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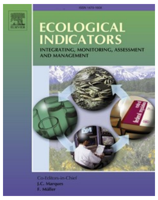

Building consensus on water use assessment of livestock production systems and supply chains: Outcome and recommendations from the FAO LEAP Partnership☆

Anne-Marie Boulay[a,b], Katrin Drastig[c,*], Amanullah[d], Ashok Chapagain[e], Veronica Charlon[f], Bárbara Civit[g], Camillo DeCamillis[h], Marlos De Souza[h], Tim Hess[i], Arjen Y. Hoekstra[j,k], Ridha Ibidhi[l], Michael J. Lathuillière[m,n], Alessandro Manzardo[o], Tim McAllister[p], Ricardo A. Morales[q], Masaharu Motoshita[r], Julio Cesar Pascale Palhares[s], Giacomo Pirlo[t], Brad Ridoutt[u,v], Valentina Russo[w], Gloria Salmoral[i,x,y], Ranvir Singh[z], Davy Vanham[aa], Stephen Wiedemann[ab], Weichao Zheng[ac], Stephan Pfister[ad]

[a] *LIRIDE, Sherbrooke University, Sherbrooke, Canada*
[b] *CIRAIG, Polytechnique Montreal, Montreal, Canada*
[c] *Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB), Potsdam, Germany*
[d] *Department of Agronomy, Faculty of Crop Production Sciences, The University of Agriculture Peshawar, Pakistan*
[e] *Pacific Institute, USA*
[f] *Instituto Nacional de Tecnología Agropecuaria (INTA) Experimental Agropecuaria EEA Rafaela, Santa Fe, Argentina*
[g] *INAHE – CONICET and UTN FRM Mendoza, Argentina*
[h] *Food and Agriculture Organization of the United Nations (FAO), Rome, Italy*
[i] *Cranfield Water Science Institute, Cranfield University, United Kingdom*
[j] *Twente Water Centre, University of Twente, Enschede, the Netherlands*
[k] *Institute of Water Policy, Lee Kuan Yew School of Public Policy, National University of Singapore, Singapore*
[l] *Department of Animal and Forage Production, National Institute of Agronomic Research of Tunisia (INRAT), Ariana, Tunisia*
[m] *Stockholm Environment Institute, Stockholm, Sweden*
[n] *Institute for Resources, Environment and Sustainability, University of British Columbia, Vancouver B.C., Canada*
[o] *CESQA, Department of Industrial Engineering, University of Padova, Padova, Italy*
[p] *Agriculture and Agri-Food Canada, Lethbridge Research and Development Centre, Lethbridge, Alberta, Canada*
[q] *AgroDer SC, Mexico DF, Mexico*
[r] *Institute of Science for Safety and Sustainability, National Institute of Advanced Industrial Science and Technology, Tsukuba, Japan*
[s] *Embrapa Southeast Livestock, São Carlos, Brazil*
[t] *Council for Agricultural Research and Economics, Research Centre for Animal Production and Aquaculture, Lodi, Italy*
[u] *Department Agricultural Economics, University of the Free State, Bloemfontein, South Africa*
[v] *Agriculture and Food, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Clayton South, Melbourne, Australia*
[w] *Environmental and Process Systems Engineering Research Group, Department of Chemical Engineering, University of Cape Town, 7701 Rondebosch, South Africa*
[x] *Environment and Sustainability Institute, University of Exeter, United Kingdom*
[y] *College of Engineering, Mathematics and Physical Sciences, University of Exeter, United Kingdom*
[z] *School of Agriculture and Environment, Massey University, Palmerston North, New Zealand*
[aa] *European Commission, Joint Research Centre (JRC), Ispra, Italy*
[ab] *Integrity Ag and Environment, Toowoomba, Qld, Australia*
[ac] *China Agricultural University, China*
[ad] *Dept. of Civil, Environmental and Geomatic Engineering, ETH-Zürich, Zürich, Switzerland*

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ABSTRACT

The FAO Livestock Environmental Assessment and Performance (LEAP) Partnership organised a Technical Advisory Group (TAG) to develop reference guidelines on water footprinting for livestock production systems and supply chains. The mandate of the TAG was to i) provide recommendations to monitor the environmental

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☆ In memory of Arjen Hoekstra, who passed away during the publication process.

* Corresponding author.
E-mail address: kdrastig@atb-potsdam.de (K. Drastig).

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performance of feed and livestock supply chains over time so that progress towards improvement targets can be measured, ii) be applicable for feed and water demand of small ruminants, poultry, large ruminants and pig supply chains, iii) build on, and go beyond, the existing FAO LEAP guidelines and iv) pursue alignment with relevant international standards, specifically ISO 14040 (2006)/ISO 14044 (2006), and ISO 14046 (2014). The recommended guidelines on livestock water use address both impact assessment (water scarcity footprint as defined by ISO 14046, 2014) and water productivity (water use efficiency). While most aspects of livestock water use assessment have been proposed or discussed independently elsewhere, the TAG reviewed and connected these concepts and information in relation with each other and made recommendations towards comprehensive assessment of water use in livestock production systems and supply chains. The approaches to assess the quantity of water used for livestock systems are addressed and the specific assessment methods for water productivity and water scarcity are recommended. Water productivity assessment is further advanced by its quantification and reporting with fractions of green and blue water consumed. This allows the assessment of the environmental performance related to water use of a livestock-related system by assessing potential environmental impacts of anthropogenic water consumption (only "blue water"); as well as the assessment of overall water productivity of the system (including "green" and "blue water" consumption). A consistent combination of water productivity and water scarcity footprint metrics provides a complete picture both in terms of potential productivity improvements of the water consumption as well as minimizing potential environmental impacts related to water scarcity. This process resulted for the first time in an international consensus on water use assessment, including both the life-cycle assessment community with the water scarcity footprint and the water management community with water productivity metrics.

Despite the main focus on feed and livestock production systems, the outcomes of this LEAP TAG are also applicable to many other agriculture sectors.

1. Introduction

1.1. Context

The FAO Livestock Environmental Assessment and Performance (LEAP) Partnership is a multi-stakeholder initiative created in 2012 to improve the environmental performance of livestock supply chains, whilst ensuring its economic and social viability. In order to let producers and stakeholders understand the environmental performance of livestock production systems and supply chains, and to set and work towards improvement targets accordingly, the LEAP Partnership has been building global consensus on environmental assessment methodology and data.

This paper summarizes the main outcomes of the consensus building process leading to the guidelines *LEAP Guidelines for Assessment - Water use of livestock production systems and supply chains* in terms of recommendations, providing rationale and context for the recommendations, and highlights the knowledge as well as the gaps and challenges identified in the process.

