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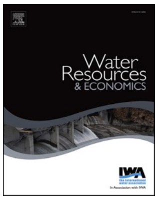

Tracking water for human activities: From the ivory tower to the ground

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ABSTRACT

Water policy requires well established metrics for success. Precise metrics allow for quantifying progress and adjusting processes to produce the desired outcomes. We analyze the different schools of thought, nomenclatures and indicators developed for tracking water for human activities. After comparing a variety of terms related to water accounting used to serve the different purposes (environmental vs. ecological economics), we found that the different approaches to water tracking utilize identical terms to refer to distinctive concepts. The characterization of widely used terms such as 'water use' varies across different branches of literature. Different approaches to water measurement and its efficiency have an impact on water allocation. Our paper points out that the current definitions and methods for tracking water for human activities may offer contradictory advice over whether progress is being made towards desirable objectives, which may differ across stakeholders. This review aims at helping the transfer of academic results to empirical decision-making by discerning the differences among the variety of indicators available in the literature and their empirical implications. The ambiguity in the water terminology should be clarified before policy decisions can be useful in practice for guiding actions.

1. Introduction

The shared and multifaceted nature of water makes the water accounting an interdisciplinary field of study that can be addressed at different scales, in different sectors and from different perspectives. As academics, policy makers, and water stakeholders realise the limitations of water in present and in future climate challenged scenarios, the qualitative and quantitative tools for water assessment have exploded over the last twenty years -life cycle assessment (LCA), water footprint (WF), environmental performance index to name just a few.

Different accounting frames exist at the level of process, product and organization [1,2], for a consumer or group of consumers from the consumption perspective [1] and for spatial units from the production perspective at hydrological (e.g. sub-basin, river basin or aquifer), administrative (e.g. municipality, district, province or country), political (e.g. constituency), management unit (e.g. irrigation scheme) or combination of all of these units [1,3–5].

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Water policy requires well established metrics for success, because without a clear indication of the size of a problem there is no reason to act to solve it. Policy makers define the rules and incentives which define the allocation of water among competing needs. At the same time, water users with competing demands (think of any economic activity dependent on the use of water: farmers, industry, urban, recreational, energy, etc, but also the natural world, as a whole or in a particular geographical area) are affected by water allocations. Precise metrics allow for quantifying progress and adjusting processes to produce the desired outcomes.

In this paper we review, compare, and contrast the theoretical frameworks, taxonomies, nomenclatures, and indicators used for helping tracking water for human activities. All of them aim at being relevant for water policymaking. We delve into the literatures dealing with water for agriculture and water for energy, the two human activities most dependent on water availability. We illustrate, with examples, some cases where the same nomenclature is used to refer to different concepts (for instance, 'water use'). We argue that the ambiguity of the academic tools for water assessment needs to be resolved before any of them are in a real position to be able to alter the behavior of water stakeholders.

2. Material and methods

Tracking water for human activities is a broad and cross-cutting area of research. This critical review paper explains the topic in detail based on previously published research.

We carried out a bibliometric analysis in Web of Science (WoS) for the period 1990–2020. First, we ran a query by topic using 'water accounting' as the keyword in all databases and collections available on the Web of Science platform. As a result, we obtained 457 scientific publications, showing a very significant increase from mid-2000 onwards (Fig. 1). Second, we broadened our search by launching queries on a wide variety of water tracking-related terms, such as 'water consumption', 'water footprint', 'water withdrawal', 'virtual water', and 'water efficiency'. This search resulted in more than 32,000 studies. According to WoS, publications containing the term 'water consumption' were the most representative of the sample (that is, more than 65% over the period analysed), followed by those studies including the term 'water footprint' (i.e., more than 10% from 2013 to present). Research containing the terms 'water withdrawal', 'virtual water', and 'water efficiency' were only representative in the second half of the reporting period (Fig. 2).

All these papers have a core common worry: they all attempt to track water for human activities, but how different are their theoretical approaches to tracking water? Do they use similar taxonomies? Do their concepts overlap or contradict each other? Do the tools and indicators used result in similar policy implications? These are the core questions guiding our enquire into the literature. The comparative method, so called, is the process of comparing groups, which are similar and yet which differ in known ways. Conventionally, comparative analysis emphasized on the explanation of differences, and the explanation of similarities. In this paper we will analyze differences and similarities in ontology, epistemology, methodology, methods, and data sources of the key strands identified in our bibliometric analysis of water-tracking related literature and how they inform and influence each other.

