March 2024

Decarbonizing *Water:* Applying *the* Voluntary Carbon Market *toward* Global Water Security

Prepared by

Evan Thomas PhD, Christina Barstow PhD, Laura MacDonald PhD
John Ecklu, Katie Fankhauser, Alex Johnson

Mortenson Center in Global Engineering & Resilience
UNIVERSITY OF COLORADO BOULDER

Ilan Adler, David Ehrhardt
Castalia Advisors

CASTALIA

Supported by

AUTODESK FOUNDATION
Gold Standard
HSBC
GORDON AND BETTY MOORE FOUNDATION
U.S. National Science Foundation WHERE DISCOVERIES BEGIN
RESILIENT WATER ACCELERATOR
VCMI Voluntary Carbon Markets Integrity Initiative
WALTON FAMILY FOUNDATION
WaterAid

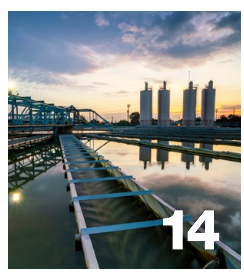
Decarbonizing Water: Applying *the* Voluntary Carbon Market *toward* Global Water Security

This report was prepared by the Mortenson Center in Global Engineering at the University of Colorado Boulder and Castalia Advisors, and supported by the Autodesk Foundation, the Gold Standard, HSBC, the Moore Foundation, National Science Foundation (Award #P23-000295), Resilient Water Accelerator, the Voluntary Carbon Markets Integrity Initiative, Walton Family Foundation, and WaterAid. The views and opinions expressed in this report are only those of authors. We thank the expert stakeholders who participated in interviews and provided resources.

Mortenson Center
in Global Engineering & Resilience
UNIVERSITY OF COLORADO **BOULDER**

CASTALIA

Inside *this* Report



Inside *this* Report *continued*

Foreword

> The water sector is not only at the heart of climate impacts - droughts, floods and weather-related natural disasters - it is also responsible for as much as 10 percent of global greenhouse gas emissions.[1]

Yet, water is on the fringes of the climate change conversation.

This report makes a compelling case that water security – including conservation and management of natural resources and infrastructure - have the potential to deliver a "triple win" of improved health for many people and increased climate resilience for even more, while helping to meet the challenge of reaching global net zero emissions.

Mobilising finance for a just transition in the water sector should be prioritised alongside the clean energy transition as an engine of green growth. This report, through reviewing and extrapolating existing studies, outlines a yet unrealised opportunity to reduce emissions from the water sector. This is estimated to be potentially around 1.6 billion tonnes of emissions savings per year, more than half of the European Union's annual emissions[2] – while increasing global water security.

To secure a prosperous, low carbon, resilient economy, public and private sector organisations, as well as civil society, need to work together to design and incentivize that future. Carbon markets, while they are not the whole solution, are a powerful tool to support climate action. They bring three key benefits: channelling finance to provide incentives to action, particularly in developing economies; encouraging greater monitoring and evaluation of environmental impacts; and helping to build institutions that mainstream environmental considerations into their approach, to be able to plan and respond to the challenges of the 21st century.

We thank the researchers from the University of Colorado Boulder and Castalia for this important global analysis that provides high level policy recommendations on the most impactful actions that could be taken to deliver a low carbon water sector. The report also sets out the role that carbon markets can play in triggering global water decarbonisation efforts. The move to a low carbon water sector needs to be made within the decade for the benefit of people and planet.

Kate Hughes
Chief Executive Officer
Resilient Water Accelerator

Lydia Sheldrake
Director of Policy & Partnerships
Voluntary Carbon Markets Integrity Initiative

Jenny McInnes
Group Head of Policy & Partnerships
HSBC

[1] "Stop Floating, Start Swimming Water and climate change – interlinkages and prospects for future action," GIZ, 2020
[2] Eurostat – "Quarterly greenhouse gas emissions in the EU" https://ec.europa.eu/eurostat/, 2023

Executive Summary

The global increase in water insecurity is one of the first perceivable effects of climate change. Today, two billion people live without access to safe drinking water, most notably in countries with the lowest per capita emissions, and four billion experience water stress at least one month a year. The linkages between climate change and water insecurity are clear, as are the implications for the global economy. The water sector produces 10 percent of global emissions, resulting largely from energy use for water treatment and transport, but also from wastewater decomposition, gas release from surface water bodies, decomposition of organic matter in reservoirs, and destruction of wetlands. While water management is typically a local challenge, climate finance mechanisms, including the voluntary carbon market (VCM), offer the potential to provide new sources of recurring revenue to create a sustainable, performance-based funding stream to incentivize safe water and sanitation management services globally.

> Carbon credit generating water programs have large-scale co-benefits for people and the planet.

Since 2010, water-related carbon projects have generated more than 45 million in issued emission reduction credits. Relying on regional and global studies and applying simplified extrapolation assumptions, we broadly estimate that across the sub-sectors of reduced grid emissions, wastewater treatment upgrades, coastal blue carbon, rural drinking water treatment, latrine value chain upgrades, and watershed nutrient reduction and irrigation, the total global potential for carbon credits generated from water projects is more than 1.6 billion tCO2e per year. At an average price of US$10 per credit, this could result in carbon credit buyers investing more than $160 billion over the next decade toward improving global water security. However, given the VCM is presently a $2B per year market, only a fraction of this potential is likely to be realized. This analysis has not attempted to estimate the cost of the various interventions that would result in emission reductions and removals, so it should not be assumed all projects, technologies or interventions would be economically viable without additional funding, subsidies or policy support. The cost of carbon credit generation within the water sector can, in many cases, exceed the sale price of these credits, necessitating either significant additional investment or higher credit prices and highlighting the financial impediments to realizing the potential of these emission reductions. We also conducted approximately two dozen interviews with stakeholders across the VCM, including those representing project developers, investors, buyers, registries, intermediaries, carbon market associations, and industry standards bodies. A consensus emerged on the future of carbon credit generating water programs, including the large-scale opportunities created by broad co-benefits. However, the complexities of generating carbon credits under existing methodologies and the limited technologies available for monitoring, reporting, and verification remain barriers to scale. There is a tension between a mature market with stable prices and potential homogenization of credits against the advantages of bespoke credits that command higher prices because of their water benefits. Finally, we provide case studies, including a blue carbon program in West Bengal, irrigation upgrades in Italy, pumping efficiency upgrades in Armenia, wastewater treatment in China, municipal desludging in Kenya, and several drinking water treatment programs in Asia and sub-Saharan Africa. We determine that the voluntary carbon market can provide a liquid market to steer private sector capital toward low-carbon activities that can help ensure water security in climate-impaired regions.

POTENTIAL CARBON CREDIT REVENUE OF

↑ $160 BILLION

OVER THE NEXT DECADE TOWARD

IMPROVING GLOBAL WATER SECURITY

Recommendations

This report has identified clear opportunities at the interface of water security programs and the VCM. Stakeholders in both the VCM and the water sector can take steps in the coming years to help realize this potential. We summarize several recommendations and potential actions.

1. **Leading stakeholders should articulate and promote the relationship between the VCM and water-related programs.** Even experts are often unaware that water contributes to 10 percent of global emissions today, or are unfamiliar with existing and potential opportunities to unlock carbon credit revenue for water programs. While this report is a start, increased promotion and awareness of the important relationship between climate change and water security and of the solutions offered by linking carbon credits to water programs may support market growth.

2. **There is a need for increased understanding among water sector developers that carbon credit revenue can be an enabling incentive for water programs.** Many of the potential projects identified in this report would not be viable on carbon revenue alone, but may still benefit from carbon credit revenue as an enabling subsidy. Moreover, carbon revenue can help pool risk with the support of a global carbon credit market among otherwise independent, local water projects.

3. **National government and VCM policymakers can clarify additionality in the water sector.** In the context of the water and wastewater sectors, the concept of additionality becomes nuanced when considering the enforcement of regulations. In low-income countries, there may be regulations that are not enforced, while in high-income countries regulations may incentivize more expensive, emission-intensive solutions. VCM methodologies must take an informed, nuanced position on additionality given these considerations.

4. **Standards bodies should encourage methodology innovation.** While the VCM has faced recent criticisms that have resulted in movement toward more standardized approaches, registries and standards bodies should be careful to reserve space for innovation in methodology and project development in the water sector, given that many potential water-related projects do not yet have approved methodologies.

5. **Investment in Digital monitoring, reporting, and verification (DMRV) technologies may increase project credibility and scale.** Consistent with the broader movement in the VCM toward the adoption of DMRV, water programs generating carbon credits could be supported by a common architecture of DMRV technologies, including the use of sensors, remote sensing, and statistical tools that support not only carbon credit verification but also direct operation of water programs.

6. **Higher resolution, more localized analysis of carbon credit potential in the water sector may support project development.** This report developed a global estimate of the potential carbon credits that could be generated from water projects. These estimates should be interpreted as broadly reflective of the general potential of various water-related projects to participate in the VCM. This analysis has not attempted to estimate the cost of the various interventions that would result in emission reductions and removals. Future work may include costing these potential programs, as well as localizing emission reduction estimates to specific projects or regions in order to increase the accuracy of these estimates and support investment.

Introduction

Today, two billion people live without access to safe drinking water, primarily in countries with among the lowest per capita carbon emissions (Figure 2) [1], and four billion experience water stress for at least one month a year [2], with an unequal distribution of risk globally (Figure 1). Water insecurity can lead to violence - more than 500 violent conflicts related to water have been logged by the Pacific Institute since 2020 [3]. Meanwhile, there are significant opportunities to reduce carbon emissions related to both direct and indirect water use. The global energy system is already responsible for roughly 10 percent of freshwater withdrawals, while the transition to renewable energy sources may demand further freshwater use [4]. Water and wastewater activities account for 4 percent of global electricity consumption, and that figure is expected to double by 2040 [5]. Water management more broadly is responsible for 10 percent of global greenhouse gas emissions, primarily related to energy use for water treatment and transport, as well as to emissions from wastewater decomposition and surface water bodies, decomposition of organics in reservoirs, and destruction of wetlands, including peatlands [6]. In contrast, the airline industry accounts for 2 percent of global emissions [7].

The linkages between climate change and water insecurity are clear, as are the implications to the global economy. A recent report by the World Wildlife Fund suggested that as much as 60 percent of the global GDP, or $58 trillion, is threatened by water insecurity [8]. This estimate includes both the direct value of water, including its use in industry, households, and agriculture, and its indirect value, including environmental regulation, sustenance of biodiversity, and mitigation of extreme weather events. However, water as a form of natural capital has proven challenging to value and manage. It is mobile, heavy, non-rival, has multiple uses, and its value varies depending on time and place [9]. These characteristics have limited the markets for managing water. While water management is typically a local challenge, climate finance mechanisms, including the VCM, offer the potential to provide new sources of recurring revenue to create sustainable, performance-based funding streams and incentivize safe water services globally. Dedicated climate financing from the private sector provides an opportunity to fund reliable, sustainable, and affordable water supply systems [10].

Carbon markets facilitate the reduction of greenhouse gas emissions worldwide through economic incentives. A voluntary carbon credit is a financial commodity, currently worth about $10 for many nature-based projects [12], and over $1,000 for some direct air capture projects [13], that represents the reduction or removal of one tonne of carbon dioxide. Many corporations are interested in buying carbon credits through the VCM to take responsibility for a proportion of their remaining emissions, to achieve sustainability targets linked to ESG criteria, or to contribute to/accelerate global net zero.

