetables, tomatoes, oilseed crops, and sugar beets.	Agricultural stageProcessing stage	Direct and indirectGreen, blueConsumptionVirtual water flows	Annual, trend analysis	m^3
40	Manzardo et al., 2016	Comparison of WFP methodologies	Companies	WFP accountingISO 140406	Tomato sauce	Agricultural stageProcessing stage	Direct and indirectGreen, blue and grey	Single Year	/g
41	Marano and Filippi, 2015	WFP of rice production	Water saving policy makers	WFP accounting	Rice	Cultivation stage	DirectGreen, blue and grey	Seasonal for two years	Mm^3/year
42	Cha et al., 2017	WFP of white radishes	Decision-makers	WFP accountingISO 14040ISO 14046	Radish	Cradle-to-gate	Direct and indirectGreen, blue	Single year	m^3/tonne
43	Fito et al., 2017	WFP of bioethanol	Government officials, Policy makers	WFP accounting	Sugarcane	CultivationStage	DirectGreen, blue and grey	Annual	m^3/tonne, L/L
44	Sweet et al., 2017	Impacts of drought from irrigation	Farmers	WFP accounting	Fruits and Vegetables	Agricultural stage	DirectBlue	Annual	Mm^3
45	Mekonnen and Hoekstra, 2014	WFP benchmarks	FarmersConsumersCompanies	WFP accounting	Crops	Field stage	DirectGreen, blue and grey	Annual	m^3/tonne
46	Morillo et al., 2015	Hotspot identification tool from WFP framework	water authorities, irrigatorsand environmental groups	WFP accountingHotspot identification	Strawberry	Farm stage	DirectBlue	Annual	m^3/ha
47	Zhang et al., 2018	WFP of agriculture production	Policy developers and decision makers	WFP accounting	RiceWheat MaizePulse Cereals Vegetables MelonsPotato Tobacco	Field stage	DirectGreen, blue and grey	Yearly average	L/Kg
48	Luan et al., 2018	WFP using hydrological model	Agricultural water management sector	WFP accounting	WheatCorn Sunflower	Field stage	DirectGreen, blue	Annual	m^3/Kg
49	Veettil and Mishra, 2020	River basin scale spatiotemporal variability of water security indicators	Regional watermanagement program sector	WFP accounting	Crops	Agricultural stage	DirectGreen, blue scarcity	Annual	m^3/cap/year
50	Veettil and Mishra, 2016	WFP and watre security in the SRB.	Water resource planners	WFP accounting	Crops	Agricultural stageProduction stage	DirectGreen, blue	Annual	mm/year

Appendix B

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Table B1
Details of phase 2 obtained from literature.