1.2. Water issues and need for guidance

Global resource scarcity and environmental degradation, along with related market and regulatory pressures, present growing challenges for the livestock sector worldwide. At the same time, there is a growing recognition of the need for comparative and standardized indicators to assess the sector's environmental performance and progress towards sustainability (FAO, 2017), which includes productivity and sustainability of water use in livestock production systems and supply chains. The LEAP works closely with the Sustainable Development Goals (SDG) and the 2030 Agenda includes a dedicated goal on water and sanitation (SDG 6), where target 6.4 deals with water scarcity. The recently published SDG 6 synthesis report presents the global status of water scarcity (UN, 2018). SDG-Target 6.4 states "By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity". As such, one of the goals of our recommendations is to address potential risks of water scarcity and identify key processes for improvement through the assessments of water productivity as well as water scarcity impact of livestock production systems and supply chains.

Water footprinting has been developed as a framework to assess both direct and indirect water use of a production process and its consequences on the environment. The water footprint community has generally been represented by two schools of thought, partly complementary (Boulay et al., 2013) and partly diverging on some concepts, as discussed in an exchange that occurred in this journal (Hoekstra, 2016; Pfister et al., 2017), as illustrated in Fig. 1. On the one hand, the water management community has focused on quantification of water footprint as the volume of freshwater consumed via a Water Footprint Assessment (WFA), with the idea of optimizing water use and productivity at the global level, while taking into account different parameters such as water stress when interpreting the assessment (Hoekstra et al., 2011). On the other hand, the life cycle assessment (LCA) community has focused on potential contributions to water scarcity from blue water consumption throughout a production system (i.e., water scarcity footprint), as well as related potential damages to human health and ecosystems (Pfister et al., 2009; ISO 14046, 2014; Kounina et al., 2013). While these approaches are not necessarily contradictory, they do sometimes point in different directions when it comes to specific metrics, and decision makers often find it difficult to reconcile these two approaches. In addition, when quantifying water productivity, or water scarcity footprints, several methodological choices are still up to the practitioner who is left without much guidance, resulting in poor reliability and comparability of such studies across livestock production systems and supply chains.

1.3. Objective of the guidelines

The main objective of the LEAP guidelines was to address all quantitative aspects associated with water use of feed and livestock production systems and supply chains, including water consumption, inventory flows, water productivity and contribution to water scarcity, whilst water quality-related aspects were outside the scope of the guidelines. Water use assessment included: Water scarcity footprint as informed by ISO 14046:2014 (ISO, 2014) and assessment of water productivity of systems, following the methods of Molden and Sakthivadivel (1999; cited in Sun et al., 2016), Descheemaker et al. (2010 cited in Bekele et al., 2017), Prochnow et al. (2012; cited in Vellenga, Qualitz, & Drastig, 2018), and the Water Footprint Assessment Manual (Hoekstra et al., 2011; cited in Karandish, Hoekstra, & Hogeboom, 2020). The Water TAG delivered the Guidelines on these aspects. The objectives were to support water management solutions through improvement over time via comparison of practices in livestock production and supply chains. Comprehensive recommendations to assess the water scarcity footprint and water productivity in the global livestock sector, anywhere in the world using existing methodologies were the results of the Guidelines.

1.4. Objectives of this paper

The objectives of this paper are therefore to communicate how different water use assessment methodologies can complement each other in a set of international and consensus-based guidelines; illustrating the relevance, limitations and interpretation of the two approaches focused on quantification of water productivity and water scarcity impact assessment. In addition, the paper provides an overview of the main recommendations of the guidelines for each section, while discussing the process itself and the challenges that arose with the main topics of discussion.

2. Method: LEAP water TAG process

2.1. General

Sound recommendations were expected on water use assessment that adequately capture the specificities of livestock production systems. Building on existing water use assessment standards and methods, the LEAP Water TAG process focused on building a global consensus on water footprinting of livestock supply chains. Hence, the objective of the Water TAG was not to perform new research or analysis, but rather to review and integrate best practices based on current and state-of-the-art knowledge.

2.2. Formation of the water TAG

The LEAP Steering Committee is composed by three stakeholder groups: governments, private sector, and civil society and Non-Governmental Organizations (NGOs). This Committee provides overall leadership, as well as approves the work programme of the Partnership. The Chair is rotated annually across the three groups to ensure equal footing in setting the agenda of the Partnership. The Committee meets regularly, and decisions are generally made by consensus. The Food and Agriculture Organization of the United Nations (FAO) hosts the LEAP Secretariat and ensures that the work of the LEAP Partnership is based on international best practices. The LEAP Secretariat is responsible for the technical support of the Partnership. Technical Advisory Groups (TAGs) are established as ad hoc groups made up of experts from academia, the private sector, and NGOs. They are primarily formed to build consensus on methodology and guidance based on the latest scientific findings and existing recommendations. The LEAP Technical Advisory Group on water use assessment, hereafter called Water TAG, was formed in 2016 and comprised experts in fields such as animal science, soil science, agronomy, agricultural science, hydrology, capacity development, water footprinting, and life cycle assessment (LCA). Scientific communities affiliated to the following three approaches were invited to join the TAG: LCA, water footprint network, and water productivity.

The LEAP Water TAG process took place over a period of two years (July 2016 to September 2018) including the technical review, face-to-face meetings, online discussions, and review and publication of the guidelines (Fig. 2). The Water TAG members were selected by the LEAP Secretariat following a call for application, representing a variety of backgrounds, geographical regions and expertise. Balance in gender, region and scientific community was sought. A total of 42 members were selected, while 30 attended at least one of the two face-to-face meetings; a requirement to be considered an active TAG member. The LEAP Secretariat, supported by the LEAP Steering Committee, also appointed two co-chairs and a technical supervisor, following a call for applicants. The co-chair's role was to support the technical discussions and coordinate the inputs from the TAG members during the development of LEAP guidelines on water footprinting as well as produce a peer-reviewed paper for publication in a scientific journal. The technical supervisor was appointed to provide the TAG with technical support and expertise on critical questions when needed, lead case studies and their publication and identify potential key issues in the application of the developed guidelines.