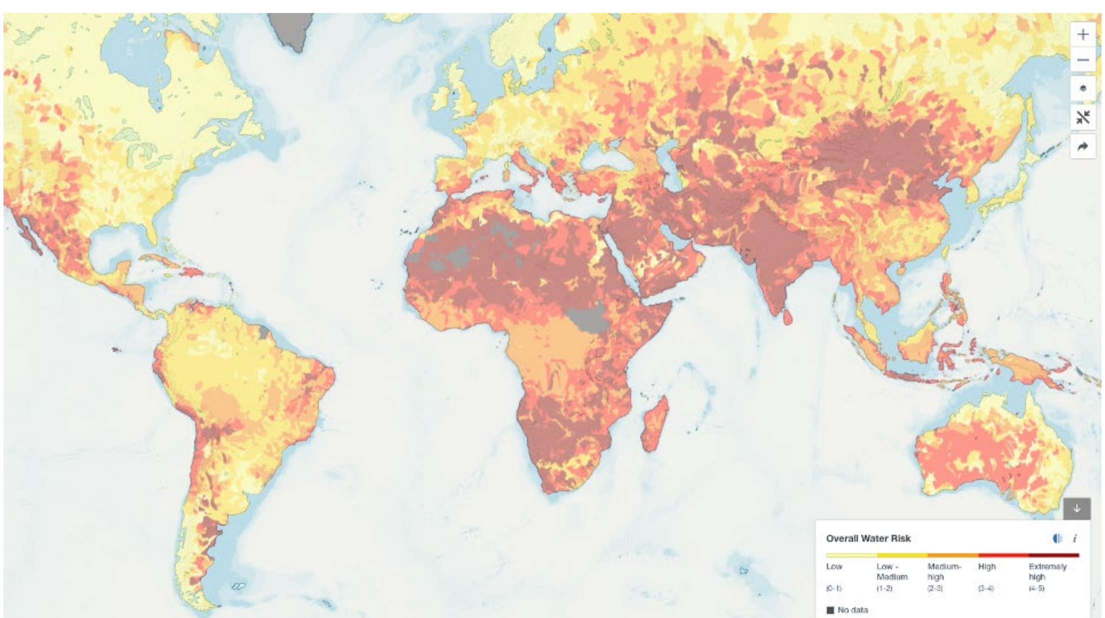


Figure 1: Overall water risk measures all water-related risks, including quantity, quality, regulatory, and reputational. Higher values indicate higher water risk [11].

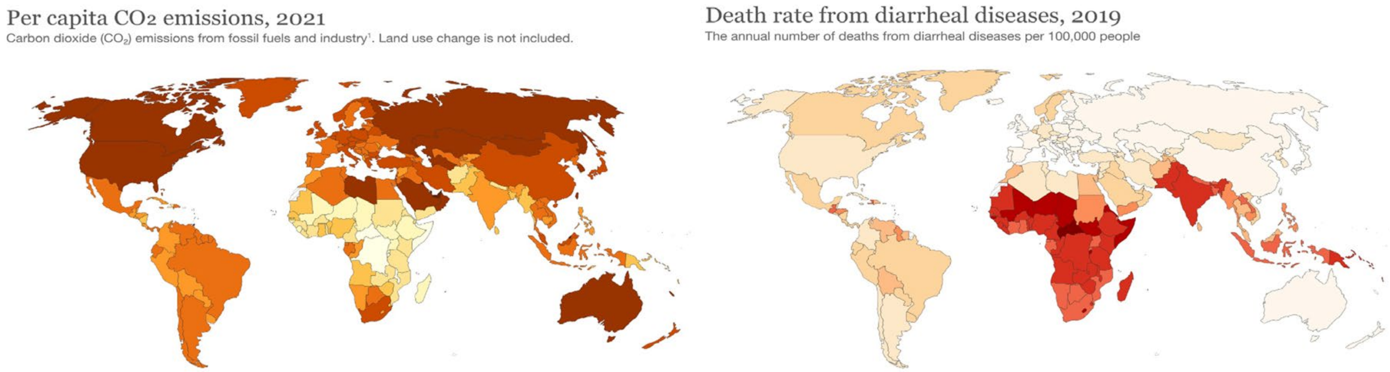


Figure 2: Global Per Capita CO2 Emissions Compared to the Global Burden of Diarrheal Disease [21].

High integrity carbon markets mean that:

1. Credits must represent real, verified emission reductions and removals and apply robust environment and social safeguards;
2. Credits must be used by companies in addition to – not instead of – decarbonization as part of their net zero transitions, and
3. Associated claims must be credible.

While there is today a growing, multi-billion dollar global market for carbon credits, water has not typically been fungible in the same way. Water is a local problem - saving water in Colorado does nothing for insecurity in Rwanda. This local feature of water has made it challenging to create effective financing and trading mechanisms and has limited the value, transactability, and liquidity of various forms of so-called water credits. such as those developed to demonstrate compliance with the US Clean Water Act [14] or the Gold Standard Water Benefit Certificates (WBCs) [15]. Alternatively, if the financial instrument is a carbon credit that motivates water conservation in Colorado or water treatment in Rwanda, that credit accesses a liquid market and can be bought and sold and create revenue, incentivizing water security actions.

The VCM is designed to financially incentivize voluntary action supporting climate change solutions. VCM projects include both nature-based solutions (NBS), such as improved forest management and reforestation, and technology-based solutions, such as renewable energy installations and improved cookstoves. The two largest registries, Verra and the Gold Standard, also are home to almost all water-related programs. As of October 2023 Verra had issued a total of more than 511 million credits, roughly half of which related to nature-based solutions [16], while the Gold Standard reported that 20 million credits had been retired by the end of the third quarter of 2023, more than at the same point in either of the previous two years, and that credit issuances were on track to exceed those of 2022 [17].

Market research conducted in 2022 projected a 20-fold increase in the demand for carbon credits by 2035, with prices rising to an estimated $80-$150 per tonne from the current $25 [18]. However, the VCM has recently faced several challenges, calling into question the additionality, permanence, and volume of credits issued, primarily those associated with REDD+ programs. Yet, there are also clear signals that the VCM may recover, including the strengthening of activities led by the Voluntary Carbon Markets Integrity Initiative (VCMII) and the Integrity Council for Voluntary Carbon Markets (ICVCM). Further, recent research suggested that corporations purchasing carbon credits decarbonize twice as fast as companies not participating in the VCM, belying suggestions that carbon credits enable greenwashing [19].

The VCM represents a fraction of overall climate finance, at about $2 billion per year. In 2022, more than $60 billion dollars in climate finance was provided by multilateral development banks to low- and middle-income economies, including loans (61 percent), policy-based financing (14 percent), and grants (10 percent). Of this, 15 percent of global climate adaptation finance, more than $3.3 billion, was directed to the water and wastewater sector, preceded only by energy, transport, and other built environment and infrastructure (30 percent), and by cross-cutting operations (17 percent), suggesting significant existing commitments [20]. Among high-income economies, the investment is even more significant, with 29 percent of adaptation funds applied toward energy, transport, and other built environment and infrastructure, and 28 percent toward water and wastewater systems. In least-developed countries (LDCs), 14 percent of adaptation funds are applied to the water and wastewater sector, ahead of crop and food production at 13 percent. Total climate adaptation finance allocations for water and wastewater in LDCs totaled nearly $900 million in 2023, with nearly 89 percent allocated to Sub-Saharan Africa [20].

Report Scope

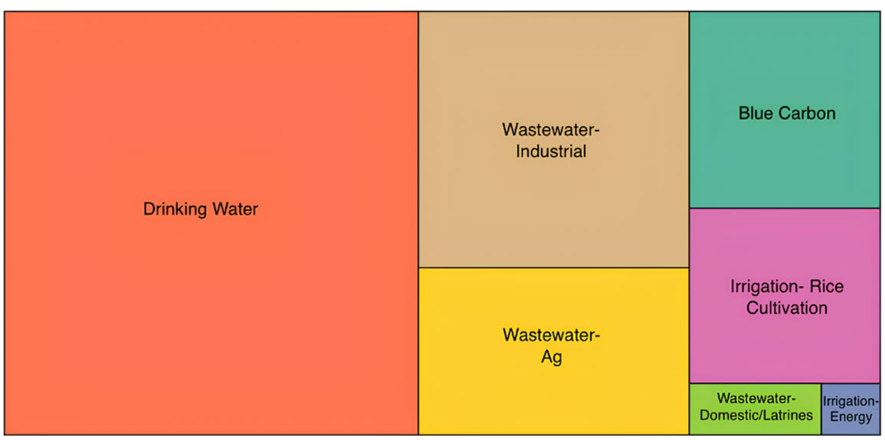
This report reviews the trends and opportunities in applying the voluntary carbon market toward global water security. We summarize carbon credit-generating water programs under the major registries, including drinking water treatment, wastewater treatment, and irrigation efficiency projects. We develop a global estimate of the potential carbon credits generated from water projects. In this analysis, some project types (blue carbon, rice cultivation and industrial wastewater treatment) had existing literature estimating emission reduction and removal volumes that we adapt here. For other project types (irrigation and energy sourcing) we extrapolated globally from regional studies. Finally, for some project types (reduced centralized treatment grid emissions, and rural drinking water treatment) we applied novel analysis and generated estimates based on disparate literature values, and application of relevant methodologies. Given these novel contributions, description of this analysis, while not dominant in overall potential emission reductions and removals, occupy a greater fraction of this report. Overall across project types, these estimates should be interpreted as broadly reflective of the general potential of various water-related projects to participate in the voluntary carbon market.

We further interviewed representatives of key stakeholders, including project developers, carbon credit buyers, registries, and industry standard bodies, to provide insight on market demand and on the limitations of and opportunities to strengthen demand, including through improved messaging, methodologies, and technologies.

Review of Registered Projects

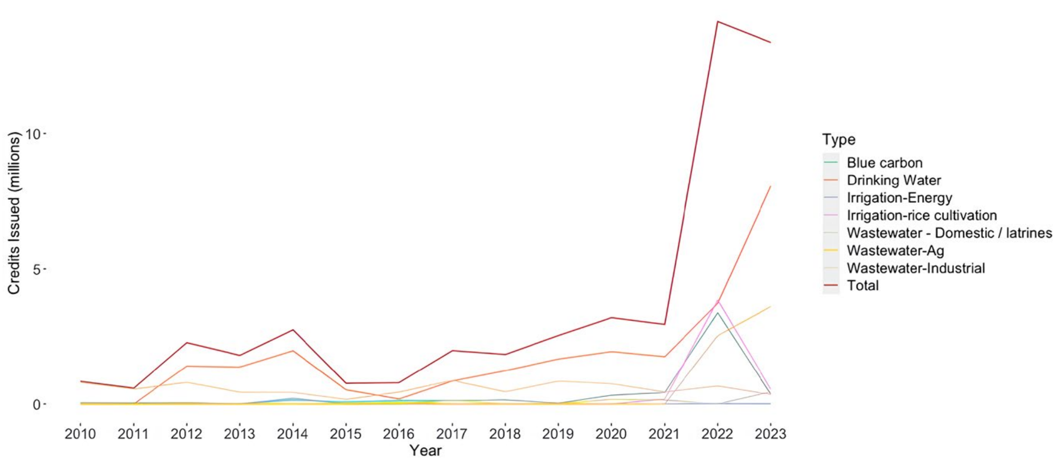
We conducted a review of the four major carbon credit registries: Gold Standard, Verra, American Carbon Registry (ACR), and the Climate Action Reserve (CAR). Each registry was polled using the search criteria **water, wastewater,** and **irrigation**. While additional relevant terms surfaced during the searches, we noted that the term water alone was sufficient to extract projects of significance. The projects identified in these search results were subsequently categorized into the classifications identified in the typology presented in Figure 5. Excluded project types included the construction of hydropower plants, renewable energy projects designed for community power generation not explicitly linked to water infrastructure, and efficient cookstoves for water boiling. Additionally, projects such as household biogas plants that predominantly relied on cow dung and reforestation efforts not directly linked to water systems were also excluded from the analysis.

After review, we excluded projects from the ACR and CAR registries from our analysis. Only seven out of the 80 projects in the search results registered to ACR were found to be relevant, with the number of credits issued and their issuance dates not available on the public registry. Considering the data gaps and the limited number of projects, these seven projects were excluded from our analysis. Our search of the CAR registry returned only five results, and the methodology for each project was not available on the public registry. Overall, our review yielded a total of 434 water-related projects that have issued a total of more than 45 million credits since 2010. These projects and issuances are summarized in Figure 3 and Figure 4.



Proportion of Credits Issued by Project Type Since 2010

Figure 3: Proportion of Carbon Credits Issued by Water Project Type Since 2010.