No.	Reference	Spatial details	Methodology	Representativeness of the data (Primary, secondary or tertiary)
1	Dekamin et al., 2018	Arabdil Province, Iran (Regional)	ISO 14040/ ISO 14044	Secondary
2	Jefferies et al., 2012	SouthIndia, Ukraine (Regional)	ISO 14046, WFP A	Secondary
3	Lovarelli et al., 2018	District (farm)	WFNISO 14044	Primary and secondary
4	Pellicer-Martínez and Martínez-Paz, 2016	River basin (Segura)	Hydrological model + DSSWFP A	Secondary
5	Aldaya and Hoekstra, 2010	Italy	WFP A	Secondary, tertiary
6	Bocchiola et al., 2013	Po valley, Italy	WFP A	Primary
7	Bulsink et al., 2010	Indonesia	WFP A	Secondary
8	Fu et al., 2019	Shandong Province, China	WFP assessment	Primary and secondary
9	Chapagain et al., 2006	Global	Allan, 1997, Allan, 1998Herendeen, 2004Falkenmark, 2003	Secondary
10	Chapagain and Hoekstra, 2007	Global	WFP A	Secondary
11	Chapagain and Hoekstra, 2011	Global	WFP A	Primary
12	Chiu et al., 2009	United States (field)	Estimated from irrigation statistics	Secondary
13	Chouchane et al., 2015	Tunisia (National,sub-national)	WFP A	Secondary and tertiary
14	Chapagain and Orr, 2009	Spain (National)	WFP A	Secondary
15	Ercin et al., 2013	France (National)	WFP A	Tertiary
16	Ercin and Hoekstra, 2014	Global	WFP A	Tertiary
17	Fader et al., 2011	Global	LPJML modelWFP A	Secondary
18	Galli et al., 2012	Global	WFP A	Tertiary
19	Gerten et al., 2011	Global	LPJML Model	Secondary
20	Herath et al., 2014	Sub national(Manawatu, Newzealand)	WFP A	Primary
21	Hess et al., 2015	Great Britain (National)	WFP A GAP 2 model	Secondary
22	Mekonnen and Hoekstra, 2020	Global	WFP A	Tertiary
23	Huang et al., 2012	Beijing Muncipality, China	WFP A	Primary and secondary
24	Palhares and Pezzopane, 2015	FarmBrazil	WFP A	Primary and secondary
25	Cao et al., 2018	Jiangsu Province,China	WFP A	Secondary
26	Garofalo et al., 2019	ItalyGermany (National)	Siebert and Doll, 2010Ventrella et al., 2015, 2017	Secondary
27	D'Ambrosio et al., 2020	D'Aiedda Basin(SE Italy) (sub-national)	WFP A	Secondary
28	Novoa et al., 2019	Cachapoal river basin Chile	WFP A	Secondary
29	Xu et al., 2019	Counties in North China Plain (NCP)	WFP A	Secondary
30	Bazrafshan et al., 2020	Iran (National)	WFP A	Secondary
31	Zheng et al., 2020	Henan and Jiangsu Province,China	WFP A	Primary and secondary
32	Li et al., 2020	Province	Cao et al., 2017 a,b,c	Secondary
33	Rossi et al., 2020	Central ItalyOlive grove (sub-national)	LCA + WFP A	Primary and secondary
34	Severo Santos and Naval, 2020	MuncipalitiesBrazil	WFP A	Secondary
35	Esmaeilzadeh et al., 2020	Bojnord County, Iran	Hoekstra et al., 2011- WFP ALCILCIA	Secondary
36	Lee, 2015	Taiwan (National)	Review	Tertiary
37	Gobin et al., 2017	Europe (National)	WFP A	Primary and secondary
38	Leenes and Hoekstra, 2012	United States (national)	WFP A	Secondary
39	Liu et al., 2015	Irrigation districtHetao, China	WFP A	Secondary
40	Manzardo et al., 2016	Different countries	WFP AISO 14,046	Primary, Secondary and Tertiary
41	Marano and Filippi, 2015	The provinces of Santa Fe and Entre Ríos, Argentina	WFP A	Primary
42	Cha et al., 2017	Korea	ISO 14,046ISO 14,040	Primary and secondary
43	Fito et al., 2017	MetaharaSugarcane Farm, Oromiya Region, Ethiopia	WFP A	Secondary
44	Sweet et al., 2017	Northeastern United States counties	Allen 2000	Secondary
45	Mekonnen and Hoekstra, 2014	Global	WFP A	Secondary
46	Morillo et al., 2015	Huelva ProvinceSouthwest Spain	Allen, 1998Hoekstra et al., 2009Levine, 1982	Primary and secondary
47	Zhang et al., 2018	Lake Dianchi basin, China	WFP A	Secondary
48	Luan et al., 2018	Hetao Irrigation district China	WFP A	Secondary
49	Veettil and Mishra, 2020	US river basins	Falkenmark, 1989Falkenmark and Rockstorm, 2006	Secondary
50	Veettil and Mishra, 2016	Savannah river basin, USA	SWAT model	Secondary

Note: Primary data is defined as data coming from processes or installations controlled by a Government organization. While secondary data represents information from data bases created by governmental organizations, suppliers and upstream or downstream sources and tertiary data, which are obtained from estimation.

Appendix C

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Table C1
Details of phase 3 obtained from literature.