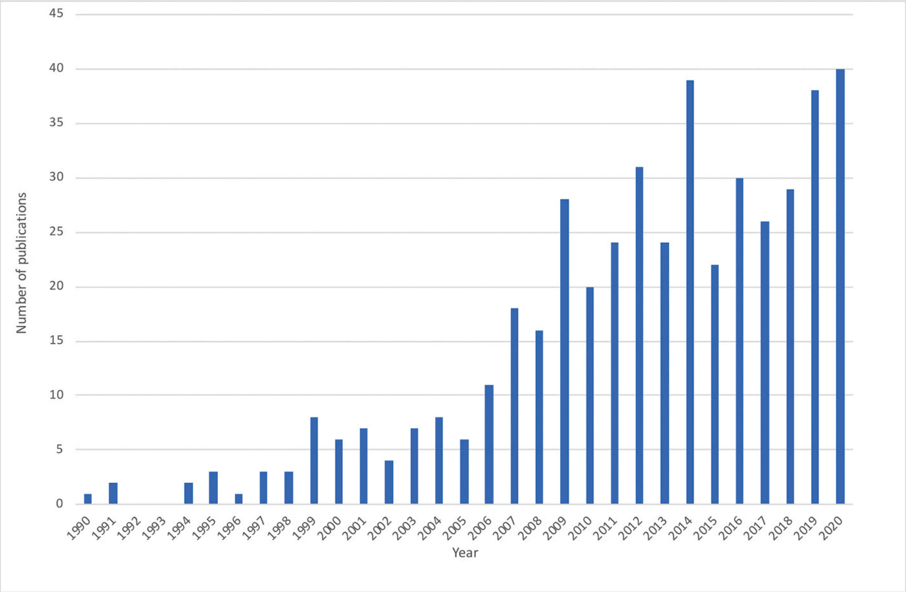

Fig. 1. Number of publications using the search term 'water accounting' in Web of Science (Accessed: September 26, 2021).

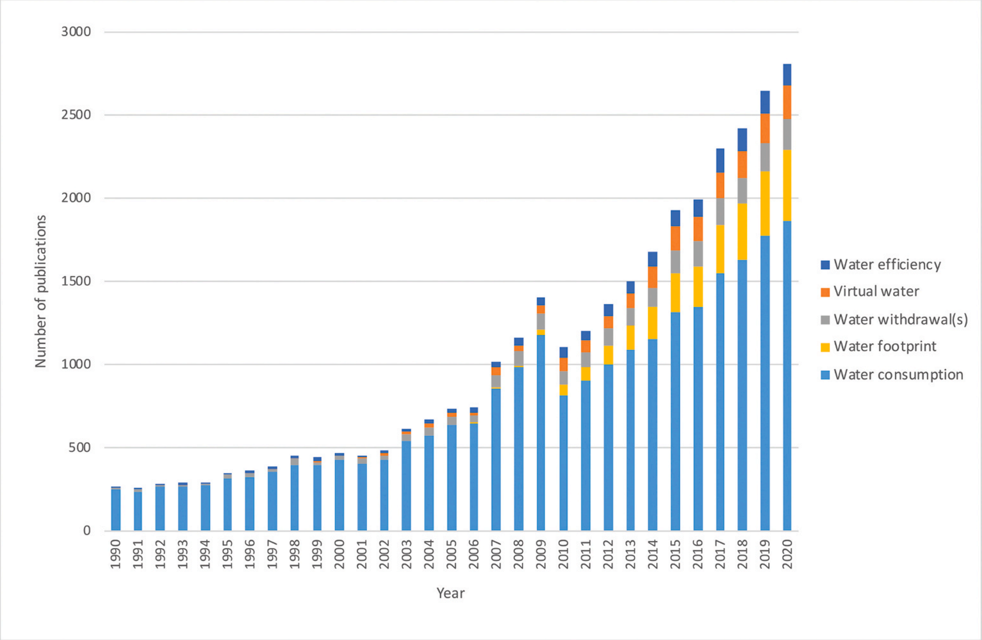

Fig. 2. Number of publications using the search terms ‘water withdrawal/s’, ’water consumption’, ’water efficiency’, ’water footprint’ and ’virtual water’ in Web of Science (Accessed: September 26, 2021).

3. Theoretical approaches used for tracking water

Approaches to water accounting may vary to serve the different purposes, and usually come from two distinct approaches: environmental vs ecological economics. Environmental economics school of thought follows neoclassical economics in viewing the environment as a subset of the economy and having as its central concerns the problem of environmental externalities and the efficient allocation of scarce resources among competing uses [6,7]. It addresses issues of pollution control, the efficient setting of emission standards, waste management and recycling, the industrial activity of environmental externalities, the conservation of natural resources, the valuation of natural resources, and so on. The objective of environmental economics is to identify policies which will move the economic system towards an efficient allocation of natural resources.

Environmental economics is distinct from ecological economics to the extent that it adheres more closely to conventional, neoclassical economics. That is, it emphasizes the desirability of attaining environmental objectives by means of using market mechanisms, like adjusting price signals, in order to influence the behavior of households and firms. There is, however, a significant overlap between environmental and ecological economics [7].