Credits Issued by Project Type per Year Since 2010

Figure 4: Total Carbon Credits Issued by Project Type per Year Since 2010.

Typology

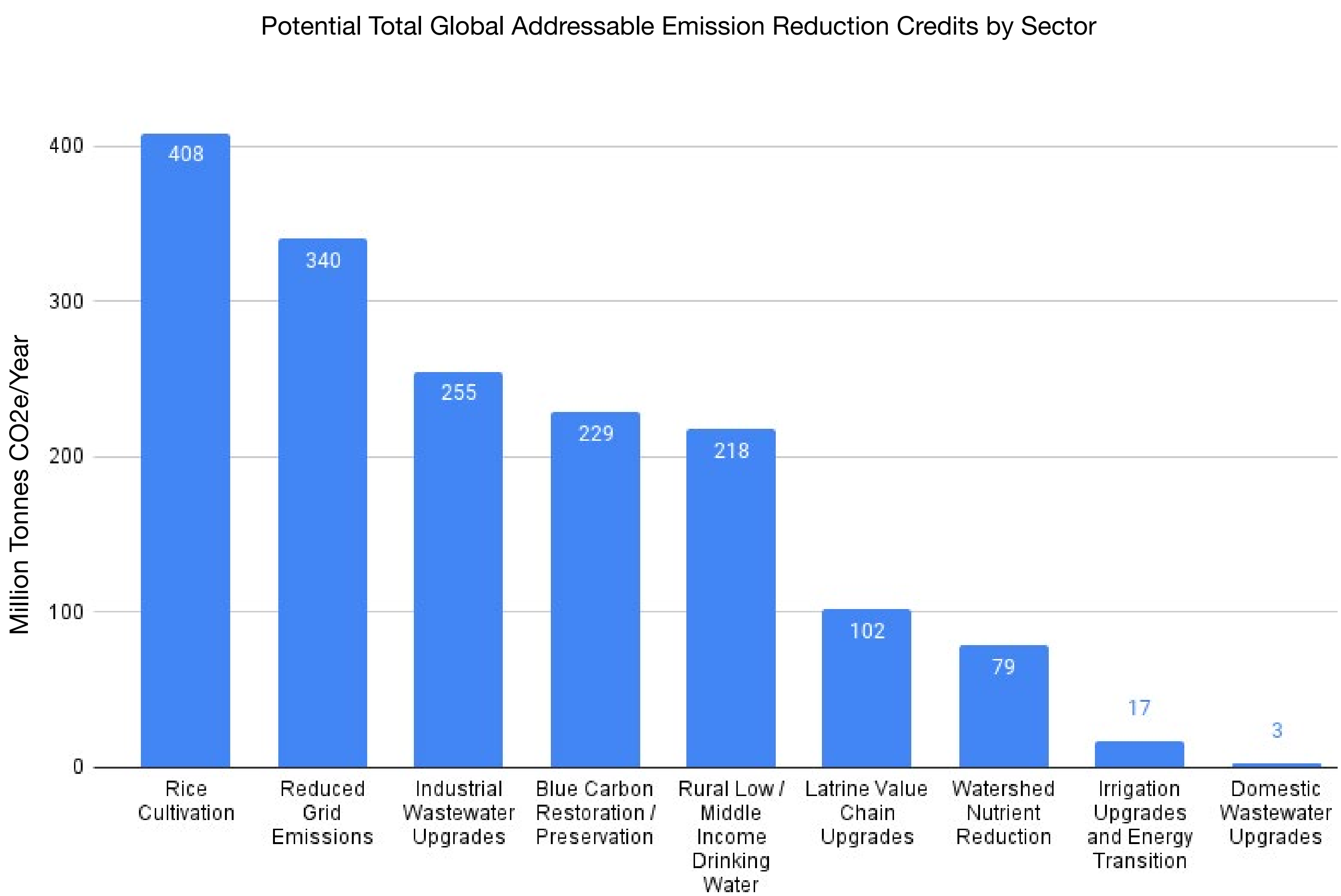
Based on a review of existing and potential water-related carbon credit programs, a proposed typology and key characteristics are presented in Figure 5. The proposed taxonomy first categorizes climate mitigation strategies into two core types: carbon removal and emission reduction. The emission reduction category is further segmented into key sub-sectors: wastewater, drinking water, and agriculture. In the carbon removal category, we focus on nature-based projects, particularly those related to coastal blue carbon. Each sub-sector is subsequently delineated into relevant project types, informed by outcomes from registry reviews and literature, as detailed in other sections of this report. Notably, wastewater treatment is identified as a project type in the agriculture sub-sector. While acknowledging that this project type could theoretically fall under the wastewater sub-sector, its closer association with agricultural processes justifies its placement within the agriculture sub-sector. Key characteristics related to each project type are provided in Figure 5.

Carbon Type	Sub Sector	Project Type	Examples	GHG reduction source	Proportion of credited projects in the major registries	Geographic scope of existing projects	Sustainable development co-benefits	Total Global potential (Million Tonnes CO2e/Year)	DMRV Opportunities	The registry having the highest number of projects with issuances
Emission Reduction	Agriculture	Irrigation- rice cultivation	Alternate wetting and drying for rice cultivation	Methane	16%	China-100%	Affordable and clean energy; Decent work and economic growth; Sustainable production and consumption; Industry, innovation and infrastructure	408.2	Internet/satellite connected sensors can allow for real time monitoring and improve data quality.	Verra (25)
		Irrigation- energy transition, irrigation-efficiency	Use of solar pumps; Use of micro-irrigation systems	Fossil fuel	3%	India- 75%	Affordable and clean energy; Decent work and economic growth; Sustainable production and consumption; Industry, innovation and infrastructure	17	Internet/satellite connected sensors, databases can reduce the time and cost of MRV and improve the quality of data.	Gold Standard (8)
		Nutrient reduction	Implementing conservation tillage to reduce nutrient runoff to watersheds	Fossil fuel	-	-	Sustainable production and consumption	79	Remote sensing, drones, machine learning can improve the quality of monitoring data.	-
		Wastewater treatment	Animal manure management systems; Biogas power generation plant	Methane, fossil fuel	8%	China-83%	Affordable and clean energy; Decent work and economic growth	Grouped with Industrial wastewater treatment	Internet/satellite connected sensors can allow for real time monitoring and improve data quality.	Gold Standard (12)
	Drinking water	Community safe water supply	Borehole rehabilitation; Piped water networks	Biomass	36% (Community + Household)	Sub Saharan Africa-71% (Community+Household)	Safe drinking water; Good health and well-being; Quality education; Gender equality; Decent work and economic growth	218 (Community + Household)	Internet/satellite connected sensors, GIS can reduce the time and cost of MRV and improve the quality of data.	Gold Standard (334)
		Household interventions	Water filter distribution; household safe water supply	Biomass			Safe drinking water; Good health and well-being; Quality education; Gender equality; Decent work and economic growth		Internet/satellite connected sensors, GIS can reduce the time and cost of MRV and improve the quality of data.	
		Reduced grid emissions for utilities	Piped water loss reduction; Utility pumping efficiency	Fossil fuel	-	-	Sustainable cities and communities; Clean water and sanitation	137.8	Internet / satellite connected sensors.	-
	Wastewater	Industrial wastewater treatment	Biogas utilization	Fossil fuel, methane	30%	Thailand-66%, Vietnam-11%, US-11%, China 7%	Sustainable production and consumption; Good health and well-being	823.2 (Industrial + Domestic)	Smart sensors, cloud computing apps can allow MRV to be done in real time.	Verra (24), Gold Standard (24)
		Domestic wastewater treatment,	Biogas utilization	Fossil fuel, methane	3%	80%-China	Improved sanitation; Sustainable cities and communities		Internet/satellite connected sensors, GIS can reduce the time and cost of MRV and improve the quality of data.	Verra (4)
		Latrines	Treatment and disposal of sludge from latrines	Methane	-	-	Improved sanitation; Sustainable cities and communities	319.2	Service value chain monitoring	-
Carbon Removal	Nature-Based	Blue Carbon	Projects that sequester CO2 from coastal wetlands such as mangroves and seagrass	Sequestration of CO2	5%	-	Sustainable cities and communities; Clean water and sanitation; Good health and well-being	841	Remote sensing, drones, machine learning can reduce the time and cost of monitoring	Verra (8)

Figure 5: Proposed typology and key characteristics of water-related carbon credit programs.

Water Sector Project Types

In our analysis of the global potential of carbon credit generation in the water sector, we consider the major possible project types of domestic and industrial wastewater treatment technology upgrades, replacement of pit latrines (and open defecation) with upgraded centralized treatment, provisioning of treated drinking water as an alternative to water boiling, reduction of nutrients in watersheds as an alternative to wastewater treatment upgrades, irrigation efficiency upgrades, and irrigation energy transition. A supplemental report to this produced by Castalia Advisors estimates the emissions reductions associated with lessening physical losses in piped water supply, improving energy efficiency of pumping, and transitioning water and wastewater utilities to renewable energy, which we group here under **Reduced Grid Emissions**. Across the sub- sectors of reduced grid emissions, wastewater treatment upgrades, coastal blue carbon, rural drinking water treatment, latrine value chain upgrades, watershed nutrient reduction, and irrigation, we estimate a total global potential for carbon credits generated through water projects of more than 1.6 billion per year, as indicated in Figure 6.



| *Figure 6: Estimated Potential Global Emissions Reductions and Removals by Water Sector.*

Reduced Centralized Treatment Grid Emissions

Piped Water Loss Reduction

Water utilities around the world supply 1.3 billion cubic meters of water per day (estimate based on a random selection of utilities' water production from IB-Net [22] and JMP data on populations with access to piped water services). Each unit supplied is typically treated and pumped from source to tap. Power for treatment and pumping typically comes from the national electricity grid, which is powered primarily by fossil fuels in most countries. This means that the more water that is pumped and treated, the greater the emission of greenhouse gasses (GHGs). Water is lost as it moves through the system, primarily because of leaks in pipe networks. In developed countries, water losses are typically around 11 percent (estimated from utility data from a sample of eight high-income countries in IB-Net [22]). In contrast, the average developing country water utility loses about 26 percent (estimated from utility data from a sample of 15 low- and middle-income countries in IB-Net [22]). This loss of water also wastes the electricity used for pumping and treatment. Reducing water losses therefore presents a way to reduce electricity consumption and so lower CO2 emissions from the power grid. The emissions reduction potential can be estimated from the volume of water that could be saved if water losses were reduced to an efficient level. The efficient level differs from system to system (based on factors such as water scarcity and energy costs), but a reasonable rule of thumb for a typical utility is that physical water losses should not exceed 10 percent of the water input volume, according to experts.

To quantify emissions, we first estimate the current level of physical losses in the business-as-usual (BAU) scenario. We find that, globally, 95 billion cubic meters of water is lost annually. Of this, 72 billion cubic meters is lost in developing countries and 23 billion cubic meters in developed countries (estimate based on utility data from IB-Net [22], JMP data for populations with access to piped water [23], and grid emission factors from UNFCCC Harmonized Grid Emission factor dataset [24]). Then we estimate the level of water losses in the optimal scenario of 10 percent [25]. We thus calculate that the optimal level of global water loss is 47 billion cubic meters, with developing countries accounting for a reduction in physical water losses of 44 billion cubic meters and developed countries a reduction of 3 billion cubic meters. The reduction in GHG emissions resulting from these lower water losses can then be calculated based on local emissions factors associated with water pumping. We estimate a reduction potential of 52.8 million tCO2e per year from the BAU scenario. The reduction potential in developing countries is 51.8 million tCO2e per year and the reduction potential in developed countries is 0.9 million tCO2e per year.

> In developing countries, water losses have remained stubbornly high for decades, despite the financial and service benefits of loss reduction.

In developing countries, water losses have remained stubbornly high for decades, despite the financial and service benefits of loss reduction. The main reason losses persist at inefficient levels is that water utilities in developing countries are not financially viable. They cannot generate their own funds for investment, their cash-strapped public owners cannot fund them adequately, and they cannot borrow commercially. For these reasons, the total financing gap for meeting SDG 6 is estimated to be $106.1 billion [26]. Funding for water loss reduction is a binding constraint. VCMs can relieve this pressure, enabling loss reduction that would otherwise not have occurred. We consider all water loss reduction in developing countries to be additional, while water loss reduction in developed countries is not.

