

REGENERATIVE WATER MANAGEMENT ACROSS SCALES: A RETROFIT VISION FOR BIOSPHERE SUSTAINABILITY

Gestão regenerativa da água em todas as escalas:
uma visão retrofit para a sustentabilidade da biosfera

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ABSTRACT

There is a need for consistency in water management across scales and sectors, which motivated this paper to formulate a “proactive” retrofit vision seeking to integrate net-positive, sustainable and regenerative design concepts. Since the Planetary Boundaries framework is the key communication tool from scientific knowledge to political instruments (e.g., Sustainable Development Goals), water-related topics are revised accordingly. It is suggested that the role of water management in Climate Change is largely overlooked, which, in turn, is demonstrated to be the driver of change and, at the same time, impacted by these changes. Furthermore, it is demonstrated that the link between water-related carbon footprint and energy use presents the Climate Change community with a strong tool to better manage two of the most valuable resources. A new approach is suggested by distinguishing water quality, quantity, and water state. So that beyond qualitative and quantitative goals, the physical state of water, which depends on hydrogen bonding, should help improve water management across scales. Understating water complexity shall facilitate communication raising awareness that every action creates a legacy. Overall, this study strengthens the idea that science-based strategies require better communication where biogeochemical science may serve a model to make knowledge more available to educators and policymakers.

Keywords: water-related carbon footprint, molecular water structure, socio-ecological regeneration.

RESUMO

Há uma necessidade de consistência na gestão da água em todas as escalas e setores, o que motivou este artigo a formular uma visão de retrofit “proativa” que busca integrar conceitos de design positivo, sustentável e regenerativo. Uma vez que a estrutura das Fronteiras Planetárias é a principal ferramenta de comunicação do conhecimento científico aos instrumentos políticos (por exemplo, Objetivos de Desenvolvimento Sustentável), os tópicos relacionados à água são revisados de acordo. Sugere-se que o papel da gestão da água nas mudanças climáticas seja amplamente esquecido, o que, por sua vez, demonstra ser o motor da mudança e, ao mesmo tempo, impactado por essas mudanças. Além disso, é demonstrado que a ligação entre a pegada de carbono relacionada à água e o uso de energia apresenta à comunidade da mudança climática uma oportunidade valiosa para gerenciar melhor dois dos recursos mais valiosos. Uma nova abordagem é sugerida distinguindo qualidade, quantidade e estado da água. Assim, além das metas qualitativas e quantitativas, o estado físico da água, que depende das ligações de hidrogênio, deve ajudar a melhorar o gerenciamento da água em todas as escalas. Entender a complexidade da água deve facilitar a comunicação, aumentando a conscientização de que cada ação cria um legado. No geral, este estudo fortalece a ideia de que estratégias baseadas em ciência requerem uma melhor comunicação, onde a ciência biogeoquímica pode servir de modelo para tornar o conhecimento mais disponível para educadores e formuladores de políticas.

Palavras-chave: *pegada de carbono relacionada à água, estrutura molecular da água, regeneração socioecológica.*

INTRODUCTION

Natural water cycles are essential to the sustainability of biosphere, cultural, social-ecological, and industrial systems. However, water resources are subject to and an integral part of global change and globalization (Hoff, 2009). There is growing evidence that human impact on water systems is already reached a biosphere scale where water management in one region may have far-reaching consequences in the global water system. As Hoff puts in his paper “Interdependencies of water resources with other ecological and social systems exist at all spatial scales” (Hoff, 2009). Therefore, water management and governance shall evolve into holistic systems addressing cross-scale and cross-sectorial impacts. It is crucial to unravel interdependencies of water resources at all spatial scales from molecular structure of water to its role in the biosphere to adapt properly to Climate Change challenges.

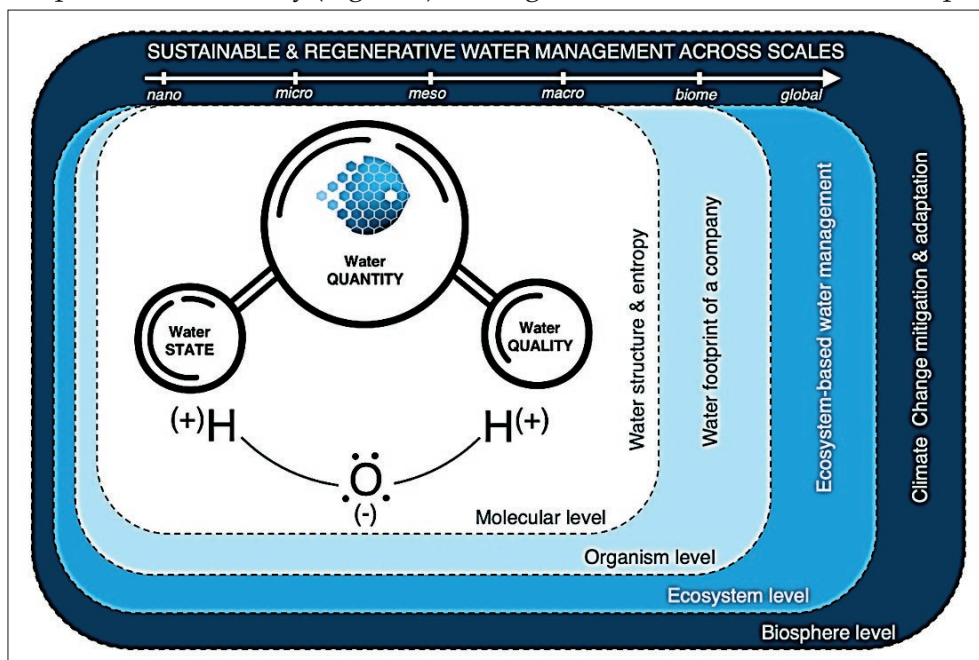
Current water management has pushed about 1 – 3 billion people into water scarcity (Hoff, 2009). The World Economic Forum’s Global Risks Report consistently lists water crises among the highest impact global risk (WEF, 2016). To mitigate the risk, countries have collectively agreed to achieve 17 Sustainable Development Goals (SDGs) by the end of 2030 (Randers *et al.*, 2019; Gupta & Vegelin, 2016), which should be supported by scientific knowledge, evidence-based policies, and active involvement of society. The Goal 6 (Clean Water and Sanitation) and Goal 14 (Life Below Water) are directly related to water issues with respect to water quantity and quality. Whereas, other SDGs, such as Goal 3 (Good Health and Well-being), Goal 7 (Affordable and Clean Energy), Goal 9 (Industry,

Innovation and Infrastructure), Goal 11 (Sustainable Cities and Communities) and Goal 13 (Climate Action) are, in turn, impacted by water management practices.

The environmental pillar of SDGs is based on a scientific framework of Planetary Boundaries (Rockström *et al.*, 2019). The framework was developed in collaboration between interdisciplinary scientists to define precautionary boundaries for major anthropogenic perturbations to avoid irreversible changes in Earth-system functioning that would generate risks for biosphere sustainability. A set of quantitative and qualitative parameters are summarized within the concept to create measurable control variables and set these limiting boundaries. The aim of the Planetary Boundaries is to define a global ‘safe operating space’ for humanity and adjust business and political actions, accordingly.