No.	Reference	Impact Assessment Method	Classification(Impact Category)	Indicator Used and Characterization/ equivalency factor
1	Dekamin et al., 2018 (Environmental)	CML 2 baseline 2000 method	Eutrophication, Acidification, Photochemical oxidation,and Global Warming	EP (kg PO4 $^{3-}$ eq)AP (kg SO2 eq)POP (kg C2H4 eq)GWP (kg CO2 eq)
2	Jefferies et al., 2012 (Environmental)	Hotspot Identification (Ercin et al., 2011).	Blue water scarcity	WSI - Water Stress Index
3	Lovarelli et al., 2018 (Environmental)	International Reference LifeCycle Data System (ILCD) (Wolf et al., 2012)	Freshwater eutrophication (FE, Kg P eq), marine eutrophication(ME, kg N eq) and freshwater ecotoxicity (FEx CTUeq)	Pollution water indicator
4	Pellicer-Martínez and Martínez-Paz, 2016 (Environmental)	Hydrology based environmental sustainability	Green, Blue scarcity and Grey indicator	Green water scarcity indicatorBlue water scarcity indicatorWater pollution level indicator
5	Aldaya and Hoekstra, 2010(Environmental)	Hotspot identification	Green, Blue scarcity and Grey footprint	Green water scarcity indicatorBlue water scarcity indicatorWater pollution level indicator
6	Bocchiola et al., 2013	Not included	Not included	Not included
7	Bulsink et al., 2010	Not included	Not included	Not included
8	Fu et al., 2019 (Environmental)	Indicator based	Blue water scarcity	Water pressure indicator (WPI)
9	Chapagain et al., 2006	Not included	Not included	Not included
10	Chapagain and Hoekstra, 2007	Not included	Not included	Not included
11	Chapagain and Hoekstra, 2011	Not included	Not included	Not included
12	Chiu et al., 2009	Not included	Not included	Not included
13	Chouchane et al., 2015(Environmental)	Hoekstra et al., 2012	Blue water scarcityGround water scarcity	Water scarcity indicator
14	Chapagain and Orr, 2009	Not included	Not included	Not included
15	Ercin et al., 2013	Hoekstra and Mekonnen, 2011, Hoekstra et al., 2012	Blue water scarcity	Blue water footprint
16	Ercin and Hoekstra, 2014	Not included	Not included	Not included
17	Fader et al., 2011	Not included	Not included	Not included
18	Galli et al., 2012	Not included	Not included	Not included
19	Gerten et al., 2011	Not included	Not included	Not included
20	Herath et al., 2014	Not included	Not included	Not included
21	Hess et al., 2016	Hotspot identification	Blue water scarcity	WSI
22	Chapagain and Hoekstra, 2007	Not included	Not included	Not included
23	Huang et al., 2012	Not included	Not included	Not included
24	Palhares and Pezzopane, 2015 (Environmental)	United Nations Environment Programme (2012)Hoekstra et al., 2011	Green water scarcityBlue water scarcity	Green water scarcity indicatorBlue water scarcity indicator
25	Cao et al., 2018 (Environmental)	Raskin et al., 1997, Hoekstra et al., 2011	Water footprint scarcity	Water Scarcity Index
26	Garofalo et al., 2019	Not included	Not included	Not included
27	D'Ambrosio et al., 2020(Environmental)	Hoekstra et al., 2011	Green water scarcityBlue water scarcityGrey water indicator	Green water scarcity indicatorBlue water scarcity indicatorWater pollution level indicator
28	Novoa et al., 2019 (Environmental)	Hoekstra et al., 2011Hoekstra et al., 2012	Blue water scarcityGrey water indicator	Blue water scarcity indicatorGrey water indicator
29	Xu et al., 2019 (Environmental)		Total water	Water scarcity index (agriculture)
30	Bazrafshan et al., 2020	Not included	Not included	Not included
31	Zheng et al., 2020	Not included	Not included	Not included
32	Li et al., 2020	Not included	Not included	Not included
33	Rossi et al., 2020	Not included	Not included	Not included
34	Severo Santos and Naval, 2020	Not included	Not included	Not included
35	Esmaeilzadeh et al., 2020(Environmental)	CML 2 baselineV3.04/EU25 method	Abiotic depletionGWPOzone layer depletionHuman toxicityFreshwater aquatic ecotoxicityMarine aquatic ecotoxicityTerrestrial ecotoxicityPhotochemical oxidation Acidification potentialEutrophication potential	Abiotic depletion (Kg Sb eq)GWP (Kg CO_2 eq) Ozone layer depletion (Kg CFC-11 eq)Human toxicity (Kg1,4-DECB eq)Freshwater aquatic ecotoxicity (Kg1,4-DECB eq)Marine aquatic ecotoxicity (Kg1,4-DECB eq)Terrestrial ecotoxicity (Kg1,4-DECB eq)Photochemical oxidation (Kg C_2H_4 eq)Acidification potential (Kg SO_2 eq)Eutrophication potential (Kg PO_4^{2-} eq)