While the United Nations Clean Development Mechanism (CDM) and Gold Standard do not have approved specifications for carbon credits from the reduction of physical water losses, the International Water Association (IWA) introduced the Leakage Emissions Initiative (LEI), which aims to establish a standard carbon balance for drinking water utilities [27] that could easily be adopted for verification and certification.

Utility Pumping Efficiency

Globally, water utilities use 837 terawatt hours of electricity every year (estimated from water production and energy efficiency data from a sample of 15 low- and middle-income countries and eight high income countries in IB-Net [22]). Of that, 70 to 80 percent goes into pumping for the distribution of treated water. The remainder is split between raw water pumping and treatment processes (estimated from water production and energy efficiency data from a sample of 15 low- and middle-income countries and eight high income countries in IB-Net [22]). Utilities draw electricity from the national grid, which in most countries is powered mainly by fossil fuels. The higher the energy needs, the more GHGs are emitted. Electricity is wasted when pumps do not operate at their optimal efficiency. This happens when they are outdated, oversized, or sub-optimally placed. Water utilities can improve pumping efficiency through the replacement of old pumps, better maintenance, better design, and better operational planning. The potential to increase pumping efficiency differs between developed countries and developing countries. In developed countries, pumping efficiency measures typically reduce water utilities' energy consumption by 14.5 percent. [28] We estimate that in developing countries, pumping efficiency measures typically reduce water utilities' energy consumption by 30 percent. This number is an estimate based on eight pumping efficiency case studies in developing countries, namely China, Brazil, Cambodia, and Ghana, that showed an average energy savings of 46 percent. We use the conservative estimate of 30 percent energy savings in our calculations.

Globally, the emissions from energy used for pumping is 311 million tCO2e per year. Developing countries produce 259 million tCO2e per year, and developed countries produce 52 million tCO2e per year (estimate based on utility data from IB-Net [22], JMP data for populations with access to piped water [47] and grid emission factors from UNFCCC Harmonized Grid Emission factor dataset [24]). Using the reduction per- centages for pumping efficiency measures, we quantify the global potential of reduced emissions at 85million tCO2e per year, 27 percent lower than in the BAU scenario. The reduction potential in developing countries is 78 million tCO2e per year, while in developed countries it is 8 million tCO2e per year. Emission reductions from pump efficiency can be registered and verified under the Gold Standard or Verra using the CDM methodology "AM0020: Baseline methodology for water pumping efficiency improvements-Version 2.0". [29]

BIOGAS GENERATION THROUGH ANAEROBIC DIGESTION
CAN REPLACE
100% OF ELECTRICITY CONSUMPTION
IN WASTEWATER TREATMENT PLANTS

Energy Sourcing

In addition to increasing electrical efficiency, water utilities can replace grid electricity with locally generated renewable electricity—also known as distributed energy—using solar photovoltaic, hydropower, and biogas generation technologies. Solar photovoltaic generation uses special silicone panels to convert sunlight directly into electricity. These PV panels are generally installed on land or on building rooftops but can also be installed on pontoons floating in water reservoirs. This provides a significant opportunity for water utilities to generate electricity at a low cost close to where they need it. Further, in some cases, biogasgeneration through anaerobic digestion can replace 100 percent of electricity consumption in wastewater treatment plants [30].

Many water utilities manage water flowing from high elevations to lower elevations. Sometimes this causes problems of excess pressure in the network, which can lead to excessive water losses through leakage. Water utilities can use this excess pressure to generate electricity, installing mini hydros on the water flow from high-elevation reservoirs, or even installing micro hydro generators in the large pipes descending from high elevations in the distribution network.

Considering the range of distributed renewable generation options open to water utilities and the ability to use solar power in the day to pump into storage for nighttime supply, we estimate that 80 percent of electricity used in treatment plants and pumping could be replaced with renewably generated electricity. We compute BAU emissions, post-intervention emissions, and reduction potential based on this assumption. The electricity used by utilities in providing water services is around 615,043 million kWh (estimate based on water production, population with access to piped water, and energy efficiency data from a sample of utilities in IB-Net [22]). Adding the annual electricity used in wastewater services (221,740 million kWh) [31] yields an estimated annual electricity consumption by utilities of 836,783 million kWh. Using the reduction percentages above, we quantify the emissions reduction potential as 422M tCO2e per year. Emission reductions from renewable energy can be registered and verified under the Gold Standard or Verra using the CDM methodology "AMS-I.F.: Renewable electricity generation for captive use and mini-grid- Version 5.0" [32].

Utility Demand-Side Management

Water must be treated and pumped to where it is needed. Both treatment and pumping use electricity, resulting in emissions from fossil fueled power grids. Grid emissions from water supply are proportional to the volume of water demanded. Studies indicate that demand-side management programs in developed countries typically deliver water savings of 10 to 20 percent. For example, a study in Australia showed that behavioral intervention strategies combined with smart metering reduced water consumption by 19 percent [33]. In California, a project to fit low-flow toilets reduced water consumption by 10 percent, water-efficient showerheads reduced consumption by 8 percent, and the implementation of water-efficient irrigation technologies saved 11 percent [34]. Studies in England and Wales concluded that retrofitting toilet devices, taps, and showerheads reduced water consumption by as much as 12 percent [34].

In developing countries, significant reductions in consumption from demand-side management initiatives seem possible. A demand-side water management program in Pakistan achieved a 23 percent cut in consumption [35]. In Namibia, a water demand management strategy that included water pricing policies, information campaigns, legislation, and technical measures, reduced consumption by 38 percent between 1992 and 1999 [35]. In developing countries, about 276 billion cubic meters of water is produced annually (estimate based on a random selection of utilities' water production from IB-Net [22] and JMP data on populations with access to piped water services [23]). In developed countries, about 200 billion cubic meters of water is produced annually (estimate based on a random selection of utilities' water production from IB-Net [22] and JMP data on populations with access to piped water services [23]). Emissions from water production can be estimated using water produced, energy efficiency, and grid emission factors. In developed countries, these emissions are about 65 million tCO2e per year, while in developing countries they total roughly 324 million tCO2e per year. We estimate the emissions reduction potential from demand-side management at 107 million tCO2e per year, of which 99 million tCO2e per year would come from developing countries and 8 million tCO2e per year from developed countries.

> Studies in England and Wales concluded that retrofitting toilet devices, taps, and showerheads reduced water consumption by as much as 12%.

Demand-side interventions through low-flow technologies can be registered and verified under the Gold Standard or Verra using CDM methodology "AMS-II.M.: Demand-side energy efficiency activities for installation of low-flow hot water savings devices - Version 2.0" [36].

Mitigating Methane Emissions from Wastewater Treatment

Wastewater treatment facility in Thailand

Methane is responsible for more than a third of total anthropogenic climate change. It is the second most common GHG, accounting for 14 percent of global GHG emissions [37]. Methane emissions from wastewater accounts for 7 to 10 percent of global methane emissions [38]. Methane emissions from wastewater can be reduced in two ways: methane capture and reuse or methane avoidance. Methane avoidance can be achieved by ensuring aerobic treatment of wastewater and sludge so that only CO2, and not methane, is emitted. Methane capture and reuse can be achieved through installing biogas capture systems at existing open-air anaerobic lagoons or by initiating anaerobic sludge digestion through new construction or retrofitting existing treatment systems. The anaerobic digesters process wastewater biosolids and produce biogas, which can displace fossil fuels.

Methane emissions from municipal wastewater treatment can be reduced by about 9 percent by improving operational efficiency and implementing advanced technologies that help prevent methane release and harvest biogas [38]. This would potentially reduce methane emission by about 3.21 million tCO2e per year in developing countries and 1.49 million tCO2e per year in developed countries.

Given the diversity of industrial wastewater sources, a more general estimate is provided for the potential reduced emissions associated with upgrading industrial wastewater systems. A 2020 study (using a 2015 baseline) estimates that upgrading industrial wastewater treatment to anaerobic with biogas recovery followed by aerobic treatment, could save about 254 million tCO2e per year globally [39]. Of course, as identified elsewhere in this report, such upgrades also require increased electricity demand and associated emissions.

Emissions reduction from methane recovery or reuse can be registered and verified under the Gold Standard or Verra using CDM methodology “AMS-III.H.: Methane recovery in wastewater treatment - Version 19.0” [40] while technology upgrades can be verified with “AMS-III.I.: Avoidance of methane production in wastewater treatment through replacement of anaerobic systems with aerobic systems - Version 8.0” [41].

Distributed Sanitation Management

On-site sanitation systems emit around 310 million tonnes of CO2e per year [42, 43, 44, 45, 46, 47, 48]. Most of these emissions come from on-site containment systems, pit latrines, and septic tanks. These account for 252 million tCO2e per year. The rest occur largely in treatment and disposal.

> Emissions from on-site sanitation can be reduced through regular desludging and improved treatment technology.

An estimated 97 percent of emissions from on-site sanitation occur in developing countries (estimate based on the distribution of on-site sanitation users between developed and developing countries [23]). One recent study suggested that 50 percent of GHG emissions from Kampala, Uganda may come from its on-site sanitation value chain [42]. Emissions from on-site sanitation can be reduced through regular desludging and improved treatment technology. Desludging is the removal of fecal sludge from containment systems to a treatment plant. In many developing cities, desludging is either infrequent and ad hoc or not conducted at all [49]. Increased regularity and coverage of desludging can reduce emissions by shifting fecal sludge from conditions in which it decomposes anaerobically on-site and thus produces methane to centralized sludge treatment plants that use sealed digesters to create methane, capture it, and allow it to be used as biogas, substituting for fossil fuels.

We estimate that under the BAU scenario, on-site sanitation systems produce a total of 310 million tCO2e per year, of which 252 million tCO2e per year come from the containment stage, 159,000 tCO2e per year from emptying and transport operations, and 58 million tCO2e per year from the treatment stage. Under the intervention scenario, on-site sanitation systems emit 205 million tCO2e per year. This is broken down into 204 million tCO2e per year in containment, 344,000 tCO2e per year in operations, and zero in treatment. In developing countries specifically, the potential reduction is 102 million tCO2e per year. In developed countries, it is 2.5 million tCO2e per year.

Blue Carbon

Blue Carbon is a subsector of the carbon markets derived from nature-based solutions [50]. Blue carbon projects focus on the conservation and restoration of coastal and marine ecosystems, such as mangroves, seagrasses, and salt marshes, to mitigate climate change by sequestering and storing significant amounts of carbon dioxide. These ecosystems play a crucial role in absorbing carbon from the atmosphere and storing it in biomass and sediments, making them valuable natural carbon sinks. Beyond carbon sequestration, blue carbon projects contribute to biodiversity conservation, coastal protection, and the livelihoods of coastal communities. By participating in the voluntary carbon market, stakeholders can support and invest in blue carbon initiatives, aligning environmental and climate goals with the preservation and sustainable management of coastal ecosystems. Blue carbon ecosystems can store between two and 10 times the amount of carbon that terrestrial tropical forest of similar area can, with mangrove forests providing the greatest potential and benefit.

Globally, the conservation of existing blue carbon ecosystems stores more than 304 million tCO2e per year across 185 million hectares, while the restoration of these ecosystems could remove more than 841 million tCO2e per year, the equivalent of roughly 3 percent of global emissions [51]. One recent study suggested that about 20 percent of global mangrove forests could be protected using voluntary carbon markets alone [52]. However, the supply of blue carbon projects remains significantly below demand. A recent estimate suggested that demand for blue carbon credits exceeds $10 billion per year [53]. As of late 2022, there are eight mangrove projects operating under a Verra methodology, 15 planned, one seagrass project, and five seagrass projects planned, as shown in Figure 7.

> One recent study suggested that about 20 percent of global mangrove forests could be protected using voluntary carbon markets alone.

It is worth mentioning that, while there are other wetland restoration projects beyond the scope of blue carbon, we observe that these projects are frequently included within broader forest initiatives. Therefore, we do not categorize them as distinct water projects. There is ongoing work to develop separate methodologies for these types of projects [54].