In contrast, the ecological economics views the human economy as a subset of the biosphere and focuses on the sustainable management and relationships of the economic and ecological systems, accounting for both the financial constraints on consumption and for natural constraints implied by the wastes of production and consumption [7–9]. These constraints, which do not necessarily bind in the present but may reduce the capacity of the economic-ecological system to provide for human wellbeing in the future, are particularly relevant to sustainability and sustainable development. Humans are considered to be a major component of the overall economic-ecological ecosystem, rather than being the dominant and central components. Human society is thought of as co-evolving with the natural world. Sustainable management of the economic and ecological system is one of the major focuses of ecological economics, and the time frame of the analysis is typically longer than that considered in conventional economic analysis.

Though overlapping in some areas, environmental and ecological approaches have different purposes, which require distinct assumptions and measures. These two distinct approaches to the evaluation of human interaction with the natural world, also differ in what is considered efficient. Table 1 summaries the different concepts of efficiency, which also impact the efficiency and improvement policies in water used for benchmarking and evaluation we examine in the next section.

Key to the evaluation of the efficiency in these different approaches is that while economic efficiency tends to be measured in monetary units, eco-efficiency is usually measured in quantities of resources. Only the pareto efficiency may be measured in quantities: no alternative allocation of water (at a given place and time) would make at least one stakeholder better off without making someone else worse off.

Table 1
Efficiency concepts.

Technical efficiency requires that, given the available inputs, no more of any output can be produced without leading to a reduction in another output.
Economic efficiency refers to a situation in which the costs of a project, programme or policy are minimized. Proper economic efficiency would include externalities in the costs considered. Efficiency is usually thought of as being distinct from the concept of optimality. Productive efficiency requires that production increase until the cost of each additional unit produced (marginal costs) equal the benefit of each additional unit produced (marginal benefits). Allocative efficiency requires that there is no alternative allocation of inputs which would reduce the total costs of producing a given output. Pareto efficiency requires that no alternative allocations exist which would make at least one person better off without making someone worse off.
Eco-efficiency involves continuing to produce goods and services which satisfy customer needs and competitive prices, while reducing over time the environmental resources used in, and the environmental damage caused by their production. Water eco-efficiency is a multi-faceted concept. It means “doing more and better with less” by obtaining more value with the available resources, by reducing the resource consumption and reducing the pollution and environmental impact of water use to produce goods and services at every stage of the value chain and of water service provision.

Source: inspired on [7,60].

4. Taxonomies, concepts, and indicators for water assessment

Like other areas of research, water assessment has required the development of its own vocabulary. Occasionally, some of the terms are ambiguous. ’Water use’ is a general term that frequently leads to misunderstanding as it describes any action through which water provides a service. However, the term can be categorized in several ways because of its unspecificity. One of the most common categorizations in the literature refers to consumptive and non-consumptive uses of water [10]. Consumptive water use refers to the part of water withdrawn (taken from a river basin, subterranean deposit, etc.) that is evaporated/transpired/incorporated into products, consumed by humans or livestock, or otherwise removed from the immediate water environment not to be returned at a later point in time. By contrast, non-consumptive water alludes to the amount of water that, despite being withdrawn from the body of water, is later returned and available for recycling and/or reuse. In this sense, ’water diversion’, which refers to the removal or transfer of water from one watershed to another, typically falls into the category of consumptive water use. Several indicators with similar practical implications are defined for each of these two categories. For consumptive use, water footprint, water consumption, and water evaporation. For non-consumptive uses, return flow and water discharges. In this context, the term ’water withdrawal’ (sometimes referred as ’water abstraction’) determines the sum of both consumptive and non-consumptive water uses. Fig. 3 graphically outlines all these preliminary classifications. Table 2 describes the most commonly used terms by the literature when analysing water uses and their relevance.

The terms ’water requirement’ or ’water demand’ are more controversial. Some papers implicitly or explicitly use those terms meaning ’consumptive use’. Others however, implicitly or explicitly use those terms meaning the total amount of water required for making the human activity feasible (both of consumptive and non-consumptive nature, thus the equivalent to withdrawals). Yet many papers, make the identification of what they meant by ’water requirements’ or ’water demand’ impossible.

Minimizing the amount of water consumed (evaporated and/or embedded) in the production process is the objective of the ecological economics. This school of thought tries to measure how much water is retained by a process (or product) never to be returned to the body of water from where it was removed. The optimization problem faced by this approach is, for the most part, an unconstrained problem. In general, papers calculating the blue water footprint/water evaporation/water consumption are not concerned with the initial allocation of water or how much is the amount that needs to be removed from the source to make feasible the productive activity as long as it is later returned. In this strand of the literature minimizing ’water demand’ or ’water use’ implies choosing the technology/process which minimizes the evapotranspiration.