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Table C1 (*continued*)

No.	Reference	Impact Assessment Method	Classification(Impact Category)	Indicator Used and Characterization/ equivalency factor
36	Lee, 2015	Not included	Not included	Not included
37	Gobin et al., 2017	Not included	Not included	Not included
38	Leenes and Hoekstra, 2012	Not included	Not included	Not included
39	Liu et al., 2015	Not included	Not included	Not included
40	Manzardo et al., 2016 (Environmental)	WFA, ISO 14046	Sustainability of blue waterSustainability of grey waterWater availabilityEutrophicationHuman toxicityEcotoxicityAcidification	Water availabilityEutrophication-(Goedkoop et al., 2013)Human toxicity (Hauschild et al., 2008)Ecotoxicity (Hauschild et al., 2008) Acidification (Jolliet et al., 2005)
41	Marano and Filippi, 2015	Not included	Not included	Not included
42	Cha et al., 2015 (Environmental)	ISO 14040, ISO 14,046	EutrophicationWater depletion	EUTREND model (10^{-11} Kg P/ton)Korean water scarcity index- Swiss eco scarcity method
43	Fito et al., 2017	Not included	Not included	Not included
44	Sweet et al., 2017	Not included	Not included	Not included
45	Mekonnen and Hoekstra, 2014	Not included	Not included	Not included
46	Morillo et al., 2015 (Environmental)	Levine, 1982	Irrigation water requirement	RIS- Relative Irrigation Supply
47	Zhang et al., 2018 (Environmental)	Volumetric and Impact orientedHoekstra and Chapagain, 2007Chapagain and Hoekstra, 2011ReCiPe impact assessment methodologyHuang et al., 2014	Water scarcity footprintWater degradation footprintAquatic Eutrophication footprint	Water Degradation Footprint indicator
48	Luan et al., 2018	Not included	Not included	Not included
49	Veetil and Misra, 2020 (Environmental)	Falkenmark et al., 1989	Green water scarcityBlue water scarcity	Falkenmark Index
50	Veettil and Mishra, 2016	Hoekstra et al., 2011	Green water scarcityBlue water scarcity	

Table C2
Details of impact assessment (fresh water ecotoxicity) obtained from literature.

No.	Reference Method	Region, Crop	Method
1	Zhai et al., 2019	China, Wheat	Ma et al., 2018b, c,dCML method
2	Marzullo et al., 2018	Brazil, Ethanol	ISO 14046
3	Roïz and Paquot, 2013	Wallonia, Bio and mineral based chain saw oil	ReCiPe, Usetox, CML and EDIP
4	Shimako et al., 2017	France, Grapes	Usetox model
5	Kim et al., 2015	Kazakhstan, Wheat	ReCiPe method
6	Bjørn et al., 2014	Denmark,	USEtox
7	Moreno-Sader et al., 2020	North Colombia, Palmoil	TRACI
8	Yang 2013	United States, Corn, ethanol	USEtox
9	Li et al., 2019	China, Wheat, rice, corn, potato, rape, and cottonMaize Hard maize, mandarins, potatoes, apples, peaches, avocados, strawberries, asparagus, rice	ReCiPe 2008
10	Fantke et al., 2018	Agriculture in general	Usetox modelUSES-LCA and IMPACT2002+)
11	Gentil et al., 2020	Martinique, Tomato	USEtox 2.11
12	Peña et al., 2018	Europe, Vineyard	USEtoxHauschild and Huijbregts, 2015
13	Brentrup et al., 2004	Europe, Wheat	Huijbregts, 2001
14	Vázquez-Rowe et al., 2017	Peru, Grapes	USEtox – freshwater toxicity, ReCiPe- water depletion categoryAWARE- Water consumption, Pest LCI modelSeppala et al., 2004
15	Mohseni et al., 2018	Iran, Grapes	CML methodData Envelopment Analysis
16	Fresán et al., 2019	USA, Food products	RecíPe, 2016
17	Esmaeilzadeh et al., 2020	Iran, Onion	Bentrup et al., 2004a
18	Darré et al., 2019	Uruguay, Corn and Soybean	Usetox model
19	Bong et al., 2020	Malaysia, Traditional food products	ReCiPe 2016 USES-LCA 2.0 (Van Zelm et al. 2009)
20	Peña et al., 2019	Denmark, Maize, winter wheat, grass, spring barley, rapeseed, and peas	Rosenbaum et al., 2015 Usetox model version 2.2
21	Berthoud et al., 2011	France, Wheat	Usetox model
22	Papasavva and Beltramo, 2006	General	Henry's law, EDIP, USES LCAATI index based on US EPA 2000
23	Nordborg et al., 2016	Sweden, Point source emissions	Usetox 2.1
24	Hamedani et al., 2019	Italy, Grapes and Olive	Recipe midpoint (H) v1.13 [46] in SimaPro software (version 8.3.0)
25	Mungkung et al., 2020	Thailand, Rice	ReCiPe 2016 Midpoint v 1.02
26	Arsenault et al., 2009	Canada, Dairy systems	Centre for Environmental Science (CML)
27	Slorach et al., 2020	UK, Food-energy water circular economy	ReCiPe V1.08 method (Goedkoop et al., 2013)
28	Borrion et al., 2012	Europe, Wheat ethanol	ReCiPe assessment method
29	Vinyes et al., 2015	Spain, Peach	Usetox model