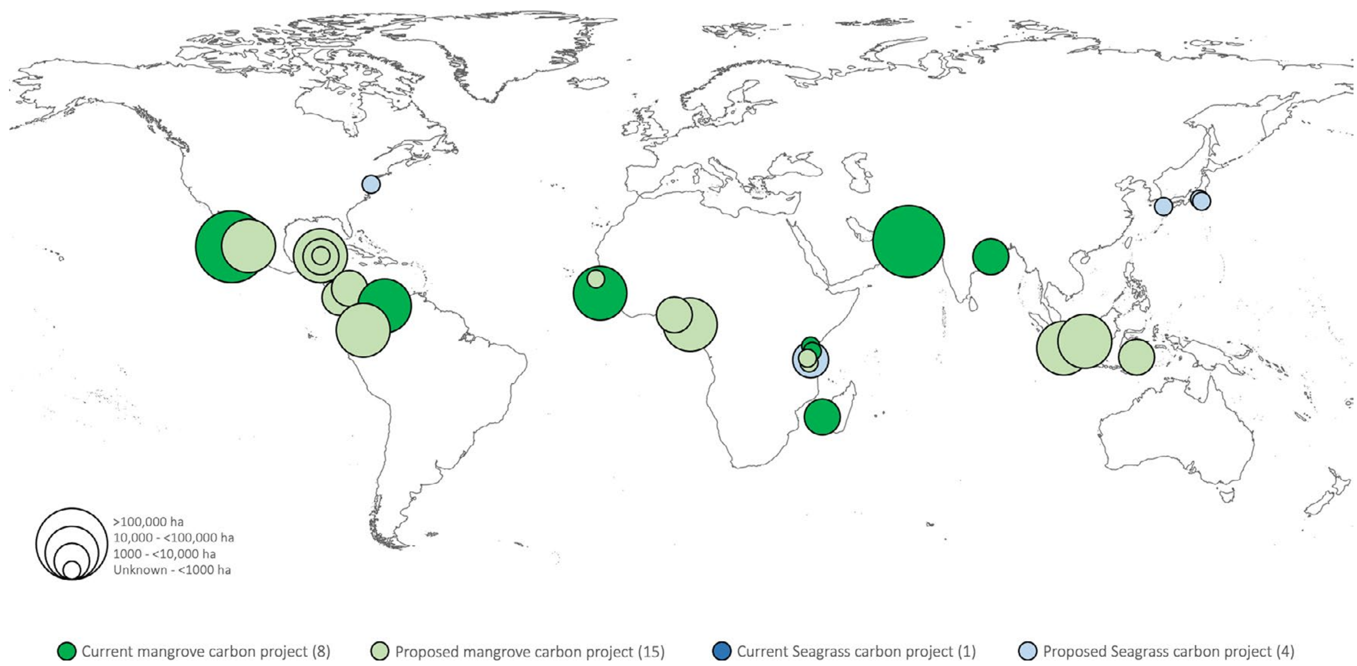


Figure 7: Global distribution of current and proposed blue carbon projects (Copyright [53], reproduced under the terms of the Creative Commons Attribution License.

Watershed Restoration Alternatives to Wastewater Treatment

Energy use by water and wastewater treatment account for 4 percent of global emissions [5]. In the United States alone, water and wastewater treatment plants currently account for about 2 percent of energy use and the equivalent of 45 million tonnes of CO2e per year [55]. Recent estimates suggest these US and global values could almost double over the coming years as utilities are obligated to increase treatment levels, even as states transition to renewable energy sources. Furthermore, freshwater quality globally is impaired by nonpoint source pollution from land-use change, agricultural and forestry practices, soil erosion, and urbanization, as well as from large-scale, short- and medium- term shocks associated with wildfires and other impacts of climate change. Fertilizer application and subsequent runoff to streams is also a dominant source of water quality impairment [56].

Distributed land-based water quality interventions, including riparian restoration, stream bank erosion control, livestock exclusion, irrigation upgrades, and fertilizer reduction, have been used to improve instream water quality in lieu of building electricity-consuming gray infrastructure. Program developers have proposed that carbon financing could provide a novel incentive to accelerate this transition. In a recent study [57] that combined data on impaired waters, treatment technologies, and lifecycle greenhouse gas emissions in the continental United States, researchers compared traditional gray treatment technologies to green technologies, which include constructed wetlands, saturated buffers, and agricultural management practices. This study suggested that, across the contiguous United States, green alternatives are less expensive, less energy intensive, and less carbon intensive than gray infrastructure alternatives and could save $15.6 billion, 21.7 terawatt-hours of electricity, and 29.8 million tonnes of CO2-equivalent emissions per year while sequestering more than 4.2 million tonnes CO2e per year over 40 years [57]. While incentivizing adoption of green infrastructure remains challenging due to utility and regulator risk aversion, green solutions may have the potential to reduce or remove about 34 million tonnes of CO2e per year in the United States alone.

Extending this opportunity globally, there are many examples of watershed and water quality trading programs in Canada, Australia, New Zealand, the United Kingdom, the Netherlands, Honduras, India, China, and Kenya. Extending the findings of the US study globally and assuming that an indicative 10 percent of irrigated croplands outside of the United States could be used to generate instream water quality benefits and thereby avoid facility-based treatment, the global potential for this approach could be close to 80 million tonnes of CO2e reduced or removed per year.

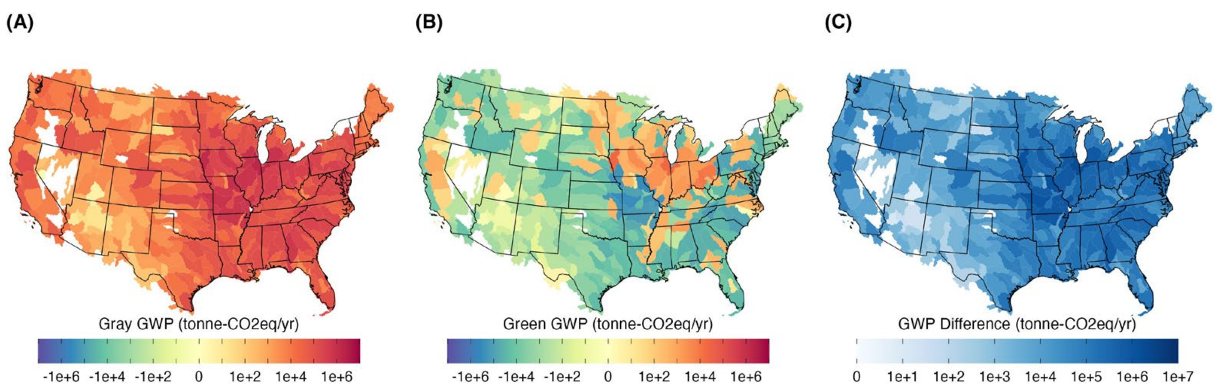


Figure 8: Continental United States global warming potential (GWP) in tonnes of CO2 equivalent emissions per year for removal of nitrogen (to 2 mg/L) and phosphorus (to 0.02 mg/L) using (A) gray treatment technologies (29.7 MtCO2e per year) and (B) green treatment technologies (-4.2 MtCO2e per year), and (C) net GWP representing potential carbon credit generation (33.9 MtCO2e per year). White space designates water basins that didn't have wastewater treatment facilities or didn't require nutrient treatment.

Drinking Water Treatment in Medium- and Low-Income Settings

Globally, two billion people do not currently have access to clean drinking water [1], either consuming contaminated water or, in about 20 percent of cases, boiling their drinking water using wood, other biomass, or fossil fuels to address microbial contamination [58]. Since 2007, the Gold Standard and the CDM have provided methodologies that enable project developers to produce carbon credits based on avoided use and demand for fuel to boil water.

These crediting methodologies rely on a concept known as suppressed demand, that presumes a wood fuel demand associated with treating water by boiling. In reality, only a minority of households boil their water, while most drink untreated water, causing a significant health burden [59]. Early criticism of these programs and finance mechanisms came from the donor-supported water and sanitation community and focused on two weaknesses of the model: First, the tenuous technical concept of suppressed demand linking a conceptual demand for non-renewable biomass burning to boiling water and second, the lack of rigor in the measurement of functionality and use of water interventions yielding proportional carbon credit issuance [60, 61, 62]. From a limited technical perspective, the suppressed demand criticism is valid. However, this legal construct was created not to reduce emissions in low-income countries but instead to recognize that energy use and associated health and economic livelihoods are suppressed in low-income communities[63]. As per capita emissions in high-income countries are still more than 23 times the emissions in an LDC [64], there is a strong equity argument for mitigating this disproportionate cause and effect of climate change. A number of adjustments have been made to the eligible methodologies in response to this critique and new technologies have been introduced to the sector that enable improved digital monitoring, reporting, and verification [65]. Today, there are hundreds of programs globally that generate revenue that is attributable to and re-invested in water services. These programs earn revenue only upon continued delivery of clean water, in contrast to many donor- and government-supported programs that pay up front for capital investments, with no direct accountability for functionality and sustainability.

To estimate the total potential global supply market for these kinds of credits, we apply the Gold Standard's "Methodology for Emission Reductions from Safe Drinking Water Supply" [66] in places where rural populations are currently without safely managed drinking water [1]. Potential savings are relative to the fraction of non-renewable biomass [67] and rural population solid fuel use in a country [68]. Optimally, improved drinking water services could provide up to 5.5 liters of clean water daily per person and would displace water boiling on low-efficiency (e.g. 0.2) wood-burning stoves. Globally, we estimate a total potential carbon credit generation of more than 218 million tCO2e per year from averted fuel use (Figure 9).

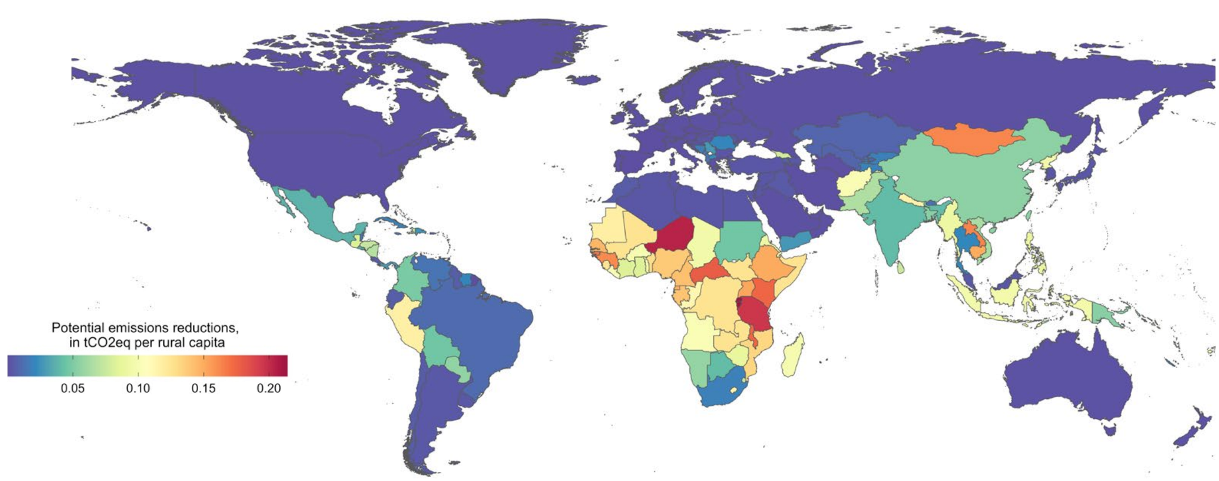
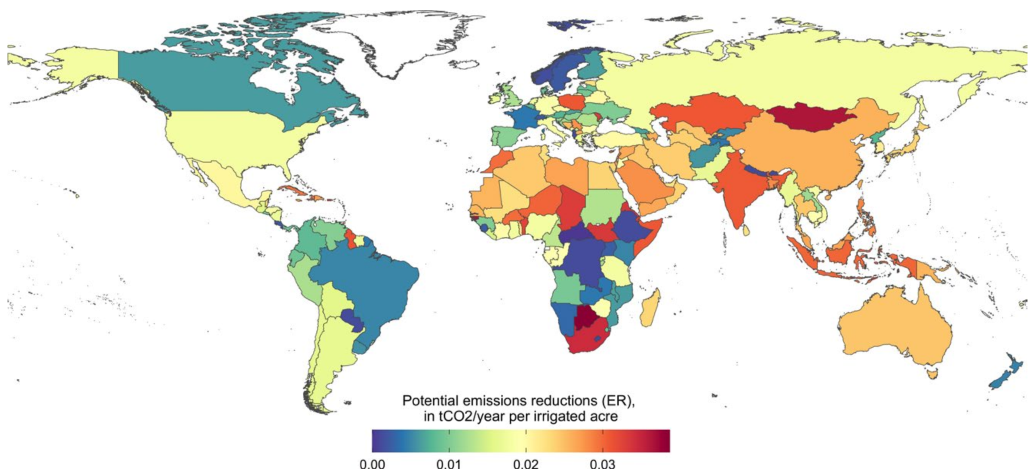


Figure 9: Estimated potential emissions reductions per rural capita replacing demand for woody biomass fuels with treated drinking water services.