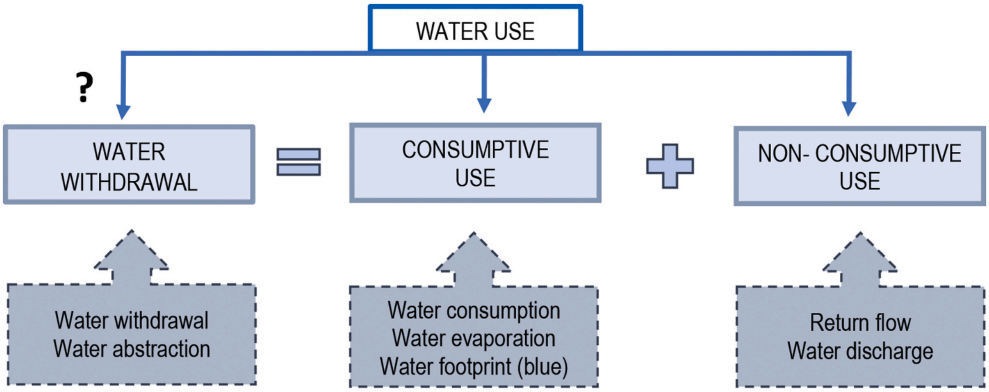

Fig. 3. An overview of water terminology and related indicators.
Source: own elaboration.

Table 2
List of basic terms, definitions, and practical relevance.

Term	Definition	Relevance
Water withdrawal	The volume of freshwater abstraction from surface or groundwater for a purpose	Measurement of opportunity cost. Although the quantity of water withdrawn is subsequently returned to the aquatic environment, the water withdrawn is no longer available at that precise place and time for other uses
Water consumption	Water consumption refers to the part of the freshwater which is not returned to the original water body (due to evaporation and/or embedding in a product)	It promotes water depletion (for aquatic ecosystems) and reduces water availability (for downstream users)
Water discharge	The part of water withdrawn and not consumed that is released back to the original water body	Water returns to the environment with deteriorated quality

Source: own elaboration. For details of the specific literature surveyed, a more comprehensive list of water assessment indicators, definitions, and taxonomies from the literature see the Supplementary Material, Table S1.

Table 3
Summary of the objectives, theoretical assumptions, indicators of interest, and questions at stake for each approach.

Approach	Goal	Optimization method	Indicators	Questions at stake	Evaluation decision
Ecological Economics	Minimise the impact of human activities (i.e., water retained in a process or product)	Unconstrained	Water footprint Water consumption Water evaporation	How much water is incorporated into a process or product?	Choose the process/technology which minimizes evapotranspiration
Environmental Economics	Maximise the number of activities that can be carried out with a given water endowment (i.e., feasibility of a process) Minimise the amount of water that makes a process feasible	Constrained	Water withdrawal Water abstraction	How much water do we initially need to make a productive activity possible (i.e., irrigating hectares of land or running a thermoelectric power plant)?	Choose the process/technology which minimizes the water costs or which maximizes the amount of output for a given water endowment

Source: own elaboration.

Papers arising from the environmental economics tradition tend to face a different optimization problem: what is the process that requires the least water to make it feasible (given that water has a monetary cost that needs to be minimized). An alternative formulation of the same optimization problem, which may be stated in quantities of water rather than in monetary units, is: what is the maximum amount of output that can be obtained given an initial amount of water (regardless of how much evaporates in the process). Environmental economists try to solve a constrained optimization problem. That is, maximising the number of activities human beings can conduct with a given water endowment. In this sense, the evaluation of alternative technologies/processes are more related the technical and economic efficiency principles aiming at minimizing 'water demand' or 'water use', but here usually implying the amount of water withdrawn. Table 3 summarises the objectives, theoretical assumptions, indicators of interest and questions at stake from ecological and environmental economics.

In this context, the opportunity cost emerges as a key issue. This term, widely used in economics, refers to the cost of the alternative we renounce when we make a certain decision (given limited resources). In a context of climate change with increasing water scarcity, minimizing the amount of water that is retained in a process or incorporated into a product may become less important than minimizing the amount of water that makes a process possible. While in some cases these two objectives are simultaneously attainable, in most instances, there is a trade-off between them which may not be obvious to policy makers and water users when they seek academic advice to minimise their 'water use'.

5. Differences across the two major strains of literature: WF vs LCA

The nuances of the different WF assessment methods may generate confusion for practitioners. The Water Footprint Assessment Manual [1], presents a detailed methodology on how to assess the water footprint at the process, product, organization, consumer, group of consumers or geographic area scale. While the Life Cycle Analysis (LCA) LCA-based ISO 14046 standard, provides the normative framework focusing on the process, product, and organization level [2]. These approached define the water footprint concept differently [11]. According to Ref. [1]; the WF is an indicator of freshwater use that looks at both direct water use, and indirect water use in the supply chain of a consumer or producer. Water use is measured in terms of water volumes consumed and/or polluted and is detailed in space and time. While the ISO14046 [2] defines the WF as a metric(s) that quantifies the potential environmental impacts related to water.