2.3. Water TAG activities

The first meeting of the Water TAG took place at the FAO office in Rome, Italy, in July 2016 and lasted three days (Fig. 2). During this meeting, the mandate, roles and responsibilities of members, code of conduct, tools to be used and consensus building and decision processes were presented the first day, as well as ice-breaking and brain-storming activities. The second day, existing documentation (FAO, 2016a, 2016b, 2016c, 2016d, 2018; PEFCR, 2015a, 2015b, 2015c, 2015d; Ran et al., 2016; Ridoutt and Huang, 2012; Scherer and Pfister, 2016; Atzori et al., 2016) was reviewed, analysed and discussed, and sub-groups were formed for the planning of the upcoming work, identifying the scope of the content. The last day served in identifying key issues for each of the sections and discussing them with the entire TAG. Following the first

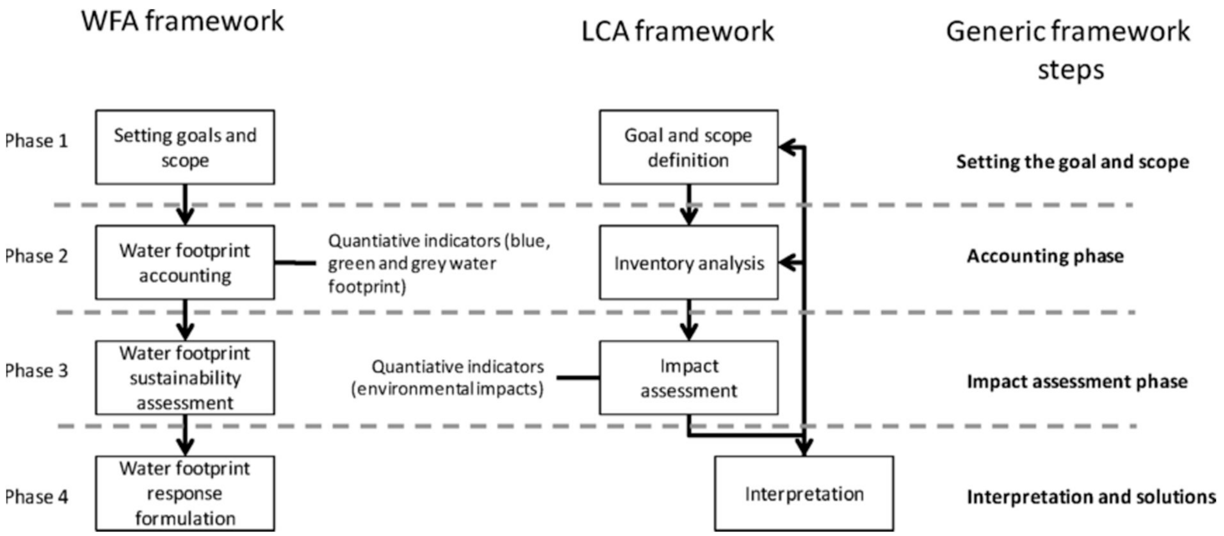

Fig. 1. Comparison of LCA and WFA, illustrating the large similarity and the difference in quantitative indicators (Boulay et al., 2013). The considered LCA framework is actually of LCA, not specifically for LCA-based water footprint.

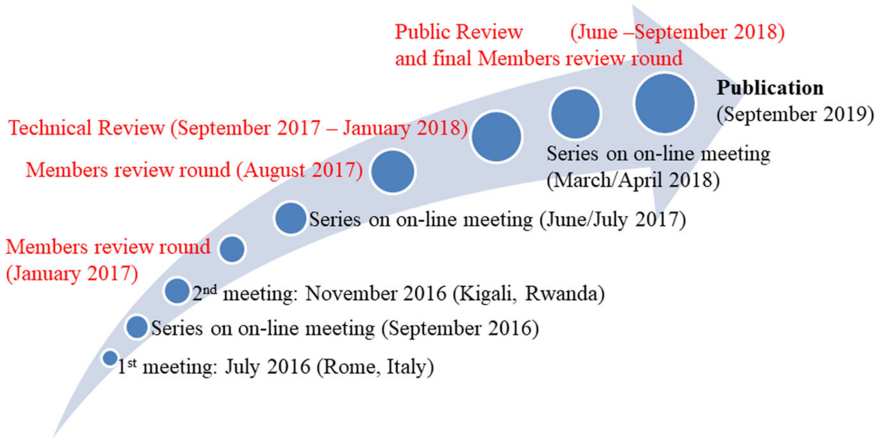

Fig. 2. Activities of the Water TAG between the first meeting in July 2017 and Publication of the Guidelines (FAO, 2019) in September 2019.

meeting, the TAG sub-groups coordinated online over the next four months from July to November 2016 and collated and reviewed relevant information and studies for their assigned specific topics of the guidelines work plan.

The second, and last, in-person meeting took place in Kigali, Rwanda, in November 2016 and lasted four days, with the first day comprising a field visit to local cattle farms, and a general workshop on the productivity and environmental assessment of livestock farming coordinated by the LEAP Secretariat. During the course of the following three days of work, technical discussions took place on specific aspects where group discussion and consensus building was the most needed: water footprint impact assessment methodology (which took almost half of the discussion time), green water (see Section 3.3.3) and water productivity metrics. Some time in the last day was spent in sub-groups for the integration of the discussion outcome into the report, drafting different sections and the planning of the remaining work.

A total of four rounds of review comments and inputs took place, two among the Water TAG members (February and August 2017), one technical review (September 2017 to January 2018) by 5 peers having background with ISO 14046, extension services, livestock systems, water productivity assessments, and water footprinting, and one public review (June to September 2018). The LEAP partnership members (or reviewers) were invited to provide comments on a designed template, including a reason for change and a proposed change. This allowed integration of the editorial changes and additional technical content or corrections, and the identification of disagreements or topics for further discussion in online meetings.

Three series of online meetings on specific topics took place in September 2016 (before the second meeting), June/July 2017 (before the submission of the draft report) and March/April 2018 (as part of the Technical Review resolution of comments). The goal of these meetings was to discuss specific aspects of the recommendations requiring discussion in each meeting (one topic per meeting), as identified by the rounds of comments. This allowed the members to choose which ones they wanted to join and aimed at avoiding costly and time-consuming travel.

2.4. Water TAG consensus building process

A consensus building process was put in place at the first Water TAG meeting, in order to clarify how decisions would be taken and disagreements dealt with. This process, aiming for consensus (large majority agrees), also provided for the possibility of consent (nobody has a (valid) objection). If valid objections (considered receivable and reasonable) were put forward, a revised alternative could be proposed and accepted, or, in the lack of acceptance, an explanation was to be provided accordingly in the deliverable.

3. Results

3.1. Defining the goal and scope

The Goal and Scope of the assessment defines the question to be answered and the level of inclusion of the system. Different metrics are proposed to answer different goals. In the guidelines, water productivity (*WP*) is defined as the “Ratio of the benefit to the amount of green and blue water consumed to produce those benefits in a production process (product units: e.g. mass, energy, nutrition per m^3 water). The *WP* is reported with fractions of green and blue water consumed.”, and water scarcity footprint (WSF) is defined as a “Metric that quantifies the potential environmental impacts related to water scarcity (based on ISO 14046, 2014)”. Hence, the goal may refer to the evaluation of the contribution of an activity (e.g. feed and livestock production) to water scarcity, and its related potential environmental impacts, as achieved via a water scarcity footprint assessment, and/or to understand the water flows in a farm and optimize water use by agronomic measures and farm management for example, as made possible via a water productivity assessment.