Irrigation Efficiency

About 70 percent of global freshwater use from surface and groundwater sources is employed in agricultural activities [8] across more than 822 million acres [69]. A recent study estimated global energy demand for irrigation to be more than 6.6 GJ per year [70]. Using continent-level estimates for irrigated cropland [69] and representative national carbon intensity of electricity estimates [21] (China applied to Asia, the United States applied to the Americas, the United Kingdom applied to Europe, Kenya applied to Africa, and Australia applied to Oceania), we estimate that the total amount of emissions associated with irrigation today is more than 85 million tCO2e per year. A recent US-level irrigation energy intensity study combined with US carbon intensity suggests an even higher energy and emissions demand, at more than 22 million tCO2e per year [71]. Extrapolation of these US estimates suggests a global irrigation emissions potential of more than 315 million tCO2e per year. The wide range between these estimates may be attributable to an underestimate of water demand in the global model and consideration only of on-farm irrigation energy use, excluding transport by irrigation utilities.

Estimates of the potential energy and associated emissions savings associated with irrigation upgrades are sparse. A detailed evaluation of low-energy precision application (LEPA) irrigation technologies in Kansas identified a nearly 20 percent reduction in energy demand (while no reduction in overall water use) [72]. Applying this estimate of 20 percent globally indicates a potential GHG savings of between 17 and 63 million tCO2e per year.



| *Figure 10:* *Potential Total Global Addressable Credit Generation for Irrigation.*

Rice Cultivation

In low- to middle-income countries, rice plays a vital role in diets, constituting over a quarter of per capita caloric intake. However, this staple crop comes with a substantial environmental footprint, accounting for 30 to 40 percent of the world's annual freshwater consumption and contributing about 10 percent of global methane emissions [73]. These methane emission are primarily due to field flooding during rice cultivation; the anaerobic conditions created by flooding during cultivation foster the activity of methane-producing bacteria [74]. China is the largest producer of rice and holds a pivotal position in global emissions. Approximately 20 percent of the world's harvested rice area is in China, making it a significant emitter [75].

Innovative approaches are being implemented to reduce such emissions. Effective strategies involve the adoption of alternating wetting and drying cycles and intermittent flooding. These not only help to reduce methane production but also result in significant water savings [76]. A 2020 study (using a 2015 baseline) estimated that improvement of water management in rice cultivation and the use of alternative hybrids and soil amendments could save about 408 million tCO2e per year globally [39].

Both Gold Standard and Verra have methodologies for the reduction of methane emissions from adjusted water management practices in rice cultivation. The Gold Standard has a methodology dedicated to rice cultivation [77], developed with inputs from the International Rice Research Institute. Verra, on the other hand, has a broader methodology for improved agricultural land management [78].

Discussion

Energy Transition

The ongoing global transition from fossil fuels to renewable energy sources will have a significant impact on the emissions associated with centralized water treatment and transport, as well as implications for energy generation. Hydropower directly harnesses water for energy generation, while solar and wind, although indirectly affecting water use through manufacturing and cooling processes, contribute to a broader effort to decouple energy production from extensive water consumption. Moreover, a noteworthy aspect of this transition is the potential reduction in energy demand for critical water-related sectors, such as irrigation and water and wastewater treatment. However, significant sources of existing emissions from the water sector, namely wastewater management and drinking water treatment in low-income settings, may both produce reductions in emissions and increase electricity demand as basic services are extended.

Sustainable Development Goal Co-Benefits

Carbon credits generated from water projects offer significant co-benefits aligned with multiple United Nations Sustainable Development Goals (SDGs). Beyond contributing to SDG 6 (Clean Water and Sanitation), these projects address SDG 13 (Climate Action) by mitigating greenhouse gas emissions and often enhancing climate resilience in water systems. Additionally, improvements in water quality and ecosystem health can positively impact SDG 14 (Life Below Water) and SDG 15 (Life on Land) by preserving aquatic ecosystems and by promoting biodiversity. Furthermore, the involvement of local communities in water security initiatives may contribute to SDG 1 (No Poverty), SDG 8 (Decent Work and Economic Growth), and SDG 10 (Reduced Inequality) by fostering economic opportunities, sustainable livelihoods, and community development. In essence, carbon credits generated from water projects exemplify the interconnected nature of the SDGs, illustrating how

> Addressing one goal can lead to positive outcomes across various dimensions of sustainable development.

addressing one goal can lead to positive outcomes across various dimensions of sustainable development.

The two major registries we searched listed the SDG co-benefits of projects. Both the Gold Standard and Verra highlight the SDG co-benefits on project webpages and provide details in downloadable project documents. For projects registered by the Gold Standard, SDG impacts are validated as part of the overall certification process. The Gold Standard's SDG impact tool is used to quantify, monitor, and verify a project's SDG contribution [79]. Projects under Verra can be certified under the Sustainable Development Verified Impact Standard (SD Vista), which confirms that the projects have sustainable development benefits [80].

The significance of SDG co-benefits for carbon markets is underscored by recent research showing that projects with the potential for the greatest co-benefits obtained a price 30.4 percent higher than projects with minimal co-benefit prospects. Notably, project quality indicators like the Gold Standard, which signal a heightened likelihood of co-benefits, resulted in a substantial price premium, ranging from 6.6 to 29 percent [81].

Parallel Water Credit Markets

Some water sector and VCM stakeholders have suggested a potential for stand-alone water credits, developed and marketed separately from the VCM. However, existing examples of these so-called water credits, developed to demonstrate compliance with the US Clean Water Act [14] or the Water Benefit Certificates under the Gold Standard [15], have failed to show significant, scaled demand outside of a large market. The emerging methodologies and projects generating biodiversity credits may reveal if parallel crediting to carbon credits can generate significant demand and stable pricing.

Regulation, Governance and Additionality

Additionality in the voluntary carbon market emphasizes that the emissions reductions claimed by a project must be additional, meaning go beyond what would naturally occur without the project's intervention. In the context of governance and regulation, it's crucial to recognize that if a regulation already mandates certain emission reductions, a project subject to that regulation may not be considered additional.

> In the context of governance and regulation, it's crucial to recognize if a regulation already mandates certain emission reductions.

However, in the context of the water and wastewater sectors, the concept of additionality becomes nuanced when considering the enforcement of regulations in low-income countries. While a certain service may be mandated, such as clean drinking water access, the actual enforcement may be limited in lower-income settings, leading to a scenario in which the essential service is required but not readily available. In these cases, projects aiming to improve access to drinking water and safe sanitation could still be considered additional as they address a crucial need that regulatory frameworks may struggle to fulfill. Robust carbon credit governance frameworks must therefore carefully consider socioeconomic context and enforcement capacity when assessing additionality in projects within the water and wastewater sectors. This ensures a more nuanced and equitable approach that recognizes local context, such as the challenges faced by countries with limited resources in implementing and enforcing regulatory mandates.

Science-Based Targets for Water

The Science-Based Targets initiative for Freshwater (SBT freshwater) [82] is a framework designed to guide companies in setting ambitious, science-based targets for sustainable water management. Aligned with the broader Science-Based Targets initiative, SBT freshwater aims to address the specific challenges of water use by taking into consideration scientific principles and local context. Companies adopting SBT freshwater guidance principles commit to developing targets that help address water-related issues in the regions where they operate while acknowledging the importance of collaboration with stakeholders, continuous improvement, and transparency in reporting. This initiative encourages businesses to play a proactive role in mitigating water-related risks by promoting responsible water stewardship and aligning their efforts with global sustainability goals.

> Mitigating water-related risks by promoting responsible water stewardship and aligning their efforts with global sustainability goals.

Cost of Credit Generation

This report has not attempted to quantify the cost of the various interventions that would form the basis of reduced and removed emissions. This analysis has not attempted to estimate the cost of the various interventions that would result in emission reductions and removals, so it should not be assumed all projects, technologies or interventions would be economically viable without additional funding, subsidies or policy support. The cost of carbon credit generation within the water sector can, in many cases, exceed the pricing available upon sale of these credits. For example, the abatement costs of emissions from latrines have been estimated at roughly $50 per tCO2e to nearly $950 per tCO2e [83], dramatically exceeding, even at the low end, most of the current pricing of carbon credits. Similarly, drinking water services among high-, medium-, and low-income communities range from about $12 per person per year in Kampong Chamlong, Cambodia to almost $700 per person per year in Boulder, Colorado [84], exposing the necessary and appropriate subsidies already required to provide basic services.

DRINKING WATER SERVICES

$12 KAMPONG CHAMLONG, **CAMBODIA**

COST **PER PERSON** PER YEAR

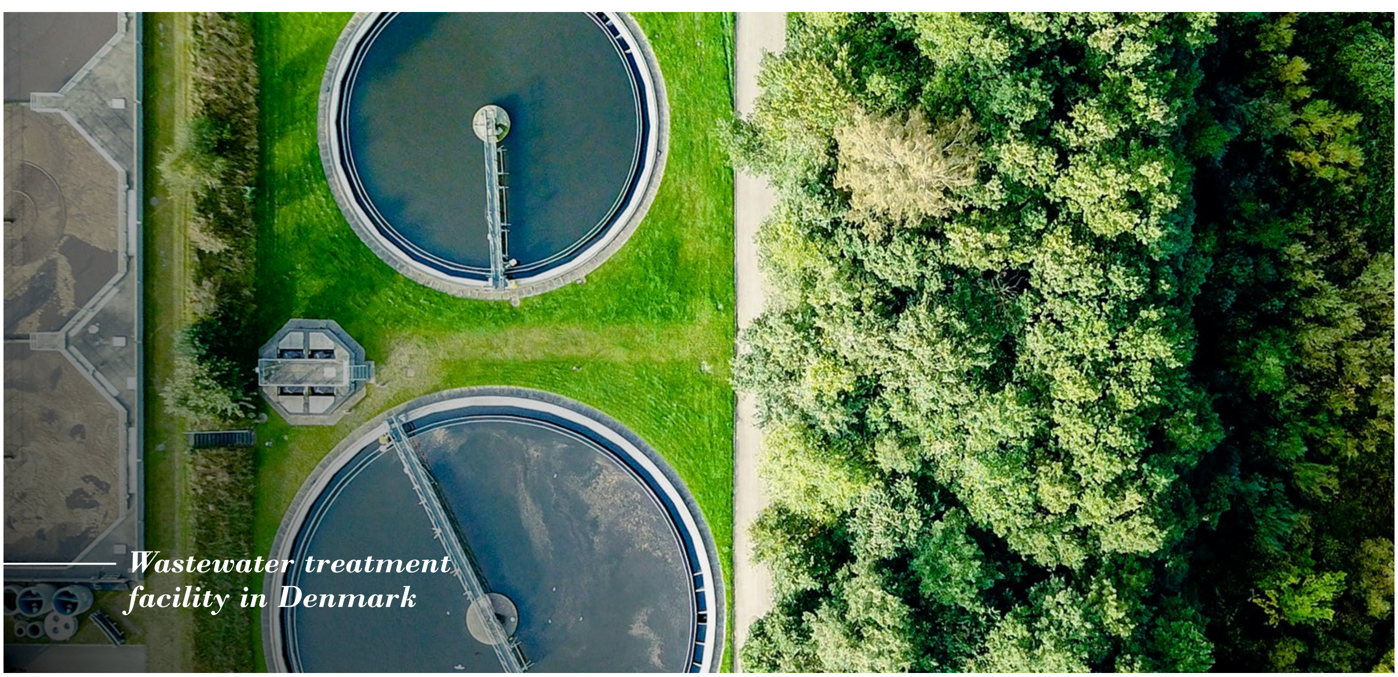
$700 BOULDER, **COLORADO**

Credit Demand

Voluntary demand, in both volume and pricing terms, for carbon credits varies. Some buyers optimize for large volumes at low prices, while others prioritize co-benefits and direct promotion of the activities generating credits. As described earlier, market research conducted in 2022 projected a potential a 20-fold increase in the demand for carbon credits by 2035, with prices rising to an estimated $80-$150 per tonne from the current $25 [18]. If these forecasts for both volume demand and pricing hold, then many carbon credit generating water programs may become viable without requiring bespoke pricing. However, it remains likely that many water programs will seek and require above-average pricing, and there will remain buyers willing to pay for these co-benefits.