Both frameworks follow a four-phase approach to the WF assessment and provide the information both on water consumption and environmental impacts: 1) Setting goals and scope, 2) Accounting phase, 3) Impact assessment phase, 4) Interpretation and solutions [12]. In the accounting phase, the WF assessments according to the ISO14046 [2], should generally include the different forms of water use, including evaporation, transpiration, product incorporation, release into different drainage basins or the sea, displacement of water from one water resource type to another within a drainage basin (e.g., from groundwater to surface water) and other forms of water use (e.g., in-stream use). The WF Assessment Manual [1], makes a detailed analysis of water consumption, complementary to the classical water withdrawal measure, considering not only the blue water consumption but also the green water consumption [1,5]. The ISO14046 does not include this concept, which is widely used in the field of water resources management. In the LCA studies, the green water is generally included as an impact of land use as it is only reachable through land occupation and it is claimed not to contribute to blue water scarcity nor to be accessible for other productive uses [13]. However, green water resources are highly variable and can also be limited and scarce and can be substituted by or act as a substitute for blue water [14] affecting blue water availability [15]. The concept of 'net green water' has also been utilized by some companies, as the difference between the water evaporated by crops and the water that would have evaporated from naturally occurring vegetation [16,17]. Large differences in estimated water footprints can occur with minor variations in the methodological approaches [18].

With respect to the impact assessment phase, the ISO standard assesses the environmental impacts related to water, leaving the economic and social impacts outside the scope of the standard. Herein lies the main gap between the two approaches. The analytical tool proposed by Ref. [1] has been developed within the water resources research community as a volumetric measure of freshwater appropriation. By contrast, the ISO 14046 LCA-based approach aims to account for environmental impacts [19]. observe for irrigated wheat production that using the scarcity-weighted WF or scarcity-weighted water use alone for policymaking, including product labelling, punishes some farmers producing their wheat in a water-sustainable way and promotes some farmers producing wheat unsustainably. Understanding the implications of both methodologies could take advantage of each other and practitioners could benefit from using these synergies in their studies [12]. They should be cautious tough when comparing quantitative indicators from both methodologies.

Finally, in both approaches, the evaluation of the WF of organizations can be approached from different perspectives, depending on the objective and scope defined by the organization. For instance, an organization may include all products or only a group of products that the organization produces; another may exclude raw materials, focusing only on the production phase; and another may exclude consumer use and end of life of the organization's products, which hinders the comparability of the results from different studies. The European Commission is developing a harmonized environmental footprint methodology to be applied at the product (Product Environmental Footprint – PEF) and Organization level (Organization Environmental Footprints– OEF), where water will be one of the 16 impact categories [20]. Table 4 summarises the most relevant aspects of each assessment method.

The connection between the present and the previous sections therefore emerges. The methodology used in the Water Footprint Assessment Manual would answer the questions posed by ecological economists. In contrast, the Life Cycle Analysis (incorporated in the ISO14046 standard and considering aspects such as water availability) would be closer to answering the questions of environmental economists.

Table 4
Differences in the definition and assessment of the water footprint according to the Water Footprint Assessment Manual [1] and the Life Cycle Analysis (LCA) based ISO14046 standard [2].

	Water Footprint Assessment Manual	LCA-based ISO14046
Terminology	Water footprint	Water footprint If the assessment is comprehensive, the term needs no qualifier. Otherwise, the term needs to be reported with a qualifier that describes what has been assessed – e.g., water scarcity footprint.
Definition	Water volumes consumed and/or polluted	Potential environmental impacts related to water
Phases	1 Setting goals and scope 2 Water footprint accounting 3 Water footprint sustainability assessment: environmental, social and economic 4 Water footprint response formulation	1 Goal and scope definition 2 Water footprint inventory analysis 3 Water footprint impact assessment: environmental 4 Interpretation of the results
Components	Green Blue Grey	Availability Scarcity Eutrophication Ecotoxicity Acidification
Addition of components	Non-additive	Inventory data (e.g., water volumes) multiplied by characterization factors. Weighting is optional.
Practical application	Process, product, organization, consumer, group of consumers, geographically delineated area (e.g., nation, river basin, province, municipality)	Process, product, organization

6. Significant inconsistencies, inadequate quantification, and misinterpretation in practice

6.1. Tracking water in agriculture

Using either water withdrawal or water consumption approaches to measure water use and efficiency in relation to irrigation water conservation technologies and management practices used in the agricultural sector has an impact on the outcomes, such as water conservation status and farmers' revenue.