Environmental indicators of Planetary Boundaries urge that the biosphere integrity and the biogeochemical flows are already in the high-risk zone, which compromises global sustainability (Steffen *et al.*, 2015; Gupta & Vegelin, 2016). As a result, the decade from 2020 to 2030 is dedicated to numerous projects on ecosystem restoration (Dudley *et al.*, 2020). For example, new initiatives aim to unite more than 150 countries by participating in the Decade of Ocean Science for Sustainable Development and the United Nations Decade on Ecosystem Restoration (Ryabinin *et al.*, 2019). In this regard, the Planetary Boundaries framework is one of the key communication tools from scientific knowledge to political drivers on water management.

There are both quantitative and qualitative water issues addressed by the Planetary Boundaries including “Freshwater use”, “Biogeochemical flows”, “Water acidification”, and “Chemical pollutants”. However, the global water system is so complex, with highly interdependent and connected feedbacks, that biosphere sustainability is still far from being clearly understood. For example, the Planetary Boundary of “Climate change” is not considered as a water management issue whereas water state, such as gaseous water vapor, is one of the strongest greenhouse gases (Tuckett, 2019). So that additionally to water quality and quantity, it is highly relevant to consider a third parameter of “water state” to assess biosphere sustainability (Figure 1) starting from a molecular level of water properties.



The future of water security must be held accountable and coherent (consistent and coordinated) in water management across scales and sectors. It has motivated this paper for a 'proactive' retrofit vision, which seeks to integrate net-positive, sustainable, and regenerative concepts into water management. Water-related Planetary Boundaries are reviewed by distinguishing whether there is an issue of water quality, quantity, or of water state. This approach provides a new system for classification of potential changes in water management strategies that fall within the range of socio-ecological, political, economic, and administrative contexts.

Water quantity within planetary boundaries

One of the nine Planetary Boundaries is called "*Freshwater use*", which is defined as the consumption of blue water with its limit of 4,000 km³/year globally (Rockström *et al.*, 2019). It is crucial to highlight that water resources are not spread evenly nor in spatial (around the world) or temporal (over the year) scales. Depending on the microclimate and local landscape specifics (hydrology, geology, topography, etc.), the withdraw boundary for freshwater can be significantly higher or lower. This is acknowledged in the recent study of Nash *et al.* (2017), which suggests reconsidering the boundary water volume value with respect to the concept of environmental water flows. It defines the level of river flows for different hydrological characteristics of river basins adequate to maintain a fair-to-good ecosystem state.

On one hand, the concept of planetary boundaries draws attention to the criticality of freshwater use for agriculture, industrial and household consumption. On the other hand, such quantitative assumption could have contributed to the false paradigm that the net water volume is more important than water mass balance within specific ecosystems. Water is a unified and continuous polymorphous self-organizing system. Being the oldest matter on our planet, water exists in a variety of physical states creating *the unified planetary body of water*. According to thermodynamics, water facilitates the exchange of energy and matter within open environmental systems and, thus, its mass balance plays a crucial role in the sustainability of the biosphere.

A great caution must be taken when using this global quantitative value as an indicator for the sustainable use of freshwater from rivers, lakes, reservoirs, and groundwater systems. When water mass balance is neglected, the Planetary Boundary of "Freshwater use" could pose a long-term risk to water availability. Therefore, additionally to net water volume withdrawals, anthropogenic perturbations to *water mass balance* shall be considered as a limiting factor to reconsider water management solutions.

For example, the bottled-water boom supported by Nestlé has been criticized to disbalance public water resources in Michigan. Although bottled water represents less than 1% of Michigan's groundwater consumption, dwarfed by agriculture (39%) and public waterworks (26%), it is important to keep in mind that bottles are being distributed out of the Great Lakes basin, thus, this water is lost for the local watersheds (Barrows, 2017). As a water management strategy, the Great Lakes Compact was signed in 2008 by all 8 Great Lakes States to prevent water losses and imbalance. In contrast to the natural resource law, groundwater, surface water, and Great Lakes tributaries are finally treated as a single ecosystem (Karkkainen, 2012). This supports the vision of the unified planetary body of water.

Another issue in water management of Michigan area is *water privatization*, which allows any private property owner to withdraw water from the aquifer directly for free. Whereas the selling price of bottled water is about 240 times higher than its production cost. As a result, Nestlé profits upwards of \$1.5 million each day by withdrawing hundreds of millions of gallons of groundwater per year (Barrows, 2017). However, water is essential to all life and, thus, cannot be substituted like other goods as prices rise and fall. With the current pace of modern globalization moving faster than the understanding of coherent science, are we creating an irreversible path where privatizing water is restricting the possibility of affordable access to clean drinking water and a future of sustainability?

With respect to global water management, it is crucial to revise the concept of *water renewability* both as water and energy sources. This concept comes from the potential ability of the biosphere for self-regeneration over a specific time scale depending on the availability of natural resources and ecological dynamics of a particular area. It has to be taken into account that on a scale of human lifetime, there are numerous biophysical limits to renew natural resources, including water overconsumption and contamination (Meadows *et al.*, 1972). As a result, water resources are becoming scarce and non-renewable. The United Nations and the World Bank predict widespread water shortages worldwide by 2030, when 3 billion people will not have consistent access to clean, affordable water. Today, 44 countries depend upon other countries for more than 50% of their water, and 45 countries do not have the sufficient 1000 m³ per person per year of water needed to sustain modern life and ensure agricultural production (Water scarcity, 2014).

Nevertheless, following the false concept of water renewability on a human lifetime scale, the old-style hydropower is still considered as the most sustainable and renewable source of energy. Large dams and their reservoirs currently hold about 8,300 km³ of water and total water withdrawals reach 4,000 km³ yr⁻¹ (Chao; Wu & Li, 2008), slowing down natural rate of water flow and limiting water renewability in both quantity (water recharge) and quality (self-purification capability). Although water quantity could be considered less impacted by hydrological constructions, water quality is detrimentally impacted all over the world. Degraded water quality is one of the chief concerns (Li *et al.*, 2019). One of the reasons is that organic materials from within and outside the river that would normally wash downstream get built up behind dams and start to consume a large amount of oxygen as they decompose leading to eutrophication and triggering toxic algae blooms.

It is suggested in this study, that the old-style hydropower shall be critically revised and its potential to be so-called “green energy” assessed according to local environmental conditions. For example, an international movement on removing dams in many countries (Hart & Poff, 2002) has already been started being inspired by clear scientific communication on ecosystem degradation (Li *et al.*, 2019). Over 1000 dams across the United States (U.S.) have been removed to date according to American Rivers (www.americanrivers.org). And the biggest dam removal project in history is now well underway in Olympic National Park in Washington State where two-century-old dams along the Elwha River are coming out.

To consider water as a renewable source of energy, hydropower design shall be upgraded to release stress from the rivers. This could be done by following the principles of Dynamic Hydro Power by Viktor Schauburger (Frolov, 2018). Other modernizations of old-style hydropower are possible by the innovations based on the re-design of water turbines of Austrian professor Viktor Kaplan to reduce water volume withdrawals, while maintaining river flows. These technologies are proven to be environmental-friendly and

are available from a variety of European companies (e.g., Hydroergia in Poland, www.hydroergia.pl).

Water management practices that do not account for the actual biocapacity of water resources to be renewable with the focus on an appropriate time-scale lead to *desertification*. One of the most striking examples of improper water management driven by the false concept of water renewability that led to desertification is the use of the Aral Sea basin for the irrigation of cotton fields. Up until the 1960s, the former Aral Sea was the world's fourth-largest inland body of water, covering 26,000 square miles. The huge demand of water for the crop made it necessary to build irrigation canals that drew water from the Syr-Darya and the Amu-Darya, the two rivers feeding the Aral Sea. The sea existed for five centuries and only within fifty years of exploitation, it turned into a new desert of Central Asia that local people call Akkum (Gaybullaev; Chen & Gaybullaev, 2012).