The Scope of the assessment clarifies the system boundaries (see Fig. 3), the functional unit and reference flows, the allocation performed, the geographical and temporal coverage as well as resolution, all in accordance with ISO 14046 (2014). This is especially important in water use assessment, as freshwater is an increasingly scarce resource whose availability varies widely over temporal and spatial scales. The spatial and temporal resolution for water scarcity footprint will likely be dictated by the impact assessment method used, however the guidelines recommend use of monthly data at a watershed scale. When such level of data resolution is not available (e.g. for background data), larger aggregation (such as annual and country level) may be performed if supported by the impact assessment method.

Fig. 3 depicts a typical livestock life cycle including feedstock and livestock production, but also all phases supporting livestock activities, such as the production of inputs (e.g. pesticides, herbicides, fertilizer, energy and seeds) and co-products. In feedstock production, green water is involved at field level (in pastures and feed crops), while blue water is involved in the feed processing stage (to produce roughages, grains and concentrates). Green water is precipitation that is stored as soil moisture and eventually transpires or evaporates. In livestock production, blue water is involved as drinking and service water (e.g. for cleaning) and during the primary processing stage as service/processing water and water used to produce other inputs (e.g. hydroelectricity). When energy along the supply chain is sourced from biomass, a green water component can be involved (Vanham, 2016). Substantial water losses can occur in water supply systems both on and off farm; these must be accounted for in the water use inventory as consumption or returned

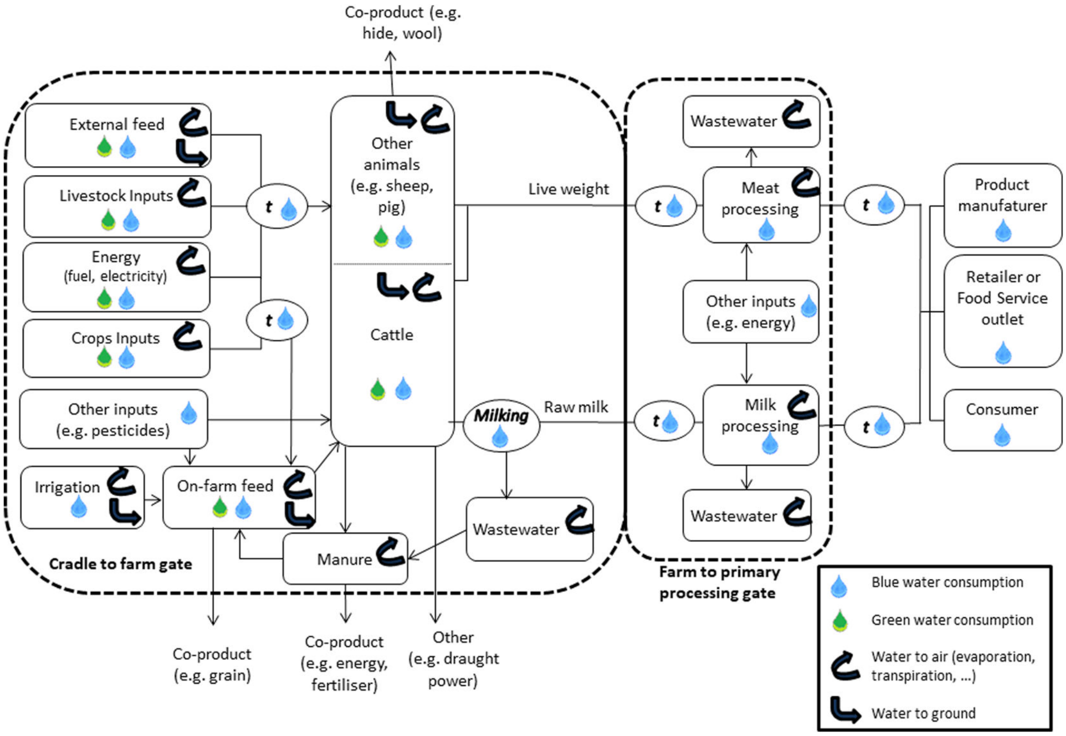

Fig. 3. System boundary and main water flows of livestock production systems: Cradle to processing gate, t: transport (FAO, 2019).

flows, depending on the context.

3.2. Data

The LEAP guidelines (FAO, 2019) are intended to provide users with practical advice for a range of water use assessment objectives for livestock production systems and supply chains. These guidelines recommend the collection of primary data for foreground processes, those processes generally being considered as under the control of the study commissioner. Primary data are defined as directly measured or collected data representative of processes at a specific facility or for specific processes within the product supply chain. Secondary data are defined as information obtained from sources other than direct measurement of the inputs/outputs from processes. This refers to data which may be available in existing life cycle inventory databases or maybe collected from published literature. However, it is recognized that for assessments with a larger scope, such as sectoral analyses at the national scale, the collection of primary data for all foreground processes may be challenging. In such situations, or when a water use assessment is conducted for policy analysis, foreground systems may be modelled using input data obtained from secondary data sources. However, when using mainly secondary data sources a proper uncertainty analysis is recommended. An uncertainty analysis could be conducted using two approaches (Pfister and Scherer, 2015):

- Analytically, e.g. by Taylor series expansion; used to combine the uncertainty associated with individual parameters from a single scenario.
- Numerically, e.g. by a Monte Carlo simulation; a well-known form of random sampling used for uncertainty analysis, a commonly used tool in commercial life cycle assessment software.

The LEAP guidelines (FAO, 2019) also recommend considering data representativeness covering: a) Temporal representativeness; b) Spatial representativeness; and c) Technological representativeness. Temporal and spatial representativeness of data include time and method of collection (primary or secondary data), time span and geographical area. Source, precision, completeness, consistency and reproducibility of the study data are important. Missing data can be handled by resorting to available specific or generic datasets to identify the main data inputs. These must meet at least "good" quality requirements and should be obtained from databases made in compliance to recognized reference data systems: e.g. ILCD (2010).