Claims

Carbon credit buyers can prove their commitment to environmental sustainability by directing their investments towards projects that specifically enhance water treatment, water security, water quality, and watershed restoration [85]. By supporting initiatives that improve water treatment processes or implement innovative technologies in wastewater management, buyers contribute to cleaner water systems. Investment in projects promoting water security through efficient water use or sustainable water resource management demonstrates a commitment to



Wastewater treatment facility in Denmark addressing global water challenges. Projects focused on water quality enhancement can also involve measures to reduce pollution and to protect aquatic ecosystems. Supporting watershed restoration projects helps safeguard critical ecosystems, maintain biodiversity, and ensure the sustainable flow of clean water. Transparency and adherence to recognized standards remain paramount to substantiate these claims and to ensure the credibility of environmental contributions.

The Voluntary Carbon Markets Integrity Initiative Claims Code of Practice [85], launched in June 2023 addresses "integrity on the demand side by guiding companies and other nonstate actors on how they can credibly make voluntary use of carbon credits as part of their climate commitments and on how they communicate their use of those credits. It provides clarity, transparency, and consistency on what these commitments and claims mean and will give confidence to all those engaging with voluntary carbon markets. Together, VCMI and ICVCM work in close partnership to create and end-to-end model to achieve a voluntary carbon market with integrity, by providing clear guidance from both the demand and supply sides."

Benefit Sharing

Benefit sharing in the voluntary carbon market refers to the equitable distribution of environmental, social, and economic advantages that arise from carbon credit projects. It emphasizes the inclusion of local communities, indigenous groups, and other stakeholders in the project's success. This approach aims to ensure that the benefits extend beyond carbon, fostering sustainable development. Common mechanisms include revenue sharing, job creation, and community infrastructure projects. Implementing robust benefit-sharing provisions enhances transparency, social acceptance, and the long-term viability of carbon credit initiatives and aligns with the broader goals of environmental conservation and community well-being within the VCM. Recently, some countries have formalized requirements for benefit sharing in the tax code.

However, water security projects within the VCM are intrinsically benefit-sharing initiatives due to their direct and positive impact on local communities and ecosystems.

Recently, some countries have formalized requirements for benefit sharing in the tax code.

These projects, which often involve sustainable water resource management, watershed protection, and improved water infrastructure, inherently contribute to the well-being of communities by ensuring reliable access to clean water. Furthermore, as described above, water security projects in the VCM are often costly due to the complexity of infrastructure development, sustainable management practices, and ecosystem restoration. Therefore, given the substantial financial investments required, additional revenue sharing beyond the inherent benefits provided needs to be determined on a case-by-case basis, in consultation with all stakeholders in particular impacted communities.

Digital Monitoring, Reporting and Verification Technologies

Monitoring, reporting, and verification (MRV) is fundamental to carbon markets and involves the measurement of emission reductions caused by an activity and the reporting of those reductions to an authorized third party that then verifies them in order for carbon credits to be issued. The current MRV process is primarily a manual one, relying on the physical input of data, making it costly, time-consuming, and susceptible to error [86].

> Stage III technologies include Artificial intelligence (AI), Distributed Ledger Technologies, and Internet of Things (IoT) and are expected to be commercial in the future. These could significantly fast-track climate action efforts.

Digital monitoring, reporting, and verification (DMRV) plays a pivotal role in the VCM by enhancing transparency, accuracy, and efficiency in tracking emissions reductions and the impact of carbon offset projects. DMRV leverages digital technologies and data analytics to remotely monitor and report on project activities, providing real-time or near real-time insights into emission mitigation efforts. This digital approach not only reduces the administrative burden associated with manual monitoring but also enables more frequent and reliable reporting. Additionally, it enhances the credibility of carbon credits by improving the accuracy of emissions measurement and verification processes. By employing digital solutions, the VCM can achieve greater accountability and streamline the verification of emission reductions, thus contributing to the market's effectiveness and encouraging trust among stakeholders.

A DMRV system can facilitate project design, automated monitoring and data assimilation, robust verification, and data visualization [65]. DMRV technologies have been categorized into three stages. Stage I technologies are those that are already available, such as remote sensing, satellite imagery, and geographic information systems (GIS). In recent years, telemetry-connected electronic sensors have been developed and applied within water service programs [87, 65] to perform objective and continuous site-level monitoring for use and functionality [88, 89, 90, 91]. Stage II technologies are those that already exist but have not yet been fully exploited; they include cloud computing and mobile applications. Stage III technologies include Artificial intelligence (AI), Distributed Ledger Technologies, and Internet of Things (IoT) and are expected to be commercial in the future. These could significantly fast-track climate action efforts. The World Bank has developed an extensive list of DMRV schemes, categorized by systems for monitoring, reporting, and verification [92].

Key Insights from Stakeholder Interviews

In addition to a desk review of the current publications and portfolios, we conducted approximately two dozen interviews with stakeholders across the VCM. These represented project developers, investors, buyers, registries, intermediaries, carbon market associations, and industry standards bodies. Interviewees were asked to provide insights on the state of and opportunities within the VCM to help finance sustainable water initiatives.

The interviews specifically focused on topics related to:

Project Development

Descriptions of key milestones, challenges, and barriers in listing a program with a registry. Qualities of successful project developers.

Project Monitoring, Reporting, and Verification

Descriptions of challenges and barriers in implementation of methodologies. Potential gaps and areas of growth in methodologies. Insights on additionality, suppressed demand, and permanence.

Buyer Motivation

Reasoning and messaging for purchasing in VCMs.

Co-Benefits and High Integrity Designations

Importance of classification systems.

General Landscape for Growth

Factors that hinder and/or enhance the VCM. Potential areas of investment to scale the VCM.

Interviews were mostly conducted virtually with consent sought both to record and to attribute comments to the individual. All interviewees agreed to be recorded but many chose to stay anonymous. Interviews were reviewed and compared in order to identify areas of agreement and topics with less consensus. We present a summary of the interview findings here.

There is Large Potential for Growth in Water Sectors Related to Irrigation Efficiency, Wastewater Treatment, Non-Formal Sanitation Upgrades, and Humanitarian Contexts, but Verification Remains a Challenge

The VCM presents opportunities for growth in projects centered on irrigation efficiency, wastewater treatment, non-formal sanitation upgrades, and initiatives within a humanitarian context. These areas are critical in addressing global water challenges and contribute significantly to climate resilience and carbon sequestration. Enhanced irrigation efficiency, for example, may or may not conserve water but can reduce greenhouse gas emissions associated with water pumping and distribution. Similarly, improved wastewater treatment and sanitation upgrades play a pivotal role in reducing methane and other greenhouse gasses. They have substantial potential for environmental impact, thus offering fertile ground for the development of innovative carbon credit projects.

However, verification within the VCM framework remains a fundamental challenge to harnessing the potential of these types of projects. The complexity of quantifying carbon benefits in programs such as wastewater treatment or sanitation upgrades presents a significant hurdle. These projects often involve varied and intricate processes that are not easily quantifiable in the terms required to generate carbon credits. For instance, accurately calculating the carbon reduction from improved sanitation facilities or from more efficient irrigation practices demands robust, detailed methodologies that can address the specificities of these activities. The current lack of standardized, universally accepted methods for such verification is a hindrance to the scalability and marketability of these otherwise impactful projects.

Aerated activated sludge tank

> There is a need for innovative approaches in monitoring and verification that are both cost-effective and scientifically sound.

Addressing these gaps would require concerted efforts from multiple stakeholders in the VCM, including policymakers, project developers, scientists, and investors. Developing comprehensive methodologies that can accurately capture the carbon reduction potential of water-related projects is a critical step forward. There is a need for innovative approaches in monitoring and verification that are both cost-effective and scientifically sound. Such advancements would not only catalyze the growth of these projects within the VCM but also ensure their effectiveness and credibility. As the market evolves, bridging these verification gaps will be key in unlocking the vast potential of projects in irrigation efficiency, wastewater treatment, and sanitation and thus contributing to global climate goals.

Water as a Co-Benefit to Carbon Credits can Increase the Attractiveness of VCM Projects and Therefore Increase Credit Prices, but this Potential is Specific to a Buyers' Business Sector, Corporate Strategy Objectives, and Direct Relationship with Project Developers

Many interviewees said that corporate entities pay a premium for VCM credits that have quantified co-benefits. Further, the clearer the link between the water co-benefit and an existing carbon project, the easier it is to sell. Additionally, many interviewees noted the importance of water as a co-benefit, especially for those companies that have policy objectives related to water or had a water component in their supply chain. One interviewee said that a water component with solid benefits could be a deciding factor in choosing one project over another. At the same time, many interviewees noted that the water co-benefit was attractive because it relates to larger values around sustainable livelihoods and human health. Still, some were skeptical or had little experience with water being considered as a co-benefit and deemed it to be an added advantage but not the primary motive in purchasing.

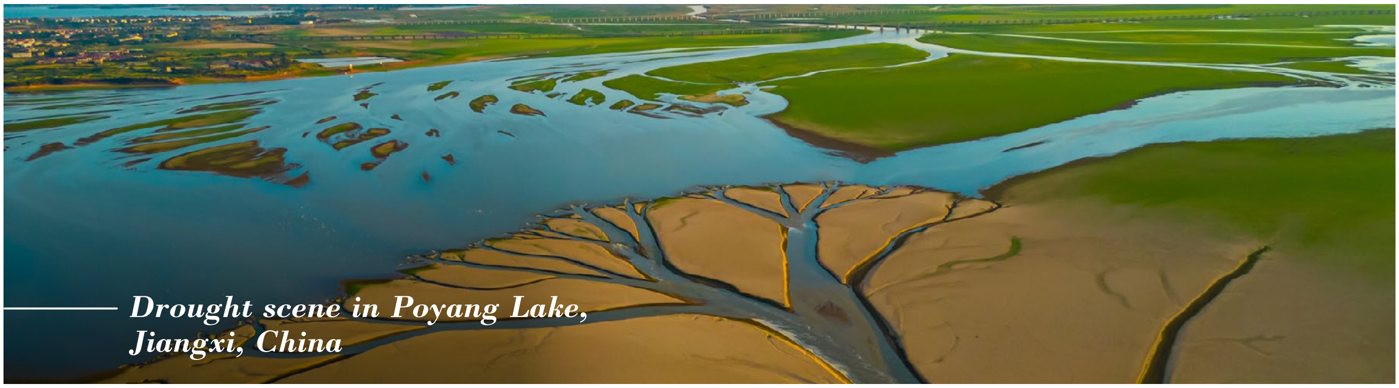
Optimism is Shared Across the Sector, Accompanied by Calls for More Robust Verification Technologies and Practices for Water Monitoring in Order to Ensure Integrity and Combat Negative Perceptions

Most interviewees were enthusiastic about the growth of the water sector in the VCM and emphasized the potential for the VCM to play a major role. However, interviewees stressed the need to move forward thoughtfully and with a high degree of transparency. Further, interviewees noted that the VCM has made important strides toward becoming more credible, noting new methodologies and standards that have “really raised the bar.” One project developer said that “the [new] requirements for monitoring are incredibly high,” which has resulted in “the creation of a lot of innovation.” Overall, interviewees were confident about growth within the VCM but would like to see “high integrity” as the primary brand and focal point moving forward.