The environmental health of rivers has a direct impact on the health of people. Nowadays, sandstorms carry toxic dust of pesticides contaminating crop fields and causing respiratory problems, as well as cancer, over the distance of hundreds of kilometers away from the former Aral Sea. Elevated concentrations of dioxin and dioxin-like compounds have been found in fish, sheep, milk, and eggs. Carrots and onions, which are important for the local diet, have been shown to contain high amounts of chlorinated organic pesticides (Wahler & Dietrichs, 2017). The entire region is experiencing detrimental changes in the ecosystem health and services.

Moreover, the false concept of water renewability directly causes Climate Change. An example of the Aral Sea demonstrates that artificial drying led to profound changes in the local climate. Winters have become increasingly harsh and summers increasingly scorching with temperatures close to 50 °C. With the disappearance of rivers discharging into the Aral Sea area, drinking water became a highly valuable resource. Water access being the most critical condition for human well-being is now restricted. Water shortage is already causing fecal-oral transmission of diseases, such as hepatitis A and diarrhea, which is leading to the infant death rate twice higher than that of neighboring areas (Wahler & Dietrichs, 2017).

The changes in climate are also observed globally with increased runoff by almost 2000 km³ yr⁻¹ (Rost *et al.*, 2008; Hoff, 2009). In most of the cases, it is caused by improper water management during the conversion of natural ecosystems to artificial croplands. In India, the rapid development of irrigation based on groundwater withdrawals has increased 113-fold between 1950 and 1985. This led to increased evapotranspiration by about 340 km³ yr⁻¹ or 17% above pre-industrial levels (55% in the dry season) (Hoff, 2009). Changes in local water system balance led to the corresponding changes in mesoscale atmospheric circulations and climate that destabilized the region's monsoon system (Douglas *et al.*, 2009), upon which hundreds of millions of people depend for their water supply (Hoff, 2009).

By analyzing the Planetary Boundary of "Freshwater use", we questioned the issues of water privatization, renewability, and imbalance that so far have been overlooked from local to global scales. To summarize these water-related modern concerns, we suggest introducing a new concept of "*hydrological (water) half-cycle*" demonstrating the impact of humans on a global water cycle and climate. This concept highlights that instead of a continuous and complete water turnover around the world through the processes of evaporation, evapotranspiration, condensation, precipitation, run-off, infiltration and percolation, the modern water cycle is severely disrupted, incomplete, and imbalanced.

Understanding this may navigate potential changes in water management strategies and regulatory protocols.

Additionally, to changes in water quantity, water half-cycle leads to the changes in water quality on a molecular level since water structure, which is defined by hydrogen bonding, is not regenerated through required water phase changes from solid to liquid and to gas (as discussed further in this study). Overall, it is suggested in this study that in the 21st century on a timescale of one human life, water shall be considered as a non-renewable resource. Appropriate changes in Climate Change policies regarding water renewability in terms of both energy and water resources are highly advisable. Further investigations are urged to regenerate the balance of the water cycle to mitigate Climate Change.

Water quality within planetary boundaries

There are numerous Planetary Boundaries that directly and indirectly address water quality issues crucial for biosphere sustainability. Although, both water quantity and quality are highly interrelated, it is still worth emphasizing the difference. For example, Planetary Boundary of the “*Biogeochemical flows*” defines two chemical elements controlled by the concentrations of phosphorus (P) and nitrogen (N) (Rockström *et al.*, 2019). The availability of these essential nutrients is used as an indicator of primary biomass production and, thus, the trophic status of a water body.

When nutrient concentrations are too low, the aqueous system is considered to experience oligotrophic conditions. So that there is slow growth, low rates of metabolism, and generally low population density. Whereas elevated concentrations lead to eutrophication with increased growth of plankton and algae, blooms of cyanobacteria, a decline in macrophyte abundance, and deoxygenation of water causing fish death. Therefore, the goal is to prevent water contamination by P and N to protect biodiversity on land and in the sea. The boundary limit for anthropogenic P going from the land into the oceans is taken as 11 million tons per year. Whereas the mass of anthropogenic N is taken as a removal of natural N from the atmosphere with the limit of 35 million tons per year.

As it is set by now, the concept of nutrient masses has been selected to define the key water quality parameters as a planetary boundary. However, there is increasing evidence that the biogeochemical flows are largely controlled by the ratios between the elements rather than by their individual concentrations (Moore *et al.*, 2013). For example, the most known “Redfield ratio” between carbon (C), nitrogen (N) and phosphorus (P) is 106C: 16N: 1P (Redfield, 1958). This ratio varies between ocean and inland waters being influenced by species composition (e.g., eukaryotes, prokaryotes, diatoms), temperature, organic matter inputs (quality, quantity), light - nutrient ratio, total P, chlorophyll, particulate organic carbon - chlorophyll ratio and water residence time (e.g., Martiny *et al.*, 2013). Therefore, it is suggested to include monitoring data on nutrient ratios for water management protocols.

Additionally, to N and P, other macro- and micro-nutrients are essential parts of the biomass stoichiometry all together defining ecosystem health. This includes carbon (C), iron (Fe), and silicon (Si). Although the biogeochemical cycle of C is partially managed within the Planetary Boundary of “*Climate Change*”, the role of C on water quality is overlooked by the policymakers leading to incomplete environmental assessment and limited decision-making for water management. With regard to Fe, its concentrations are found to limit the photosynthesis in the Southern Ocean, where only a fraction of the C and

other nutrients that return to the surface are consumed for potential sequestration in the deep sea (Robinson *et al.*, 2014). Therefore, nutrient ratios between not only N and P, but also between C, Fe, and Si shall be considered within the Planetary Boundaries of “Biogeochemical flows”.

Beyond nutrient composition, water quality is also defined by the presence of a variety of contaminants, which are referred to as a Planetary Boundary of “*Chemical pollutants*”. Plastic and microplastic are becoming emerging water pollutants both in fresh and seawater. This synthetic material is so widespread throughout the environment that plastic is now considered as a geological marker of the Anthropocene (Villarrubia-Gómez; Cornell & Fabres, 2018). Most of the world’s ocean plastics enter the ocean via rivers and coastlines (80%) with the rest coming from marine sources, such as fishing nets, ropes, and fleets (20%) (Li; Tse & Fok, 2016). On the other hand, microplastic comes from hidden sources embedded in the beauty industry, cleaning products and washing polymer (synthetic) clothes (Gallagher *et al.*, 2016). The boundary concentrations of microplastic are not yet quantified to guide biosphere sustainability.

Other synthetic or anthropogenic entities released into the environment that pose risk to biosphere sustainability include persistent organic pollutants (POPs) and heavy metals. Synthetic organics are extremely prone to environmental degradation through chemical, biological, or photolytic processes. Many POPs are currently or were in the past used as pharmaceuticals, pesticides, solvents, and industrial chemicals. The environmental impact of such water pollutants is being under intense investigation; however, the subject remains complex, and it is very complicated to reach conclusions nor consensus, due to the lack of analytical methodologies and expertise (Villarrubia-Gómez; Cornell & Fabres, 2018). Therefore, as of today, no quantitative limits are set as indicators of planetary boundaries.

Beyond mentioned anthropogenic water contaminants, there is a big variety of chemical pollutants that are not routinely measured and monitored at the wastewater treatment plants. The sewage discharge creates detrimental environmental conditions for the accumulation of toxic compounds bound to suspended organic matter. For example, polycyclic chlorinated biphenyls (PCBs) and polybrominated diethyl ethers (PBDEs) are found in the Río de la Plata, which is the source of drinking water for the city of Buenos Aires (García-Alonso; Lercari & Defeo, 2019). However, no quantitative limit is yet globally set to protect human health and well-being.