3.3. Inventory

3.3.1. General

Water requirements for livestock growth vary considerably according the species, breed, age, growth rate, and pregnancy of the animal, as well as the production status, activity, feed type and climate. Up-to-date guidance to calculate drinking water requirements of livestock species (as influenced by physiological status and environmental conditions) can be obtained from standard scientific guidelines detailing nutrient requirements of a livestock species. For example, the latest equations to determine the drinking water requirement of various classes of beef cattle are presented in a document released recently by NAS (2016). As with any inventory exercise, the steps involved are: data collection; recording and validation of the data; relating the data to each unit process and functional unit (i.e. useful output, including allocation for different co-products); and aggregation of data when relevant, ensuring all significant processes, inputs and outputs are included within the system boundary. Primary data should be preferred for the setting up of the inventory; if not available, the data necessary for the calculations can be obtained from scientific literature and/or from national or international databases (AQUASTAT, World Bank, etc.) verifying its scope and precision. The water use inventory shall be in compliance with ISO 14046 (ISO, 2014) standards. According to ISO 14046, water footprint inventory results are not to be reported using the term *water footprint*. In accordance with ISO 14046 "water consumption" refers to water removed from, but not returned to, the same drainage basin. Water consumption can be due to evaporation, transpiration, integration into a product, or release into a different drainage basin or the sea. Water consumption can refer to both blue and/or green water and should be identified as such when building the inventory. In terms of inventory, all green and blue water inputs and outputs along the life cycle should be reported separately. Water use at farm scale requires construction of a series of water balances to determine flows in each different component of the system. Ideally, primary data collected from water meters located on the farm may provide accurate water use data, but they may provide little information on water consumption. In many cases, water consumption and flows must be predicted by indirect means, based on livestock production, feed intake, crop production, climate and other data collected during a site assessment. Accurate estimates of crop water consumption could be achieved using locally calibrated and validated crop models such as EPIC (Erosion-Productivity Impact Calculator), SWAP (Soil, Water, Atmosphere and Plant), FAO's AQUACROP (Steduto et al., 2008), or FAO's CROPWAT (Smith, 1992).

3.3.2. *Blue water*

Blue water is defined as freshwater flows originating from runoff or percolation, contributing to freshwater lakes, dams, rivers and aquifers. Soil moisture is only considered blue water if it originates from blue water added through irrigation or owing to permanently saturated soil or ponded conditions from hydrological events, like flooding, from springs or capillary rise. Mainly, blue water is reflecting irrigation of field crops, pastures and grasslands but also drinking and cleaning water for livestock, and servicing water in livestock product processing. The water footprint inventory shall be crop specific, including geographic location of the watersheds when available, or country of origin. Estimates of averages crop and livestock water consumption made over diverse geographies (specifically) from the perspective of water scarcity should be avoided as different water impact assessment values would result and lead to high uncertainties in study results.

3.3.3. *Green water*

Natural rainfall that is stored in the soil profile, often referred to as *green water*, is a critically important natural resource supporting global food and energy production (Vanham, 2016). It is estimated that between 60 and 70% of all food production is on rain-fed land relying entirely on green water (Rost et al., 2008) and where irrigation is used, it is usually supplemental to green water. The careful management and use of green water are therefore paramount to safeguard food production and sustain terrestrial and freshwater ecosystems. The LEAP guidelines considered in depth the inclusion of green water in the inventory, impact assessment and interpretation phases of water use assessment in livestock production systems.

In developing the water footprint inventory, it is recommended to include green water flows in addition to blue water flows. However, following ISO 14046:2014 (ISO, 2014), green water flows are required to be accounted for separately and not aggregated with blue water. The separate accounting for blue and green water flows facilitates the application of relevant water impact assessment procedures to each resource. For example, at this stage the quantification of a water scarcity footprint is recommended based on blue water consumption only. The guidelines note that in some special cases, such as a floodplain that is seasonally inundated, there can be an unclear boundary between green and blue water. In such cases, the principles used to differentiate water types need to be transparently explained.

The LEAP guidelines (FAO, 2019) also differentiate absolute green water flows and changes in green water flows. To a greater or lesser extent, absolute green water flows, relating to evapotranspiration from pastures and crops, are part of the natural hydrological cycle. As such, these absolute green water flows are not considered water consumption attributable to the livestock system for the purposes of impact assessment. The relevance of absolute evapotranspiration measurements relates to the improvement of pasture or crop water use efficiency in a local context. Where a livestock production system leads to a change in green water flows compared to an alternative land use or land management system, water use impact assessment (water scarcity footprint) may be considered for the difference. For this approach to be undertaken, increases and decreases in evapotranspiration relative to a reference land use need to be definable with each having different impact pathways and impact assessment modelling requirements (Quinteiro et al., 2015).

3.3.4. *Feed production*

Both green and blue water consumption are generally not measured in feed production, because evapotranspiration (ET) is not typically measured, especially for large areas. Hence, most commonly, green and blue water consumption are estimated by measuring the other components of the water balance with ET as the closing entry, or by locally calibrated and validated modelling of crop water relations. Where feed is produced on-farm, as is common in ruminant systems, collecting irrigation water footprint inventory data is an important aspect of the foreground system. In this case, the efficiency of different techniques for irrigation schemes must be taken into account. Small differences in irrigation can have very large impacts on freshwater consumption for livestock production systems (Wiedemann et al., 2017). In regions where water availability is variable, it is also important to ensure that the season when water use inventory data are collected is representative. In the specific instance of grazed pasture, the water use inventory of field-grown feed systems shall be expressed using a water balance of all inflows and outflows, distinguishing all irrigation water applied and evapotranspiration of the entire pasture, as well as for the feed eaten only (used in impact and productivity assessments). It is however assumed that all feed produced using irrigation will be eaten (i.e. no field is irrigated for nothing) and hence all effective irrigation water should be included in the assessment, whereas only a fraction of the land's received green water may be used for the assessment.

3.3.5. *Other processes*

Often, more than 90% of the water consumption in livestock and poultry production is associated with the production of feed (Legesse et al., 2017; Mekonnen and Hoekstra, 2012). However, water use assessment of livestock supply chains must include all other sources of water consumption. This includes drinking and servicing, as well as the different life cycle stages taking place before and after the livestock farm: animal product processing, transport, production of other inputs (electricity, fertilisers, pest management, antibiotics, etc.).

3.4. *Water use assessment*

3.4.1. *General*

In the guidelines, water use assessment includes both: 1) *Water scarcity impact assessment* and 2) *Assessment of water productivity*. The *water scarcity impact assessment* is the assessment of the environmental performance related to water of a livestock-related system by assessing potential environmental impacts of blue water consumption, following the water scarcity footprint according to the framework provided by ISO 14046. The *assessment of water productivity* is the assessment of the water productivity of the system (e.g. performance tracking purposes), following the methods of Molden and Sakthivadivel (1999), Descheemaeker et al. (2010), Prochnow et al. (2012) and Water Footprint Assessment Manual (Hoekstra et al., 2011).

The metrics from these two standards complement an understanding of the pressure exerted by the livestock production sector on the water resources worldwide in order to support potential improvement of its water productivity as well as reduction of its contribution to water scarcity.