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Table C2 (*continued*)

No.	Reference Method	Region, Crop	Method
30	Wagner and Lewandowski, 2017	Germany, Miscanthus, Willow	ReCiPe
31	Nordborg et al., 2016	Sweden, Food products	USEtox version 2.01PestLCI v. 2.0.5
32	Payen et al., 2015	Morocco, Tomato	ReCiPelife cycle impact assessment method (Goedkoop et al., 2009),
33	Palmieri et al., 2014	Italy, Rapeseed	ReCiPe 2008 method
34	Vinyes et al., 2017	Mediterranenan food sector, Apple and Peach	Recipe Midpoint (H)
35	Parajuli et al., 2017	Denmark, Maize, grass-clover, ryegrass and winter wheat straw for biorefinery	ILCD method (European Commission, 2012a)
36	Tasca et al., 2017	Lombardia, Endive	International Reference Life Cycle Data System (ILCD)
37	Campiglia et al., 2020	Mediterranean, Hemp	Re.Ci.Pe. 2016 method,
38	Roer et al., 2013	Norway, Milk, meat	ReCiPe method (Goedkoop et al.,2012)
39	Renou et al., 2008	France, wastewater treatment	CML 2000 Eco Indicator 99 EDIP 96 (Environmental Design of Industrial Products) EPS (Environmental Priority Strategy in product design) Ecopoints 97
40	Corrado et al., 2018	France, Arable crops	ILCD Midpoint v 1.06 characterization method (EC-JRC, 2011)
41	Noya et al., 2015	Italy, Feed cereals	Recipe Midpoint (H) method
42	van Zelm et al., 2014	General, Crop production	USEtoxILCD
43	Bacenetti et al., 2016	Italy, Rice	ILCD method
44	Rivera et al., 2017	Denmark, Italy, Barley	ILCD 2011 methodology v1.05 (Hauschild et al., 2013)
45	Rybaczewska-Błażejowska and Gierulski, 2018	EU-28, Agriculture	ReCiPeMidpoint (H))
46	Yang and Suh 2015	USA, Cotton, Corn	TRACI 2.0ReCiPe model (Goedkoop et al.2009)
47	Pacetti et al., 2015	Italy, Energy crops	ReCiPe 2008 (Goedkoop et al., 2013).
48	Nordborg et al., 2014	US, Sweden, Brazil, Germany, Maize, Rapeseed,Salix, Soybean, Sugar Cane, and Wheat	USEtox v.1.01
49	Knudsen et al., 2019	Europe, Organic and Conventional milk	ILCD 2011 Midpoint + V1.06
50	Berthoud et al., 2011	France, Wheat	Usetox model
51	Wang et al., 2007	China, Winter wheat	Bentrup et al., 2004b Huijbregts et al., 2000
52	Naderi et al., 2019	Iran, Bell pepper	CML2 baseline method
53	Bhattacharyya et al., 2019	US, Wheat-based vodka production	ReCiPe (v.2.0) methodology
54	Greer et al., 2020	US (IL), Maize, Soybean	USEtox model
55	Romero-Gámez and Suárez-Rey, 2020	Spain, Strawberry	ISO 14040
56	Lovarelli et al., 2020	Spain, Italy, Barley	ILCD, 2011
57	Petti et al., 2006	Italy, Grapes	CML 2001
58	Iriarte et al., 2010	Chile, Sunflower, rapeseed	CML 2 baseline 2001

Appendix D

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Table D1
Details of phase 4 obtained from literature.