Another concern is endocrine disruption in water systems, which is already a worldwide phenomenon. Estrogen in birth control pills and other chemicals that mimic natural hormones in trace amounts (as low as one part per trillion) are known to impact fish health (Hicks *et al.*, 2017). In most cases, these concentrations are below of what conventional wastewater treatment can typically remove. Despite that, there are successful examples demonstrating how timely changes in water management in response to scientific findings can rapidly regenerate the ecosystem health of a river.

Canada is one of the most unique examples with its case study of collaboration between the Kitchener Wastewater Treatment Plant (MWWTP) and the Department of Biology at the University of Waterloo. Since 2007, the population of rainbow darter fish was found to experience changes in the number of intersex male species. This could indicate a result of exposure to natural and synthetic hormones in water, which causes male fish to grow eggs in their testicles. At some point, the rate of intersex changes in the Grand River was one of the highest in the world (Hicks *et al.*, 2017).

Following scientific recommendations of the Mark Servos' group, in 2012, the MWWTP was upgraded with a new aeration tank. The upgrade was based on currently available technology and did not require extremely expensive tertiary treatments. These changes were based on the replacement of a carbonaceous activated sludge to the nitrifying activated sludge treatment process. As a result, already within one year, the proportion of intersex males dropped from 100% in some areas to 29%. A full recovery of the fish population was achieved within 3 years of modified water management (Hicks *et al.*, 2017).

This example demonstrates that water management practices can be upgraded to facilitate immediate changes in biological responses at a reasonable cost. Considering the tremendous cost of wastewater infrastructure most chemical wastewater plants today still employ archaic principles built during the 1900s comprise eroding infrastructure. Chemical wastewater plants today remain the dominant source of PCBs, toxic compounds, and oxygen depletion. If not removed efficiently, anthropogenic contaminants leach into aquifers and the Ocean. Freely dissolved PCBs are orders of magnitude far exceeding the safe threshold for human consumption accumulating in drinking waters (Alava *et al.*, 2018; Needham & Ghosh, 2019).

Overall, this is important to recognize the need to support changes and responsible modernization of water treatment practices. For example, old-style chemical-based methods for disinfection can be substituted by non-chemical technologies based on the physical properties of water structure and state (e.g., resonance- and frequency-based methods). Moreover, to become more efficient in wastewater treatment, local environmental conditions must be examined within a specific context of interrelated biogeochemical reactions with a complex interplay between elements. It has been demonstrated that the same contaminants behave differently depending on the co-existence of other contaminants (Markelova *et al.*, 2018). Since there is a great diversity of substances released to the environment and high uncertainties in their individual and interacting behavior, a quantitative planetary boundary cannot be set globally. Further area-specific investigations are needed worldwide.

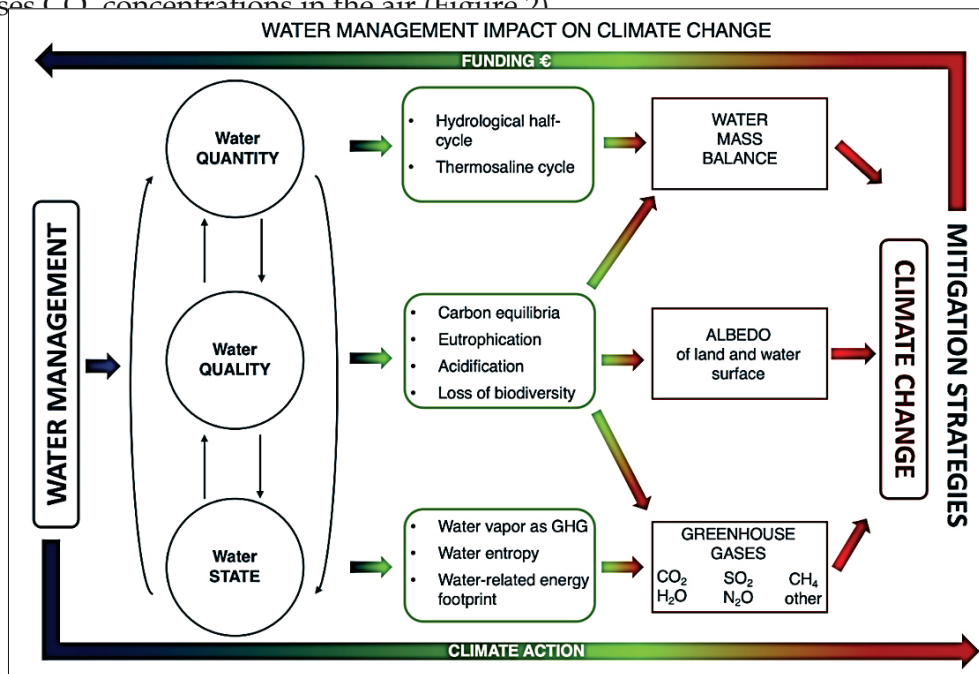
The concept of Planetary Boundaries provides a global status of the environmental situation and to some extent has a strong influence to navigate government officials and respective funding opportunities for restorative projects. However, great caution must be taken for not extrapolating scientific data over temporal and spatial scales. Water management practices have to "think global but act local" with respect to not only environmental conditions, but also the overall context of the natural system, where local culture and social systems are an inevitable part of it. The content of local products and the lifestyle of citizens impact and to some extent even define water quality in natural systems. Therefore, a "*socio-environmental context*" of any specific local area is recommended as a complimentary chapter to water management protocols.

Water state and climate change

The Planetary Boundary of "*Climate Change*" is probably the most famous among the public (Rockström *et al.*, 2019). Due to the extremely high complexity of the topic, it is recommended to distinguish causes and effects of Climate Change. For example, the key effects include warmer temperatures of the global ocean, water acidification, and oxygen depletion from the atmosphere. According to the Intergovernmental Panel on Climate Change (IPCC, 2019), there is medium confidence that the oxygen content of the upper

1000 m has declined with a loss of 0.5-3.3% of total (100%) oxygen in the atmosphere between 1970-2010. The key reason is the increase in the ocean stratification, which is changing ventilation and biogeochemistry reaction network fueled by oxygen. As to the water temperatures, it is virtually certain that the global ocean has warmed unabated since 1970 and has taken up more than 90% of the excess heat in the climate system. Moreover, the eutrophication of natural waters leads to the decrease of surface albedo also contributing to warmer temperatures. In turn, the increase of albedo by healthy algae and phytoplankton is considered as a Climate Change mitigation method (Raven, 2017).

The decrease of water pH is such a widespread phenomenon that there is an individual Planetary Boundary of “*Water acidification*”. On one hand, it is an effect of Climate Change due to higher uptake of carbon dioxide gas (CO₂) from the atmosphere to the Ocean. Carbon dioxide reacts with water in solution to form the weak acid, carbonic acid (H₂CO₃), which further disassociates into hydrogen ions (H⁺) and bicarbonate ions (HCO₃⁻). And on the other hand, there is a feedback loop causing Climate Change due to decreased oxygen production by phytoplankton under lower pH. The loss of biodiversity due to both eutrophication and acidification decreases the capacity of natural waters for carbon uptake. It alters chemical equilibria between the atmosphere and the Ocean that increases CO₂ concentrations in the air (Figure 2)



The carbon footprint of anthropogenic activities has been identified as a major contributor to Climate Change (Mikhaylov *et al.*, 2020). Nevertheless, there are still a vast number of uncertainties in the causes of this phenomenon. For example, until very recently, the scientific concept of Planetary Boundaries has been based only on the terrestrial point of view, which has led to significant underestimations of the role of the Ocean in Climate Change. Recent findings of Nash *et al.* (2017) demonstrate that when adding a marine perspective into account, we obtain a better understanding of Climate Change, stratospheric ozone depletion, ocean acidification, freshwater use, and earth surface change.