3.4.2. *Water scarcity footprint*

The potential impacts related to the potential deficit in water resource is categorized as the impact category "water scarcity" in the ISO standard ISO 14046: 2014 (ISO, 2014). It depends on the extent of demand for water compared to the replenishment in an area, and thus is not represented only by accounting for the volume of consumed water (inventory). In the calculation of the impact category *water scarcity* (ISO, 2014), a scarcity index is used and results in a category indicator generally representing the potential impacts, via deprivation of water resources to users in an area. In most cases the index is continuous, allowing for a range of level of scarcity being described (as in AWARE method (Boulay et al., 2018)). In some cases where it is used in a binary approach, equivalent to using a value of 1 when demand is larger than availability, and 0 where this is not the case (as in the Blue Water Scarcity Index, BWSI (Hoekstra et al., 2012; Mekonnen and Hoekstra, 2016)).

Many indicators have been developed to quantify water scarcity. Most of the scarcity indicators that exist, both within and outside LCA practices, relate human (blue) water use (withdrawals or consumption) to local and renewable (blue) water availability (Boulay et al., 2015c). Several of them also reserve part of the flow for aquatic ecosystems requirements, generally called environmental flow requirements. The way that these parameters are related to each other, additional modelling aspects, scales, units and data sources result in a variety of scarcity indicators and interpretation. A good understanding of the chosen method(s), units and meaning is necessary when interpreting results from a water scarcity footprint, and results obtained from different methods should not be compared in absolute terms. While some of them are conceptually similar, there are differences in the details of modeling (model structures, data source of parameters, definitions of scarcity and environmental water requirement, spatial coverage and resolution, temporal resolution, etc.). As already tested in a method comparison study (Boulay et al., 2015a), some differences in models characterizing the same impact pathways were found although most characterization factors were similar and consistent in rank. A case study of sensitivity analysis of model choices proved that the impact assessment results are different depending on the choice of models (Boulay et al., 2015b; Ridoutt and Hodges, 2017; Ridoutt et al., 2018). Therefore, the choice of an appropriate impact assessment model is a crucial step in conducting a proper impact assessment.

A consensus could not be reached within the group regarding one water scarcity impact assessment method. A large majority recommended to apply at least two methods: the AWARE (Boulay et al., 2018) and the Blue Water Scarcity Index (BWSI) (Hoekstra et al., 2012), or another method from literature. These two scarcity indexes are recommended for different reasons, including: 1) the detailed resolution at which they are provided (monthly and watershed based), 2) the consideration of environmental water requirements, and 3) the level of support from their respective communities. Nevertheless, the user was invited to consult most up-to-date literature and to justify with reasoning if an alternative method was chosen.

The AWARE method provides factors between 0.1 and 100 m^3 *world-eq/*m^3 *consumed* and the BWSI allows identifying regions where blue water consumption is larger than blue water availability. Both methods assess water scarcity at a localized spatial scale, on a monthly basis, and account for the flows required to sustain flow-dependent ecosystems and livelihoods. While these two indicators are recommended here, the reader is invited to consult the literature for the most up to date reviews which describe and analyze other available methods (such as Liu et al., 2017; Sala et al., 2017). In addition, the ISO document TR 14073 "Water footprint – Illustrative examples on how to apply ISO 14046" (ISO/TR 14073, 2017) contains a series of application examples of ISO 14046 (ISO, 2014), with several methods used and illustrated. LEAP Water TAG recommends applying at minimum the two recommended water scarcity impact assessment methods for best practice and as sensitivity analysis.

3.4.3. *Water productivity*

Generally, water productivity (*WP*) is defined as the relation of output to input of water (Bouman, 2007). An increase in water productivity could be achieved with an increased output with the same amount of water input or the same output with less water input or a combination of both options (e. g. Molden and Sakthivadivel, 1999; Prochnow et al., 2012). More specifically, *WP* is used as a measure relating the livestock product system value (e.g. kg of meat, litre of milk, number of eggs, calories or protein content in the case of food products, or its economic value) to its water consumption (Molden and Sakthivadivel, 1999; Descheemaeker et al., 2010; Prochnow et al., 2012).

Zanella Carra et al. (2020) applied and discussed the LEAP guidelines in assessment of water productivity of pig and poultry production in a Southern Brazilian watershed. The study highlighted a close relation between feed crop practices (summer versus winter maize, soy) and water productivity values of pig and poultry production in the study area. An analysis of existing studies assessing water productivity of livestock production (Drastig et al., in press) has shown important differences between their assessment goals, scope and different methods for accounting water use in livestock production processes. The two main differences are i) "Treatment of green water" and ii) "Including or excluding background processes as water input" to be seen directly in relation to farm boundary versus the whole supply chain boundary. In addition, the consideration of purchased feed, fertilisers, pesticides, antibiotics, and building of barns, etc. in the water consumption of livestock is handled differently.

In these recommendations, the assessment of a WP_{direct} (i.e., only direct water consumption and in the same location as the production system) is recommended to identify improvements in the efficiency of direct water use and compared with existing benchmarks, as a means to help track the performance of the system. This assessment can be complemented with indirect water consumption ($WP_{direct+indirect}$) metrics performed on more than one unit processes and life cycle stages, with water being aggregated over different locations. These indirect metrics look over the entire supply chain but should always be accompanied by the WP_{direct} as well as the water scarcity footprint to provide an accurate picture on the productivity and impacts of water use at the several locations where production takes place.

The recommended water productivity concept offers a conceptual framework and can be defined using different terms for the numerator (e.g. biomass, economic value) and denominator (volume of water consumed, e.g. transpiration, evapotranspiration) for the process or stage assessed. All water evapotranspired is considered consumed (for green and blue water). Because the majority of the water used in agriculture stems from precipitation, the improvement of precipitation productivity must be assessed, and the precipitation water must be included. As an innovation regarding existing water productivity methods, it is recommended to report the *WP* with fractions of green and blue water consumed, quantified as: *WP* [kg/m^3] (percentage share of blue water/percentage share of green water). An example for the value of the direct and indirect water productivity for a Brazilian broiler production (including purchased feed, animal breeding) on a mass basis is $WP_{indirect+direct,Farm} = 0.292\ kg_{carcass\ weight}/m^3$ (0.3%/99.7%) (Drastig et al., 2016). Also the water productivity should be assessed including background processes such as electricity production, etc.

In the case of ruminant animal production systems which mainly rely on green water due to animal grazing, we further recommend distinguishing between green water consumption from 'rangelands not suitable for crop production' versus green water from 'croplands' and 'rangelands potentially suitable for crop production'. This distinction allows to capture the ranges of water productivity depending on the land use capabilities regarding food production.

3.5. *Integration of water productivity and water scarcity impact assessments*

The overall aim of the interpretation of the results should be to inform decision makers about the performance related to water use of their product systems and to aim for more efficient and sustainable ways of producing livestock, both from resource use efficiency and overall environmental impacts. While the interpretation of the relative environmental impacts shows the urgency to act, that of the relative water productivity shows room for improvement within the system. The interpretation has different audiences; the results should be interpreted in light of who is going to use the report and for what purpose. This interpretation phase of the results should highlight which points in the production chain can be improved, using best practices that minimize the water scarcity impact and promote a more productive water use over the supply chain of livestock production.