The decision to evaluate water efficiency in the agricultural sector based on withdrawals versus consumption (here understood as evapotranspiration and embodied in plants) could result in different incentives and water management decisions on the ground. For instance, generally, surface irrigation requires more withdrawals to deliver water to crops per unit area, but a significant portion of that water is returned to the system, albeit often with degraded quality. Sprinkler irrigation requires less water withdrawals but can result in higher water consumption per unit area to grow an equivalent crop. This happens particularly in hot and/or windy areas, where crop evapotranspiration (i.e., beneficial evapotranspiration) and non-beneficial evapotranspiration (i.e., non-productive evapotranspiration mainly from non-productive plants –weeds or phreatophytes, direct evaporation from water bodies, wind drift and evaporation losses) are higher in sprinkler irrigation (mainly wind drift and evaporation loses) [21,22]. In the case of surface irrigation of corn, alfalfa and winter cereal production in the Ebro River in the north of Spain, the actual evapotranspiration is lower than the potential evapotranspiration exposing plants to water stress [22]. This means that, in certain cases, increasing agricultural efficiency based on water withdrawals alone could increase water consumption and depletion.

Likewise, it is questioned whether the shift from traditional surface gravity irrigation to a 'more efficient' drip irrigation reduces water consumption in arid and semi-arid countries such as Spain, Morocco or New Mexico [23–25]. Drip irrigation tends to be associated with higher crop density, a shift to more water-intensive crops, and the reuse of 'saved water' to expand cultivated areas, resulting in higher overall water consumption or 'rebound effect' [25].

Surface irrigation is generally associated with higher water return flows, which are losses from the economic point of view. However, a large part of these 'losses' return to its source or to another surface or groundwater body, becoming available for aquatic ecosystems and reuse [26]. Measures to reduce 'losses', while maintaining existing levels of withdrawal, would increase the productive efficiency of water use, but may deprive downstream water users who depend on surface or groundwater bodies that are fed in part by the return flows [26].

Both water withdrawal and water consumption-based indicators would encourage switch to rainfed agriculture where possible. However, just green and blue water consumption-based indicators would promote better management of soil moisture (such as conservation tillage or mulching) and higher yields and productivity improvements in both irrigated and rainfed systems [27,28].

In summary, carrying out a fractional water accounting analysis, which draws attention to the relevance of return flows and differences between water consumptive use (beneficial and non-beneficial) and non-consumptive use (recoverable and non-recoverable flows) in space and time (Table 5) [3,29,30], together with the green water footprint analysis [1] would provide a more complete picture. Fractional analysis draws attention to the inter-connectedness of hydrological systems, as increasing consumptive water use in one part of a catchment or basin can impact on water users and uses elsewhere in the basin [3].

Table 5
Water accounting framework: Water use fractions of the water use fractional analysis.

Water use fractions	Definition
Water withdrawals:	Any water removed from surface or groundwater bodies for any use
1. Consumed fraction:	Water converted to vapor through plant transpiration and evaporation
1.1. Beneficial consumption	Water that is purposefully converted to water vapor, such as through crop transpiration
1.2. Non-beneficial consumption	Water that is not purposefully converted to water vapor, such as through transpiration by weeds or evaporation from wet soil
2. Non-consumed fraction:	Return flows
2.1. Recoverable return flows	Water reaching a useable aquifer or stream with down-stream demand
2.2. Non-recoverable return flows	Water flowing without benefit to a sink such as the sea, saline sink or heavily polluted aquifer, and therefore not useable

Source: [26,30,55].

6.2. Tracking water for energy

Energy represents the second thirstiest sector worldwide after agriculture. Water withdrawals for energy production are estimated at 583 billion cubic meters (about 15% of the world's total withdrawals), of which 66 billion cubic meters are consumed [31]. Since 90% of global power generation is water intensive, water implications of different electricity generation technologies have been widely addressed in the literature [32–36]. Studies assessing the volumes of water needed for energy production make use of different water-related metrics, methods, and terminology resulting in significant inconsistencies, which hinder a proper quantification and lead to misinterpretations of the outcomes [37].

The correct use of terms has significant implications on the estimation of water volumes of energy production. For example [38], used recent research on water use in the US energy system as a case study and showed that minor changes in the definition of 'water consumption' may change the consumptive water volumes estimated in previous works by −50% (when considering only fresh water, assuming that transfers are non-consumptive, and assuming that combustion water is a consumptive offset) to +270% or +4000% (when including green and grey water, respectively), without changes in the underlying data. Likewise, water-use terminology often differs among state agencies and, occasionally, water-use terminology adopted by a same institution changes even over time, resulting in differences in different measurements.[1]