Since Climate Change has numerous feedback loops with other planetary boundaries (Steffen *et al.*, 2015), its causes must be further investigated and re-evaluated with respect to water management. The unravelling hidden causes of Climate Change and taking appropriate actions are considered as one of the greatest challenges the society must face in the coming decades (McEvoy; Fünfgeld & Bosomworth, 2013). In this study, we attempt to lay the foundation for the impact of water management on Climate Change, which could support the development of respective mitigation practices (Figure 2).

There are both positive and negative feedback loops between water management and Climate Change. The role of water quality and quantity on Climate Change has been discussed earlier within this study. For example, urbanization reduces catchment permeability and increases surface water runoff, which prevents water from going through its full cycle and results in only a half-cycle of water. On one side, the hydrological half-cycle reduces opportunities for water to be managed naturally with the potential for self-purification (water quality) and flooding prevention (water quantity). On the other hand, it increases the concentration of *water vapor* (H_2O_g) in the atmosphere (water state), which is itself a powerful greenhouse gas (Tuckett, 2019).

Therefore, it is suggested to add the role of water state additionally to the management of water quality and quantity. Gaseous phase of water can be further evaluated as one of the causes and effects of Climate Change. Once in the atmosphere, elevated concentrations of water vapor prevent heat to escape from the Earth back into space, which is essential to cool down the surface's temperature, otherwise, leading to Climate Change. Nevertheless, the mitigation actions are still overlooking the impact of water vapor and focusing mainly on other greenhouse gases, such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), ozone (O_3), sulfur dioxide (SO_2), and some artificial chemicals such as chlorofluorocarbons (CFCs).

Recent calculations estimate that water vapor gas accounts for about 50% of the Earth's greenhouse effect, with clouds accounting for 25%, carbon dioxide for 20%, and minor greenhouse gases and aerosols for the 5% remaining (Schmidt *et al.*, 2010). Therefore, water vapor can be considered as the major greenhouse gas that absorbs most of the infrared heat emissions from the Earth's surface (Tuckett, 2019). However, being a highly reactive gas, the measurements of atmospheric water vapor are difficult leading to large uncertainties in published data that varies from 50 to 95% depending on meteorological conditions (Schmidt *et al.*, 2010; Easterbrook, 2016).

Water vapor is continuously being generated from evaporation and continuously removed from the atmosphere by condensation. Increasing concentrations of water vapor create more clouds, that reflect sunlight and contribute to the cooling effect of albedo. At the same time, higher water density in the atmosphere leads to warmer temperatures, which cause more water vapor to be absorbed into the air. Warming and water absorption increase in a spiraling cycle. So that the concentration of water vapor is variable in amount and not routinely measured in the atmosphere. To better understand the role of water vapor as a greenhouse gas, its monitoring could be included into water management protocols and environmental impact assessment studies.

In contrast to direct impact of water management on Climate Change via the concentrations of water vapor as one of the greenhouse gases, we suggest considering indirect impacts as well. For example, the carbon footprint of water management as the concentrations of carbon dioxide emissions embedded in water sourcing, treatment,

distribution, use and wastewater treatment (Griffiths-Sattenspiel & Wilson, 2009). The concentration of carbon dioxide (CO₂) is taken as the key indicator of carbon footprint and its boundary value of 350 ppm (by volume) is set based on the preindustrial value of 280 ppmv (Rockström *et al.*, 2019). Recent evidence suggests that Earth, now passing over 412 ppmv CO₂ in the atmosphere, has already transgressed this Planetary Boundary and is approaching several Earth system thresholds.

In this regard, the decarbonization goals (reduction of carbon footprint) could be achieved, firstly, by recognizing the magnitude of water-related energy use and, secondly, by optimizing water management systems. For example, energy savings can be achieved via water-efficient appliances and fixtures. If every household in the U.S. installed efficient water appliances that reduce hot water use by approximately 20%, this could save about 4.4 billion gallons of water per year. In turn, this would result in energy savings of 41 million MWh of electricity and 240 billion cubic feet of natural gas. In terms of carbon footprint, it would have a positive impact associated with CO₂ reductions of about 38.3 million metric tons per year (Griffiths-Sattenspiel & Wilson, 2009).

Another example of water-related energy savings is by redesigning water supply systems to eliminate water leakages and avoid losses. Just a 5% improvement of water distribution systems would save 270 million gallons per day of water and 313 million kWh of electricity annually, which is the equivalent to the electricity use of over 31,000 homes in the United States. This would result in an annual reduction of carbon footprint by 225,000 metric tons of CO₂ emissions (Griffiths-Sattenspiel & Wilson, 2009).

There is a great potential for decarbonization goals by upgrading water management across scales. Only in the U.S., water-related energy use is at least 521 million MWh a year, which accounts for 13% of the nation's electricity consumption with the corresponding carbon footprint of about 290 million metric tons of CO₂-equivalent a year (Griffiths-Sattenspiel & Wilson, 2009). Considering rapid changes in all Planetary Boundaries discussed in this study, the carbon footprint of water management is expected to continuously increase due to several reasons. Reduced availability of freshwater resources caused by Climate Change, longer distances for water supply systems, and old-style wastewater treatment technologies are among them.

Moving beyond sustainable water management towards the regenerative one, we need to consider not only water quality and quantity, but also water physical state and properties. Water is a unique matter existing on the Earth that we can touch and still, which is driven by wave behavior. The interference patterns of water are similar to all wave processes like light and electromagnetic field. Therefore, changes at molecular- and pico-levels of water structure drive corresponding changes in its physical properties defined by hydrogen bonding interactions present in water (Cai *et al.*, 2009; Wang *et al.*, 2013).

Magnetic resonance is proven to alter macroscopic features and microscopic structures of water leading to improved physical properties (Pang & Deng, 2008), such as decreased surface tension, greater fluidity, altered heat capacity, and increased rates of evaporation and freezing (Amiri & Dadkhah, 2006; Wang; Wei & Li, 2018). By regenerating water properties, water management comes more effective with significant reductions in related energy use. For example, regenerative technologies by Nanoresonance Industries are based on electromagnetic resonance, where water and other fluids (e.g., fuel) are subjected to specific frequencies. The regenerated water has higher electron density and

lower specific entropy, which demonstrated a 13%-reduction in energy requirements for water pumping in cooling towers of EVAPCO power plant (www.nanoresonance.org).

The energy savings by Nanoresonance Industries were even higher in the heating circuit of a health centre leading to savings on heating by 18% and 20% in 2015 and 2016 years, respectively. Moreover, based on the principles of quantum physics, resonance- and frequency-based water treatment provides 100% free-of-chemicals solutions, allowing for low-energy and environmentally friendly methods to regenerate natural water cycle. Therefore, we suggest that understanding the role of physical water state (e.g., water vapor, surface tension, viscosity) should help to upgrade water management across scales beyond only its qualitative and quantitative goals.