No.	Reference	Key Issues	Consistency check	Response by whom (Recommendations)
1	Dekamin et al., 2018	Environmental effects due to agricultural processes	Analytical hierarchy process (Saaty, 2005)	GovernmentsFarmers
2	Jefferies et al., 2012	Precise sourcing locations of data	Not included	Governments/investors
3	Lovarelli et al., 2018	Not included	Not included	Farmers Governments
4	Pellicer-Martínez and Martínez-Paz, 2016	Over exploitation of blue water makes SRB an unsustainable basin.	Not included	Farmers Governments
5	Aldaya and Hoekstra, 2010	Mozzarella production - a potential threat to water quality in the Po valley.	Not included	Companies Consumers Farmers
6	Bocchiola et al., 2013	Not included	Not included	Not included
7	Bulsink et al., 2010	Not included	Not included	Not included
8	Fu et al., 2019	Not included	Not included	Governments Farmers
9	Chapagain et al., 2006	Not included	Not included	Not included
10	Chapagain and Hoekstra, 2007	Not included	Not included	Not included
11	Chapagain and Hoekstra, 2011	Not included	Not included	Governments Shared responsibility
12	Chiu et al., 2009	Increase in water consumption more compared to the ethanol production in the United States.	Not included	Companies Governments
13	Chouchane et al., 2015	Not included	Not included	

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Table D1 (*continued*)

No.	Reference	Key Issues	Consistency check	Response by whom (Recommendations)
				Consumers Farmers
14	Chapagain and Orr, 2009	Not included	Not included	Not included
15	Ercin et al., 2013	Not included	Not included	Not included
16	Ercin and Hoekstra, 2014	Not included	Not included	Governments
17	Fader et al., 2011	Not included	Not included	Not included
18	Galli et al., 2012	Not included	Not included	Governments Investors
19	Gerten et al., 2011	Not included	Not included	Consumers
20	Herath et al., 2014	Not included	Not included	Farmers
21	Hess et al., 2015	Not included	Not included	Farmers
22	Chapagain and Hoekstra, 2007	Not included	Not included	Consumers Companies Shared responsibility
23	Huang et al., 2012	Not included	Not included	Governments Farmers
24	Palhares and Pezzopane, 2015	Not included	Not included	Companies Governments Farmers
25	Cao et al., 2018	Not included	Not included	Investors Governments
26	Garofalo et al., 2019	Not included	Uncertainty analysis	Governments
27	D'Ambrosio et al., 2020	Not included	Not included	Governments
28	Novoa et al., 2019	Not included	Not included	Governments
29	Xu et al., 2019	Not included	Not included	Governments Farmers
30	Bazrafshan et al., 2020	Not included	Not included	Governments
31	Zheng et al., 2020	Not included	Not included	Companies
32	Li et al., 2020	Not included	Not included	Investors Farmers
33	Rossi et al., 2020	Not included	Not included	
34	Severo Santos and Naval, 2020	Not included	Not included	Governments
35	Esmaeilzadeh et al., 2020	Not included	Not included	Farmers Companies Governments
36	Lee, 2015	Not included	Not included	Governments
37	Gobin et al., 2017	Not included	Not included	
38	Leenes and Hoekstra, 2012	Not included	Not included	
39	Liu et al., 2015	Not included	Not included	Governments Farmers consumers
40	Manzardo et al., 2016	Not included	Not included	Companies
41	Marano and Filippi, 2015	Not included	Not included	Governments Investors
42	Cha et al., 2017	Not included	Not included	
43	Fito et al., 2017	Not included	Not included	Governments
44	Sweet et al., 2017	Not included	Not included	Farmers Governments
45	Mekonnen and Hoekstra, 2014	Not included	Not included	Farmers
46	Morillo et al., 2015	Not included	Not included	Farmers Consumers Governments Shared responsibility
47	Zhang et al., 2018	Not included	Not included	Farmers Investors
48	Luan et al., 2018	Not included	Not included	Not included
49	Veettil and Mishra, 2020	Not included	Not included	Governments Investors Companies
50	Veettil and Mishra, 2016	Not included	Not included	Farmers Companies Governments Shared responsibility

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