The lack of publicly, complete, consistent, and updated official statistics is another barrier to proper water use accounting [39]. Even though in some regions the power sector is the largest water-use activity, national statistics on water use by individual power plants are characterized by inconsistencies and gaps. In general, the inconsistency, incompleteness, and age of individual estimates of water intensity may prevent a correct inventory of overall water use [40]. And, as well as the lack of sources of information containing data on cooling system configuration, the most important characteristic governing the water use of a power plant together with the fuel type [41,42]. [43] also confirmed the existence of data gaps among international studies for factors driving water footprints (e.g., resource quality, power plant specifications, and environmental conditions), with most values coming from assumptions and other publications, rather than direct measurements. Furthermore, they found no evidence of increased reporting of these factors over time. According to Ref. [44], the available data on thermoelectric water use in the U.S. are self-reported by plant operators, whose techniques for measuring water flows are not standardized. For its part, the United States Geological Survey (USGS) reports water withdrawals for thermoelectric power production every five years and consumptive water use has only been reported since 1995. Another official agency such as the U.S. Energy Information Administration (EIA) provides energy statistics on an annual basis but omits data on nuclear installations and some natural gas-combined cycle technologies [45]. Additionally, all those thermoelectric power plants with generation capacities of less than 100 MW are not required to report water use to the EIA. Furthermore, in 2010 almost half of the installations that were required to report water consumption failed to do so or reported zero consumption [46]. In Spain, one of the most arid countries in Europe, annual data on water uses at power plant level were only available from mid-2000, when Spanish law made it compulsory for electricity companies to publish environmental reports certified by the Eco-Management and Audit Scheme (EMAS). Yet, data on water uses provided by electricity companies are usually estimates and not direct measures from primary sources and, in most, cases these reports usually neither specify the accounting methodology used nor report data on both aspects of water use -i.e., water withdrawal and water consumption [47]. Also noteworthy are the reviews focusing on water consumption but omitting withdrawals for many of the energy processes [32,48–50]. Finally, the thoughtless use of old data sources may also result in *echo-chambers*, which alludes to amplification and repetition of information within closed network, and leads to biases, intensification of viewpoints and analyses based on incompatible data [51]. Therefore, setting common standards by reporting consistent terminology and making sufficient and updated data available is crucial for the correct calculation of water uses for electricity generation and to translate into better political decision-making in the water and energy sectors.

Finally, the use of common criteria methods for analysing water-energy (and food) trade-offs and addressing complex resource and development challenges remains limited [52]. Likewise, the choice of the most appropriate indicators to measure the desired phenomenon according to the geographical location and thereby hydroclimatic conditions takes special relevance for water policymaking. Is the consumptive use of water always the most important aspect? Significant volumes of water must constantly pass through the systems of thermoelectric power plants to ensure their operation regardless of whether these are ultimately consumed in the cooling processes. Generally, studies conducted from water-abundant countries tend to pay attention to consumptive use of water. However, arid and semi-arid countries lack sufficient water in the summer months of the year, limiting the regular operation of such facilities. Both water withdrawal and consumption values are important indicators for water managers determining power plant impacts and vulnerabilities associated with water resources, but the indicator of water withdrawal might prevail over that of water consumption when making policy decisions in water-stressed countries.

7. Discussion

Most of the institutions and academics tracking water aim at providing better short and long-term strategies to cope with vulnerability and resilience in future water stress scenarios. Indicators have been shown to have a significant influence on societies in general, but also specifically in the case of policymaking [53,54]. Yet, from the revision of concepts and indicators we have undertook

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[1] The series of USGS water-use circulars published from 1950 to 2015 represent a clear example of how water-use terminology has evolved over time (available online at: https://www.usgs.gov/mission-areas/water-resources/science/water-use-terminology?qt-science_center_objects=0#qt-science_center_objects).

in the forgone sections several ambiguities emerge that complicate the adoption of such strategies by those stakeholders for whom water is an essential asset. When the concepts and indicators about water are far removed from the daily experience of those that must decide which technology/technique to apply, it is likely stakeholders ignore the academic recommendations. A typical irrigator in an arid region would have serious difficulties understanding why the water footprint of sprinkler irrigation is greater than that of open-furrow irrigation, when the first technique allows him to irrigate a much larger area by extracting a quantity of water several orders of magnitude smaller than the second technique. By the same token, the manager of a thermal power plant in any arid country would prefer any cooling system that minimizes the overall water volumes required to pass through their system than a cooling system that minimizes the evaporation if that requires far more water to pass through the cooling system (volumes that may not be available during the dry season). In both these cases the stakeholders would ignore the technique/technology that reduces 'water consumption' (defined as evapotranspiration/embodied water) in favor of techniques/technologies that guarantee the output. When the water indicators and recommendations have additional implications, such as product labeling, further caution is due and the use of complementary indicators advised, including fractional analysis.