Total energy savings are yet to be assessed worldwide to evaluate the potential to reduce energy demand and greenhouse gas emissions. The authors highlight that there is a lack of information on water-related energy use in Europe and, therefore, relied on the statistics for the U.S. mainly. To gain a better understanding of the potential decarbonization and non-chemical water treatment, all relevant data for other countries is needed. It is suggested to include water quality, quantity, and water state issues into the Climate Change as a Planetary Boundary both as drivers of change and, at the same time, impacted by these changes. Meanwhile, the respective upgrades towards more efficient and regenerative water use could be recommended as the first obligatory steps within every water management strategy.

New funding opportunities and channels need to be created to increase scientific knowledge on water management regarding its impact on Climate Change. Following the European Green Deal, about €503 billion are allocated to the targets related to Climate and Environment with €100 billion for transition mechanisms. Additionally, to governmental incentives, the EU budget triggered the creation of the InvestEU program with the private and public Investment Plan for Europe of about € 270 billion. This includes the European Investment Bank Group, National Promotional Banks and International Financial Institutions (*InvestEU*, s.f.)). As discussed in this section, sustainable and regenerative water management shall be included as Climate Change mitigation practices and, thus, attract financial support from related funding opportunities.

Ecosystem-based water management

At the ecosystem level, the destruction of aquatic ecosystems is of particular concern. Marine and freshwater ecosystems are experiencing biodiversity loss more rapidly than their terrestrial counterparts (O'Higgins; DeWitt & Lago, 2020). At the same time, water management of aquatic ecosystems is much more challenging and sophisticated than that of single water bodies. Global Assessment Report on Biodiversity and Ecosystem Services (IPBES, 2019) highlights those sustainable transformations require cross-sectoral approaches, including landscape approaches, integrated watershed and coastal zone management, marine spatial planning, bioregional scale planning for energy, and new urban planning paradigms.

The principles of unified water bodies and socio-ecological context of water management discussed in the previous sections are the core of the Ecosystem-Based Management (EBM) gaining momentum over the last years. A holistic approach is applied to integrate interdisciplinary knowledge and improve the prominence of water governance considering the relationship among aquatic species as well as with their abiotic environment,

interactions with terrestrial ecosystems and coastal zones. As a step forward to the co-evolution of humans with nature, EBM takes the perspective that human social systems are contained within the ecological ecosystem and completely interdependent within it (O'Higgins; DeWitt & Lago, 2020). The key highlights of the EBM are summarized below, whereas the reader is recommended to address the original publication "Ecosystem-based management and ecosystem services: Theory, tools and applications" by O'Higgins, Lago and DeWitt (2020).

Water management at the ecosystem level shall involve spatial coupling of local ecosystems, such as global source-sink dynamics, diversity-productivity patterns, stabilization of ecosystem processes, and indirect interactions at a landscape or regional scales. According to EBM, aquatic ecosystems are implied as unified water bodies and this mindset moves away from a limited (partial) consideration of single services, such as drinking water, water for irrigation, natural assimilation capacity of pollution, etc. (O'Higgins; DeWitt & Lago, 2020). We notice this tendency of merging the knowledge on water bodies in other works, such as "conjunctive use" of both surface and groundwater (Singh, 2014). So that more and more, freshwater ecosystems, coastal ecosystems, transitional waters, and marine ecosystems are being assessed as a continuous polymorphous self-organizing system.

Following the EBM concept, each social-ecological system is respected to be unique, so that instead of general assumptions for sustainable water management, a set of specific recommendations is developed based on the characteristics of the socio-ecological system itself (O'Higgins; DeWitt & Lago, 2020). An example of the EBM implementation in the North Sea can provide a template for other case studies as demonstrated by Piet *et al.* (2020). The coupling of both natural and social ecosystems is necessary to elaborate the best practices in active communication with stakeholders and the legal basis of local environmental law. While environmental information may be most important to conservationists, economic values can be persuasive tools in the development of management options (O'Higgins; DeWitt & Lago, 2020).

Within the EBM, there is a well-established Plan-Do-Check-Act cycle that includes Phase I - Identification of societal goals; Phase II - Setting up the knowledge base and conducting a risk assessment; Phase III - Planning of ecosystem-based management (EBM); Phase IV - Implementation, monitoring and evaluation. Ecological and social criteria are revealed in detail to assess the required knowledge for the development of EBM program. In order to compile an ecological model, the following criteria and indicators shall be considered for each specific case-study: ecological integrity and biodiversity, ecosystem connections, dynamic nature of ecosystems, acknowledgment of uncertainty, spatial and temporal scales, distinct boundaries, coupled social-ecological system, cumulative impacts.

At the same time, additionally to ecological criteria, successful implementation of EBM requires cooperative agreements and collective action to share the range of aquatic ecosystem services obtained across different stakeholders and policy domains (O'Higgins; DeWitt & Lago, 2020). Therefore, social EBM criteria include the use of scientific knowledge, inter-disciplinarity, stakeholder involvement, integrated management, adaptive management, precautionary approach, appropriate monitoring, decisions that reflect societal choice, and sustainability (Piet *et al.*, 2020). Overall, we highlight that a socio-

ecological context must be integrated as a new holistic tool assessing water management actions and their impact on water quality, quantity, and water state across scales.

Regenerative development and tools

Considering that water ecosystems are dynamic by their nature, it is impossible simply to “restore” them and return to the original condition as if assuming they have been static. The water ecosystem, like any living creature, can never stand still and can only be in process - either a process of evolution, or a process of de-evolution (degradation). To move from the degradation to regeneration of natural environments, a step forward beyond “restorative programs” is recognized in a holistic decision-making with the active involvement of society.

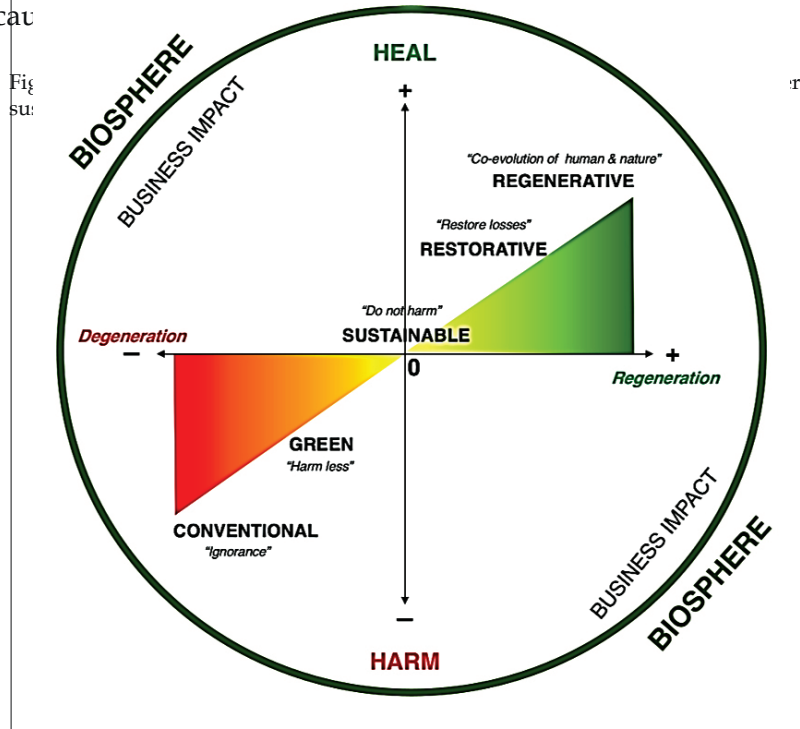
Just like any living organism, a business company has its environmental footprint comprised of water, land, raw materials and energy use, while also the amount and type of waste produced. Today, companies are starting to realize that mismanagement of water can damage their brand, their credibility, their credit rating, and their insurance costs. It creates the demand for novel water management beyond just only the scale of a company (micro-ecosystem) to the larger body of the Environment, its macro-ecosystem, which, in turn, requires the understanding of environmental impact across scales and sectors.