The water use impact assessment results provide insight into the potential environmental impacts associated with water consumption for livestock production and livestock products in terms of the physical quantity of water available. This is done via two main metrics: 1) *AWARE* water scarcity factor, and 2) *Blue Water Scarcity Index*. Both metrics relate the system's water consumption to the local water scarcity, as an indicator of its potential environmental impacts (in the former) or overuse (in the latter). The results of water use impact assessment shall be analysed from both an aggregated and disaggregated perspective along the life cycle of livestock production and livestock products. Aggregated impact assessment results provide the overall performance of the target related to physical water scarcity, whereas disaggregated results provide the contribution of each stage and process to water scarcity.

The water use impact assessment (water scarcity footprint) can identify the significance of the potential environmental impacts of water consumption in different areas, therefore, provide insight into prioritization or choices of alternative site. However, the change of the concerned process location may not necessarily be feasible because of other limitations, like socio-economic impacts. In this context, water productivity assessment and impact assessment are complementary, thus the results from both assessments should be interpreted together. If a process is identified to result in a significant potential environmental impact, the impact should be disaggregated into water use inventory and characterization factor of an area to determine the causes of the impact and identify the most relevant issue, water productivity of a process or its potential impact in the area.

WP assessment can help to identify the potential of improvement in water consumption efficiency along the life cycle of livestock products, whereas the improvement of water productivity in different areas cannot be prioritized only based on the volumetric aspect. A consistent combination of water productivity and water scarcity footprint metrics provides robust information to identify scope and priority actions towards water productivity improvements, as well as reduction of potential water scarcity impacts.

We recommend that interpretation must clarify the level of aggregation used, i.e. that interpretation of results for different types of water use (i.e. green and blue) should be presented separately and put in the context of each other.

3.6. Reporting

For reporting, to be successful in improving the environmental understanding of products and processes, it is important that technical credibility is maintained while adaptability, practicality and cost-effectiveness of the application provided. Reporting conveys information that is relevant and reliable in terms of addressing environmental areas of concern (adapted from ISO 14026, 2017). Reporting of water scarcity impacts and water productivity assessment results is a fundamental step in improving the understanding of the environmental performance of products and processes and conveying relevant and reliable information to the final user. Generally speaking, the LEAP guidance on reporting builds on the requirements of ISO 14046 (ISO, 2014) on water footprint assessment and ISO 14026 (ISO 14026, 2017) on footprint communication giving additional information, where applicable, when water productivity results are reported.

Considering this, the principles of credibility, reliability, life cycle perspective, transparency accessibility and regionality are applicable when reporting is performed. In order to prepare a report in conformity with the LEAP guidance document the following requirements shall be met. First of all, considering the variety of the objectives of the study, its scale (geographical and temporal), and the audience identified in the goal and scope definition, it is important to determine the type and format of the report. The report may be intended for internal (e.g. the company that commissioned the study) and/or for external use (e.g. policy makers, suppliers, consumers etc.). The format can be chosen based on the needs of the commissioner of the study (e.g. available online, on printed copies etc.).

Secondly, the content of the report should be carefully planned. The commissioner of the study may be interested in reporting either water productivity assessment results alone or water related impacts assessment alone. In the third-party report, when only one of the two assessments is performed, the limitations of not performing the other one shall be clearly stated. Despite the boundaries of reporting, a fundamental aspect to be considered when planning the content of the report is that water productivity data (e.g. water use from different locations) shall not be reported in an aggregated manner without the respective water scarcity footprint performed according to ISO 14046. This is very important to keep transparency and report results without bias respecting the principle of regionality. Such a requirement is applicable also in the reporting of a benchmark when performance tracking is performed. Another choice that may influence the content of the report is the intention for comparative assertion. In this case, it is fundamental that water scarcity impacts and water productivity assessment results are reported along with all of the other environmental impact assessment results obtained through a more comprehensive life cycle assessment study (ISO 14040, 2006).

For a third-party report, additional requirements are set by the LEAP guidelines (FAO, 2019). For example, a critical review according to ISO 14071 (ISO/TS, 2014) should be performed and its results shall be included in the report. This is important to guarantee informed decisions by potential third-party users.

4. Gaps and challenges

In the previous sections, the main points of the Water TAG recommendations were summarized. Some of them were the results of extended discussions and reflect a compromise found to reflect the group's input. While unanimity would have been desired, consensus is not necessarily a synonym for unanimity and can be achieved despite a minority or individuals disagreeing. In the process, disagreements were received, discussed and evaluated to build compromise positions, as can be seen in the results. The guidelines allow for the calculation of a wide range of water use and impact assessment metrics. Different types of metrics were considered in depth and not all members of the Water TAG supported all the possibilities that are allowed in the recommendations. Diverging opinions were mostly related to three core topics: 1) green water assessment, 2) aggregated water productivity metric, and 3) water scarcity indicator.

4.1. Including green water in assessments

The separation of green and blue water was an important topic of discussion due to the nature of livestock production system and their reliance on feed. While the majority of the Water TAG agreed that it was important to distinguish green water from blue water and to include it in the assessment, the concern of its interpretation with respect to blue water was raised. The equivalence of the green water resource to the blue water resource remains a point of difference between the philosophy of the two metrics in the guidelines: while both types may be considered sufficiently equivalent to be added in a water productivity metric, it is not the case for the water scarcity footprint. Still, even in a water productivity metric, it was recommended to also report blue and green water productivity separately in order to allow for separate interpretation. In terms of water scarcity, no consensus exists on assessing green water scarcity footprint and therefore it is left out of the water scarcity impact assessment, and at this point rather associated with land use metrics in LCA. The use of the terminology *blue* and *green* was also debated, and for this reason the following statement was added: "The TAG recognizes that the terminology "blue water" and "green water" is not recognized by all, and that other wordings exist to refer to these different types of water flows. Although the terms blue and green water are used in this document, their adoption is not necessary for the application of these guidelines". Additional disagreement concerned the inclusion of green water from pasture for water productivity indicators: some argued for total green water of the pasture, while others preferred only the green water of the consumed biomass.