There is no one truth but a combination of good principles, and both withdrawals and consumption are relevant. The water footprint assessment is important but not enough: withdrawals must also be accounted and reduced (even if eventually a part of the water withdrawn returns to the water environment) for the following reasons: 1) to reduce non-beneficial consumption and evaporation associated to inefficiency; 2) to raise awareness of water use efficiency/individual responsibility of users; 3) to keep water in aquifers and rivers (if not needed): downstream users will have it available from the original source (aquifer or river) and avoid reuse; 4) to manage pollution better: the more water is used and discharged the more is degraded quality; 5) energy use is connected with the raising share of groundwater irrigation globally: the energy crisis goes together with freshwater crisis in heavy energy consuming regions.

The solution can be different from place to place, depending not only the different temporal and spatial scales, but also sectors and climatic conditions: the type of water availability during the yearly water cycle and most efficient and beneficial use of it. It is all about not using water if you do not need it. Understanding the socio-economic and environmental limits through the year at the local and basin context is also crucial for understanding the incentives of the water stakeholders. The appropriateness of a technology depends on the local situation and the resources available. Academic recommendations should avoid being normative: what is appropriate in a water abundant scenario may not be so in an arid setting. Academics, analysts, and institutions tracking water for human uses must strive to contextualise the implications of their results and recommendations.

In order to establish mechanisms for ensuring policy coherence across the water accounting methods, the data recollection and the precision of the definitions and calculations shall be enhanced. Water audits are a starting point to benchmark its status, measure usage and identify areas for improvement in both the demand and supply sides.

A final note of caution: the cross implications for the rest of environmental footprints. One must bear in mind the fact that some of the issues this paper rises about the water footprint also apply to other footprints (data availability, definition/calculations inconsistencies and usability for end users in particular). But more importantly, one should consider the existence of trade-offs across the different footprints: technologies/techniques that improve the water footprint may, for instance, worsen the carbon footprint and vice versa. We require far more encompassing and holistic approaches to guide and drive informed actions that help make meaningful change and ultimately benefit people and nature.

8. Recommendations

The production of food and energy is accompanied by adverse water consequences. Academics have made considerable efforts to tackle these drawbacks in recent years. Today, many of these advances still remain impractical on the ground among other things because the messages of academics to practitioners get lost in translation. That occurs when the same wording is used to refer to rather different things, but only academics are truly aware of the nuances implied by minimizing 'water use', as it implies different things for different strands of the literature. This study suggests that considering only water withdrawal or water consumption when talking about water use might not reflect actual impacts on the water environment.

One of the world's main water problems is scarcity. Reducing water scarcity requires a full understanding and accurate measurement of current and future water flows and uses at different scales [55,56]. A first step would be accurate water accounting at a basin-wide scale, distinguishing between: (1) beneficial evapotranspiration; (2) non-beneficial evapotranspiration; (3) non-recoverable runoff/percolation; and (4) recoverable runoff/percolation [30]. Furthermore, coupling this fractional water accounting frame together with the green water footprint analysis would provide incentives for promoting better management of soil moisture both in irrigated and rainfed systems, getting higher yields and productivity improvements [27,28]. We suggest that models should include somehow water availability for proper interpretations of the water-energy-food nexus and for managing the allocation of water, as a scarce resource, among alternative uses.

However, measuring non-recoverable and recoverable flows is sometimes challenging in practice. It would be useful to test this comprehensive combination of indicators in pilot studies to show case their positive outcomes on the ground.

Accurate accounting and measurement of water use can help identify opportunities for water savings, increase water productivity, and improve the rationale for water allocation among uses [56]. However, the theoretical and empirical research shows that the production and conservation goals are generally incompatible, unless complementary water conservation policies are implemented [55]. An appropriate accounting framework must be coupled with administrative action, including an adequate register of water rights, legal actions and fines, involvement of water users in law enforcement and control, capacity building of water users to help them comply with abstraction restrictions, establishment of cross-compliance requirements in agricultural subsidies and raising awareness about the consequences of over-abstraction [56,57].

Finally, certain aspects of institutional design also need to be reconsidered. Spanish Royal Decree 198/2015, of 23 March, regulates the fee for the use of inland waters to produce electricity in inter-community demarcations.[2] However, according to this law, only *"water concessionaires whose water is intended for the production of hydroelectric power shall be liable to pay the levy for the use of inland waters for the production of electricity"*. The remaining power plants using significant amounts of water, such as conventional thermal and nuclear power plants, are not required to pay this fee. If they do not pay for the water they use, what incentive do stakeholders in the thermoelectric power sector have to make efficient use water in one of the most arid countries in Europe? The incentive system needs to be rethought to promote a more efficient and environmentally friendly water use.

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CRediT authorship contribution statement

Maite M. Aldaya: Data curation, Investigation, Writing – original draft. **Diego Sesma-Martín:** Data curation, Investigation, Writing – original and final drafts. **Mar Rubio-Varas:** Conceptualization, Investigation, Supervision, Editing - original and final drafts.

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. Supplementary data

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