In response to the European Commission’s “Roadmap to a Resource Efficient Europe” (EC, 2011), the Organization Environmental Footprint initiative provides a multi-criteria measure of the environmental performance of a company. This aims to increase resource productivity and to decouple economic growth from both resource use and environmental impacts by taking a life-cycle perspective along the entire supply chain. Such an approach is essential to effective management because of the important environmental effects that may occur “upstream” or “downstream”, and hence may not be immediately evident. This approach is also essential to making transparent any potential trade-offs between different types of environmental impacts associated with specific management decisions and to help avoid unintended shifting of burdens.

The scale of the business risks resulting from climate emergency and water insecurity is vast – as are the opportunities to address them. Therefore, the private sector has a vital role in tackling environmental risks by providing more sustainable and even regenerative strategies. Many companies are reporting progress on environmental, social, governance metrics, and climate response (e.g., ESG) (Fatemi; Glaum & Kaiser, 2018). This creates a competitive advantage that empowers companies to participate in ranking assessments and make environmental sustainability a priority. It is encouraging and at the same time misleading. New labels appear every day and the definitions of sustainable actions are changing rapidly. Companies increasingly label themselves as “eco-friendly,” “environmentally sustainable”, “green”, “circular”, “regenerative”, etc.

It is essential to highlight that all business efforts are complementary and are not exclusive of one another as all practice levels are necessary to achieve this change towards regeneration (Craft *et al.*, 2017). To classify different strategies, we elaborate the classification of Mang and Reed (2019) from “Conventional” to “Green”, “Sustainable”, “Restorative”, and “Regenerative” models. We summarize the updated concept aiming to improve communication of business goals between the stakeholders in Figure 3.

A “Conventional” business model can be characterized as “ignorance” of a company about its environmental impact, which is not an excuse according to legal principles. Once a company starts Environmental Impact Assessment activities it already can be referred to as a “green” company. Although at this stage, a company is aware of its environmental footprint and has objectives to minimize its negative impact (“harm less” principle), it continues to cau



An “Environmentally Sustainable” company is aiming for neutral impacts in terms of water, energy, carbon, or waste by offsetting negative impacts with positive ones. This can be related to the principle “do not harm”. Although these aspirations are crucial to reach SDGs, a greater effort is needed to restore the natural environment. Business strategies of the XXI century must go beyond sustainability and aim for a net positive environmental benefit for the living world.

“Restorative” business models are supported by the UN Decade on Ecosystem Restoration, which was officially launched on June 5th, 2021, and will run from 2021 to 2030. It applies reforestation, permaculture and aquaculture projects to restore previously degraded areas. Planting trees (Stubbs; Cocklin & Stubbs, 2008) and creating artificial reefs (Rinkevich, 2015) are some of the examples.

Following the principles of Industrial Ecology, regenerative tools for water management may include (1) Circular Economy business models, (2) material and energy flow studies (“industrial metabolism”), (3) dematerialization and decarbonization, (4) technological change and the environment life-cycle planning, (5) sustainable product

design for the environment (“eco-design”), (6) extended producer responsibility (“product stewardship”), (7) eco-industrial parks (“industrial symbiosis”), (8) product-oriented environmental policy, (9) eco-efficiency, (10) non chemical water treatment by resonance- and frequency-based technologies.

The implementation of “Regenerative” business models means moving away from fear-based approaches focused on the scarcity of resources, uncertainty, and sacrifice towards a positive model which aligns humanity within a larger community of life (Craft *et al.*, 2017). Its principles are based on “healing” the environment via the dynamic network of natural and human ecosystems within a specific geographic region. Regenerative approaches seek not only to reverse the degeneration of the earth’s natural systems, but also to integrate socio-ecological design thinking in a way that both humans and the place co-evolve. It requires spreading ecological intelligence – knowledge about how nature works to raise environmental responsibility and elaborate policy-making strategies. When possible, the community and clients are actively involved in nature preservation, restoration and regeneration.

It is an extremely challenging task for business to drive lasting positive environmental changes: the private sector needs to promote sound business models that deliver environmental outcomes while proving financial feasibility and the creation of quality jobs for the local economy. Businesses shall employ socio-ecological regenerative development and provide regenerative tools as first steps towards water management across scales. After all, regenerative business models may play an essential role for global movement via the inclusiveness of clients to co-create and evolve with nature together.

In this regard, the *Underwater Gardens International (UGI)* initiative is an example of an ambitious business model that promotes collaboration between the world of finance and ecology to create a positive impact on the environment. Its mission is to create global scalable solutions to mitigate Climate Change and protect other Planetary Boundaries by carrying out scientific studies, driving conscious cultural shift and optimizing in-house ocean restoration methodologies while involving the public (www.underwatergardens.com).

UGI is designing and creating *Regenerative Parks* as drivers for transformation born from the necessity of adaptation to Climate Change. It is a space where science, education and entertainment join towards active regeneration of the place through the visitors’ involvement. Environmental regeneration includes the application of scientific knowledge to restore natural water cycle and increase biomass in its full biodiversity of both land and marine sites around the Regenerative Parks. Its holistic program is described as an Active Restorative Program, where the visitants of the parks are taught to become sea gardeners (Underwater Gardeners). This socio-ecological approach has the purpose of jointly developing through science, art, consciousness and harmony with nature.

The business model of UGI provides positive social and cultural impacts highlighting that every action, decision or land transformation constitutes a legacy. In this context, the business model is at the service of heritage regeneration. Economic profits generated by this program provide financial sustainability to the company, as well as allow advanced monitoring of climate change indicators and biodiversity dynamics. Overall, it provides regenerative solutions and benefits for the local economy, while driving innovation and the competitive advantage for the company.

DISCUSSION

In the time of globalization, there is a great challenge of integrating scientific facts to evolve from the mechanistic understanding of molecular-level data into the more complete and comprehensive processes occurring on a global scale. As a soviet scientist Vladimir Vernadsky stated a hundred years ago, systems thinking across scales is needed to understand our planet the way it is (Vernadsky *et al.*, 1926). It inspired the purpose and holistic approach of this study integrating water knowledge beyond its quality and quantity to water state and socio-ecological culture. As a result, critical assumptions and drawbacks behind water-related issues are revised with respect to the most popularized environmental concepts (e.g., Planetary Boundaries, Sustainable Development Goals) influencing water management practices.

This opinion paper does not claim to be a complete study on water management practices. Rather, it covers a variety of water-related concepts from molecular to biosphere scales and is intended as an informative basis for a further thorough investigation. To facilitate discussions, we provide our revised set of definitions to “water vocabular” (Table I).