4.2. Aggregated water productivity metrics

The Water TAG discussed the nature of a water productivity metric in the context of livestock supply chains, given their complexity and common reliance on feed produced off-farm. The calculation of a water productivity (*WP*) metric aggregated across life cycle stages ($WP_{direct+indirect}$) introduces the possibility of adding together water of different types (e.g. green and blue water) and water from different locations where environmental conditions differ. This is clearly a point of departure from ISO14046:2014 (ISO, 2014) as well as the international standard on eco-efficiency assessment of product systems (ISO 14045, 2012) that require impact assessment prior to aggregation. The critical issue is that it is possible to reduce water consumption across the life cycle (an apparent improvement in water productivity), yet increase water scarcity impacts, if less blue water is consumed throughout the product life cycle and at the same time higher blue water consumption is recorded in regions faced with higher scarcity. It is for this reason that it is repeatedly stated that "the $WP_{direct+indirect}$ metric shall always be accompanied by the WP_{direct} for all individual parts of the system as well as the water scarcity footprint". As highlighted by WWF during review steps, local conditions shall always be considered. What is important in applying the Guidelines is that results are interpreted carefully, with thorough understanding of their meaning and limitations.

4.3. Water scarcity indicator

Numerous water scarcity indicators exist, both from within and outside of the LCA community. While the LCA community has recently achieved a consensus on which metric to use (Boulay et al., 2018), this also does not mean unanimity of all members. A consensus could not be reached within the group regarding one water scarcity impact assessment method.

While recommending more than a single indicator may seem cumbersome, it actually presents several benefits: 1) in LCA, good practice also recommends using a second impact assessment methodology to assess uncertainty and the robustness of the results with respect to the choice made, 2) both water scarcity indicators require the same data to be applied, i.e. water consumption ideally at the level of watershed and monthly resolution, and 3) both metrics relate the total human consumption and ecosystem water requirements to the total renewable water available, relying on the same input data for some aspects. Thus, differences in results would point to the consequences of the mathematical modelling of the indicator, which would be of added value for interpretation.

4.4. Testing and application

Further testing and applications of the guidelines are instrumental to identify and address any methodology gaps and help improve a consistent and coordinated assessment of water use in livestock production systems and supply chains. Also, water use assessment should put in context of other environmental performance of livestock production systems and supply chains. Other groups work on related topics e.g. water quality aspects (FAO 2018), environmental performance of animal feeds supply chains (FAO, 2016d), and indicators and methods to assess biodiversity (Teillard et al., 2016). The recent FAO LEAP Partnership Phase 3 (2019–2021) activities contribute to consolidate the current guidelines through road testing and development tools in support of guideline application and uptake. In its phase 3, the FAO LEAP Partnership is strengthening collaboration with its partners to disseminate the guidelines on water use assessment as part of a broader package of normative work, which also addresses greenhouse gases, land occupation, nutrients cycles, soil carbon stocks, biodiversity. While relying on the life cycle assessment for feed and livestock production systems, LEAP guidelines also recommend using complementary assessment framework such as nutrients efficiency and ecological indicators based on the pressure state response framework depending on the scale and context of application.

The dissemination of the FAO LEAP guidelines is also instrumental to identify and fill methodology gaps, improve consistency across technical documents and to mainstream uptake of the normative work in existing databases and assessment tools. In 2021, FAO LEAP envisages to release a catalogue of applications so that practitioners making use of FAO LEAP guidelines will be able to populate their assessment findings in order to contribute to flag (a) better production practices, (c) disruptive eco-innovation, and (d) opportunities for circular bio-economy. By sharing assessment findings, FAO LEAP aims at sharing knowledge among countries and stakeholders in order to accelerate the pathway towards the Sustainable Development Goals and the Paris Agreement objectives. The private sector from the feed and livestock sectors will also be able to make use of the FAO LEAP catalogue of applications to flag commitments for environmental improvement and to populate periodical environmental statements as a way to show contribute to the SDGs and the transformative change envisaged in the latest IPBES report and the climate change community.

5. Conclusion

This paper presented the process and the outcome of the consensus building leading to recommendations on the water use assessment of livestock production and supply chains, as part of the FAO LEAP Partnership Phase 2. This process included the formation of the Water TAG, consensus building activities over the course of two years and the decision process put in place. Results presented the main recommendations of the different sections: goal and scope, data, inventory, water scarcity footprint and water productivity, interpretation and reporting. The main points of disagreement were elaborated in the discussion section, providing more context and background to the most challenging aspects of the recommendations. This process resulted for the first time in an international consensus on water use assessment, including both the life-cycle assessment community with the water scarcity footprint and the water management community with water productivity metrics. This consistent combination of metrics provides a complete picture both in terms of potential efficiency improvements of the water consumption as well as minimizing potential environmental impacts related to water scarcity. In order to work on improvement targets for water use in livestock systems and supply chains as well as to assess implications of climate change mitigation options on water scarcity, FAO is invited to incorporate a water module in the Global Livestock Environmental Assessment Model (GLEAM) and related tools (GLEAM-i). The authors of this paper also call all providers of product-specific methodologies, tools and data to update their products in order to ensure alignment with LEAP guidelines on water use assessment.

Within FAO, the guidelines on water use assessment are being used in order to include blue water scarcity footprint in the Global Livestock Environmental Assessment Model (GLEAM), often used for stimulating action from the climate change corner so far.

In addition, the FAO LEAP guidelines have informed additional methodology development on livestock water productivity as part of a broader suite of tools and approaches in support of sustainable water management and nutrition sensitive agricultural practices.

CRediT authorship contribution statement

Anne-Marie Boulay: Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Katrin Drastig:** Conceptualization, Methodology, Writing - original draft, Writing - review & editing. **Amanullah:** Methodology, Methodology, Writing - original draft. **Ashok Chapagain:** Methodology, Writing - original draft. **Veronica Charlon:** Writing - original draft. **Bárbara Civit:** Methodology, Writing - original draft. **Camillo DeCamillis:** Methodology, Writing - original draft. **Marlos De Souza:** Methodology, Writing - original draft. **Tim Hess:** Methodology, Writing - original draft. **Arjen Y. Hoekstra:** Methodology, Writing - original draft. **Ridha Ibidhi:** Methodology, Writing - original draft. **Michael J. Lathuillière:** Methodology, Writing - original draft. **Alessandro Manzardo:** Methodology, Writing - original draft. **Tim McAllister:** Methodology, Writing - original draft. **Ricardo A. Morales:** Methodology, Writing - original draft. **Masaharu Motoshita:** Methodology, Writing - original draft. **Julio Cesar Pascale Palhares:** Methodology, Writing - original draft. **Giacomo Pirlo:** Methodology. **Brad Ridoutt:** Methodology, Writing - original draft. **Valentina Russo:** Methodology, Writing - original draft. **Gloria Salmoral:** Methodology, Writing - original draft. **Ranvir Singh:** Methodology, Writing - original draft. **Davy Vanham:** Methodology, Writing - original draft. **Stephen Wiedemann:** Methodology, Writing - original draft. **Weichao Zheng:** Methodology, Writing - original draft. **Stephan Pfister:** Conceptualization, Methodology, Writing - original draft.

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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