Table I - A glossary of terms and concepts created in this study

Term or Concept	Definition
Water	A polymorphous self-organizing system that is present in a variety of physical states with a continuous flow and dynamic transformations within a unified planetary body of water. Specific entropy and frequency values of water serve as indicators for water cycle regeneration and biosphere evolution.
Water Quantity	A specific volume of water in the context of water mass balance within natural and anthropogenic water cycles.
Water Quality	Chemical water characterization as of natural solvent and carrier for dissolved and dispersed chemical compounds, minerals, and microorganisms.
Water State	Physical properties of water molecules and cluster, which are defined by the angle of hydrogen bonding, water frequencies, and specific entropy values. The state of water impacts its solvent capacity, viscosity, fluidity, surface tension, and the heat/entropy of vaporization and freezing.
Regenerative Development	A socio-ecological framework incorporating regenerative tools and technologies, while based on the inclusiveness of humans to co-create and evolve with nature recognizing the dynamics and coupled socio-ecological nature of the ecosystems (e.g., water systems).
Regenerative Tools	Methods and processes that are able to recover natural physical, chemical, biological, and biogeochemical properties of matter (e.g., water molecule) and its ecosystem (e.g., aquifer).
Regenerative Water Management	Holistic programs of understanding and managing water quantity, quality, and water state that are embedded in socio-ecological context of a particular area.
Hydrological (Water) Half-cycle	Incomplete and disrupted water cycle by anthropogenic activities leading to imbalance between natural processes of evaporation, evapotranspiration, condensation, precipitation, run-off, infiltration and percolation.
Water Non-Renewability	Uncontrolled anthropogenic interference to the natural water mass balance and its cycle causing the inability of the water system for self-regeneration and purification leading to water deterioration, desertification, and Climate Change.

For example, we define water itself as a polymorphous self-organizing system that is present in a variety of physical states with a continuous flow and dynamic transformations

within a unified planetary body of water. Raising awareness on this, might open the possibility to understand that every action creates a legacy. In contrast to common sustainability agendas, water systems are suggested to be considered as non-renewable resources for both energy and freshwater production. The renewability context needs to be critically revised with respect to natural capacity for self-regeneration at a relevant for human lifetime scale. Otherwise, following political misnomers of immediate water renewability, the old-style production of energy from hydropower and archaic methods of water production for drinking and irrigation are leading to misleading decisions and contributing to global desertification.

Characterisation of the Planetary Boundary of “Freshwater use” with respect to water mass balance indicated the emerging phenomenon of *hydrological half-cycle* when the rate of the water cycle is either speed up too fast or water does not pass all its physical transformations losing natural capacity for self-regeneration. Therefore, it is suggested to expand water management protocols from specific water quantities, as net water volume withdrawals for urban and industrial cycling, to water mass balance models. Moreover, the molecular structure of water, which is on one hand, is defined by the angle of hydrogen bonding, and on the other hand, controls physical water properties, is acknowledged as crucial water characteristics. It is suggested that understanding the role of physical water state should help to upgrade water management practices across scales beyond only its qualitative and quantitative goals.

This study provides a value to Climate Change mitigation programs via unraveling hidden connections between water management and its carbon footprint. Efficient fixtures and avoided leakages during water sourcing, distribution, use and treatment may play a significant role in water-related energy savings. The corresponding decarbonization goals are recommended as new reporting standards in water management strategies. Moreover, the consideration of not only water quality and quantity, but inclusively, of water state provides the link between water and energy that presents the Climate Change community with a valuable opportunity to better manage two of the most valuable resources.

A simple navigating question is suggested to better classify water management strategies and further facilitate communication between scientist, educators, and policymakers: “*Is it an issue of water quality, water quantity, or of water state?*”. For example, water vapor as one of the physical states of water is a powerful greenhouse gas. Therefore, in addition to achieving decarbonization goals, Climate Change mitigation practices may also focus on water management as both as driver of change and, at the same time, impacted by these changes. It is suggested that the regeneration of initial water structure could be done by the application of magnetic resonance and frequency-based methods at a pico level, while avoiding the use of toxic chemicals for water treatment and disinfection. Corresponding improvements in water solvent capacity, viscosity, fluidity, surface tension, and the heat of vaporization and freezing provide a significant reduction in water-related energy use and can be considered as decarbonization strategies.

Governmental funding support is urgently needed not only for a selected Planetary Boundary of Climate Change, but for all of them to regenerate biosphere integrity and sustainability. The already allocated budget to Climate Change mitigation shall include water-related topics (e.g., freshwater use, acidification, eutrophication, chemical pollution, biogeochemical flows, non-chemical water treatment) to cover corresponding R&D activities and promote innovative technologies. With respect to water quality, its chemical

and biological parameters are suggested to be reported as effective ratios under dynamic equilibrium additionally to their net concentrations. Emerging contaminants from pharmaceuticals, beauty industry, agriculture and industrial processes are recommended for consideration in monitoring programs.

This work contributes to the rapidly expanding field of coupled socio-ecological systems with water being an absolute link between humans and nature. In the future, water management strategies shall apply systems-thinking approach recognizing the dynamics and coupled socio-ecological nature of the water system. Moreover, water management should achieve 'vertical integration of governance systems across levels' (Hoff, 2009). So that multiple levels of government will work together with subnational authorities playing an essential role. Coordination, consistency, and collaboration across different levels of government is critical in order to ensure coherence in water management.

The concept of Regenerative Development is still relatively new and most of the projects are still focusing mainly on reducing their negative impacts, i.e., on Sustainable Development. Whereas, in order to shift the aim towards Restorative and Regenerative Development, more emphasis needs to be placed on business strategies that focus on net-positive impact. To make sure that after restoration an ecosystem will not begin to decline again, true regeneration requires early education, the increase of environmental awareness, consciousness, and active transformation of the human lifestyle. Whereas most environmental practices are trying to simply keep humans as far away from nature as possible to protect the land and ocean for restoration, Regenerative Development takes a different approach, which is based on the inclusiveness of humans to co-create and evolve with nature together.

The co-evolution of human consciousness with nature requires the increase of awareness on the role of humans in the biosphere. In the book "Scientific Thought as a Planetary Phenomenon" written in 1936-1938, V. Vernadsky demonstrated that despite relatively small biomass of all humans within the biosphere's mass balance, "mankind became a single totality in the life on Earth". The changes in the lithosphere, hydrosphere, and atmosphere (e.g., Climate Change) caused by human's lifestyle already then were shaping a completely new environment. In this regard, V. Vernadsky suggested that the key role of humanity could be beyond its anthropogenic activities being mainly defined by human consciousness creating the field of "Noosphere". As he said: "The most important characteristic of the noosphere is that the instrument of its stabilization appears to be human reason, or better to say, scientific reason. Scientific thought is seen as a function of the biosphere or a planetary phenomenon". Therefore, scientific communication and knowledge transfer across disciplines from molecular to biosphere levels may serve as one of the tools to evolve from the biosphere to noosphere (Trubetskova, 2010).

In this context, biogeochemistry (founded by V. Vernadsky) was one of the first and truly inter- or multi-disciplinary sciences that are now actively expanding from small scales (microbiology, 'omics approaches) to large scales as a component of the Earth System Science (Bianchi *et al.*, 2020). More recently, the field of biogeochemistry is evolving even further into the integration of social sciences, which will make biogeochemical knowledge more available to policymakers and educators. As it is suggested by Bianchi *et al.* (2020), an intense collaboration between scientists, government officials, the public, internationally funded programs, and other social sectors shall facilitate sustainable and equitable

responses by society to biosphere changes with regard to Climate Change and other anthropogenic impacts.

Under the 21st century conditions of population growth and hyperconnectivity, human impact on biosphere sustainability becomes more tangible, fast, and evident, therefore making it unavoidable to take responsibility and action. This study provided new insights into the complexity of water as not only a unique matter responsive to electromagnetic resonance, but also as an absolute link between humans and nature. It is hoped that these findings will contribute to a deeper understanding of both mechanistic and socio-ecological regeneration of the water cycle and water culture in small settlements and united nations. Overall, this study has given rise to questions in need of further investigation to upgrade water management across its various scales.

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