The Challenges of Registering and Monitoring Water Projects within the VCM Discourage Even Well-Established Water Organizations from Entering The Market

Project developers interested in the water sector face the many challenges already recognized with the registry of any carbon mechanism, including the need for upfront capital, a long runway, and the risk inherent in a volatile market. Water project developers involved with a range of implementation technologies, including borehole rehabilitation, chlorine dispensers, and water mini-grids, all noted that registration took several years and that entering the market required both “grit and belief.” Aspiring water project developers view the methodologies across all VCM registries as complex, with even the most sophisticated monitoring and evaluation departments needing to hire carbon specialists to wade through the requirements. This has likely led to the majority of carbon developers in the water sector, with a few exceptions, wholly or mostly specializing in only carbon for water projects. The unique and comprehensive data collection needs of water methodologies deter more mature water organizations, as integration into common operations and monitoring frameworks is difficult. More generally, uncertainty regarding the future viability of the VCM is the most common sentiment among potential water developers in entering the carbon market.

> All noted that registration took several years and that entering the market required both “grit and belief”



Successful Water Project Developers Must Be Able to Optimize Water Methodologies While Maintaining Genuine Connections to Local Communities

Water project developers who successfully register must then navigate the monitoring, reporting and verification process. Interviewees conveyed how difficult it can be to do so efficiently. In order to be profitable, project developers must know how to maximize the parameters within the methodologies. Further, changes in the methodologies may have a large impact on the processes project developers have created. One example given was the Gold Standard drinking water methodology, which was significantly changed in 2021 as a result of a grievance investigation. Consequently, the resulting methodology required project developers to introduce new processes and included restrictions on some parameters, which resulted in lowering the amount of emission reductions that could be realized. Audits were also mentioned as a major pain point, as finding an auditor, particularly one with local experience, can be time-consuming and costly. Interviewees noted that navigating the MRV process can be particularly difficult for small project developers, who have challenges in terms of technical capacity and who are "being squashed by the… larger developers."

However, once MRV systems are put in place, successful project developers find them easy to replicate and appropriate, as long as there is enough potential for scale within the program. Many buyers noted that they only purchase from "trusted sources" who can demonstrate their ability to get through the process. Unfortunately this can lead to only highly experienced companies with solid track records getting commitments from buyers and to newcomers facing significant barriers on the demand side. Finally, the need for experience at scale was highly emphasized, and interviewees across the spectrum noted the importance of local relationships. "Successful project developers are really intentional with, first and foremost, that community engagement aspect and getting buy-in from local communities, because that really ensures that the project will be sustainable for those community members." With all of this in mind, project developers have the difficult task of showing a depth of experience, from methodology optimization to contextualization down to the community level.

Better Articulation of the Interplay Between Carbon Emission Reductions and Water Security Could Strengthen the Supply of and Demand for Projects

Many differing viewpoints were shared on connecting carbon and water. On one side, interviewees expressed skepticism about linking the two, noting that "it's hard enough as it is" and that "carbon and water, in my world, are very separate." At the same time, these interviewees did not want to diminish the importance of the water sector, calling for water projects to be their own "unique commodity" whereby water benefits could be quantified outside the realm of a carbon credit. Further, this set of interviewees articulated a general desire for more simplification within the VCM and said the linking of carbon and water added layers of unnecessary complexity. Others shared more optimism and saw opportunity in keeping the two connected. "There's a big nexus between the sort of things we can do to help improve water… and [to] address the climate crisis. The overlap in the Venn diagram exists and should be further explored and fleshed out."

Some said that the VCM could be the right tool for this, given how adaptive it is. Still, interviewees stated that the carbon market may not be appropriate for all water contexts and that a clear understanding and enumeration of the crossover is needed for future growth.

Case Studies

The following section presents a cross section of example water-related carbon credit programs, bringing to life these potential solutions at the interface of water security and the voluntary carbon market. These examples are illustrative, and do not imply an endorsement by the authors or sponsors of this report. Further, several examples in Kenya and Rwanda have included several authors of this report as developers.

Blue Carbon in West Bengal

The Sundarbans in the Indian state of West Bengal is the largest contiguous mangrove forest in the world. Over the last four decades, climate change has caused rapid deterioration, with more than 28 percent of its habitat lost. In order to strengthen this fragile ecosystem, Livelihoods Venture and the Nature Environment and Wildlife Society (NEWS) launched a program to restore more than 16 million mangroves. During the life of the program, which begin in 2011 and is slated to last 20 years, more than 5,000 hectares will be restored, equating to more than 700,000 tonnes of CO2 sequestered [93, 94]. The mangrove program is part of the Livelihoods Carbon Funds (LCF), which link project developers, corporations, and social impact investors to implement nature-based programs that contribute to climate change mitigation. Companies that invest in the LCF receive certified carbon credits, mainly through the Gold Standard and Verra. In addition to the climate benefits, LCF programs include co-benefits, such as providing new income streams. In the case of the mangrove program, new income is being generated through the sale of the increased numbers of crabs, shrimps, and mollusks. Moreover, the mangroves have provided additional food supplies and timber production for communities living in the Sundarbans. An estimated 250,000 people will be impacted by the program during its 20-year lifespan.

Irrigation in Italy

Rice is one of the most important food sources globally, with the regions of Asia, Sub-Saharan Africa, and South America consuming the majority of it. In low- to middle-income countries, rice represents over a quarter of the per capita caloric intake while accounting for between 30 and 40 percent of the world's annual freshwater consumption and producing over 10 percent of total global methane emissions [73]. Rice paddies produce methane through the process of methanogenesis; in flooded rice fields, bacteria break down organic matter in the soil without oxygen, leading to the release of methane as a byproduct. Various methods can be used to reduce methane

> Rice is one of the most important food sources globally

production, such as intermittent flooding, water-saving techniques, and alternating wetting and drying cycles [76]. In 2022, the company Netafim announced a program that allowed rice farmers using its drip-irrigation system to earn carbon credits. Drip irrigation eliminates the need for flooding, thus reducing water use by 70 percent and lowering methane emission to almost zero. The first program was to be registered with Verra and implemented in Venice, Italy [73].

Rice field

CASE STUDIES

Pumping Efficiency in Armenia

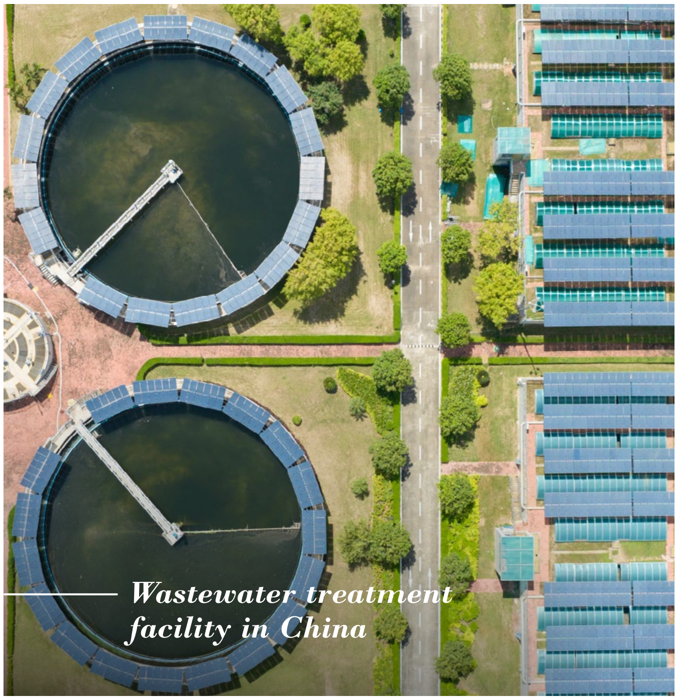
In 2000, Yerevan faced widespread dissatisfaction with its water services. The Yerevan Water and Sewerage Enterprise (YWSE) operated an under-maintained system with unreliable and inefficient pumps. Outdated infrastructure resulted in inadequate water supply, with 80 percent of residents receiving tap water for only six hours a day. Insufficient water pressure, especially in upper-floor apartments, prompted residents to invest in storage tanks and expensive booster pumps.

> The project yielded significant energy efficiency gains, reducing YWSE's largest O&M cost item—energy consumption—by 30 percent.

Financially, the utility struggled to cover its operation and maintenance (O&M) costs. In 2001, YWSE engaged in a performance-based management contract with Acea, a private operator. Investing $24 million, Acea converted the water supply at one station from pumped to gravity fed by laying out pipes from a river to transmission mains. Acea also adjusted pump impellors and upgraded three pumps to match demand. At three other pumping stations, Acea replaced old pumps with newer, more energy-efficient ones.

The project yielded significant energy efficiency gains, reducing YWSE's largest O&M cost item—energy consumption—by 30 percent. Despite increased service levels, energy use dropped to 169 million kWh in 2003 from 240 million kWh in 1999. This resulted in an annual CO_2 emissions reduction of 27,690 tonnes of CO_2e [24]. The energy savings translated into an estimated $4.83 million in annual electricity costs, significantly improving the water utilities' bottom line. Moreover, the project strengthened the overall operation of the water sector and improved service for Yerevan residents. By 2004, customers enjoyed an 18-hour daily water supply, a substantial improvement over the six hours in 2000 [95].

Wastewater Treatment in China



Wastewater treatment facility in China

In the Guangdong province in southeast China, the Profit Carbon Environmental Energy Technology Co. implemented a wastewater treatment project to generate carbon emission reductions [96]. The Yunshui Wastewater Treatment Plant Project includes the construction and operation of 16 wastewater treatment facilities with a total maximum design influent flow of approximately 175,000 cubic meters per day. The wastewater comes from both domestic sewage and industrial sources within the Guangdong province. Before the program, deep open anaerobic lagoons were used for water treatment, releasing methane directly into the atmosphere. The new wastewater treatment plants use an aerobic process that includes pre-treatment, secondary biological treatment, tertiary deep treatment, and a final sludge treatment process. The aerobic process reduces the methane emissions to nearly zero. The project is registered with Verra and operations began in 2020. The program is expected to produce about 80,000 tCO2 of emission reductions per year, with the total emission reductions estimated at nearly 800,000 tCO2 over the ten-year crediting period. As of May 2023, more than 172,000 carbon credits have been issued.

Citywide Scheduled Desludging in Malindi, Kenya

Malindi, a tourist town with a population of about 120,000, relies on overstretched on-site sanitation systems. Of the 94 percent of the population that depend on on-site sanitation, only 11 percent get their pit latrines or septic tanks emptied. There are no facilities for treatment of the fecal sludge and septage that is emptied. Unemptied and improperly dumped sludge leaches into groundwater, with 90 percent of wells testing positive for fecal contamination. Unemptied sludge also emits methane due to the anaerobic conditions in which it is stored in situ. Based on calculations done on emissions from similar sanitation technologies in Kampala, Uganda, we estimate that unemptied sludge in Malindi likely emits more than 1,000 metric tonnes of methane per year [97, 42, 98, 99].

USAID, through its WASH-FIN 2 program, is conceptualizing a citywide desludging program for Malindi in which a private operator would provide emptying and transport services to the entire municipality under a public-private partnership (PPP) agreement with the city. Emptied sludge would be delivered to a fecal sludge treatment plant (FSTP) that would process fecal solids into briquettes usable as cooking fuel. Liquids would be treated and then safely disposed of into the environment.

Malindi, Kenya

Implementing a citywide desludging program would reduce sanitation-related methane emissions in Malindi by 17 percent, based on measurements of emissions from sanitation technologies in Uganda. The reduction is achieved by diverting organic matter that would break down anaerobically in containment or treatment to the FSTP's briquetting process, where it remains inert until the briquettes are burned as cooking fuel. When burned, the organic material combusts as carbon dioxide, producing only 1/28th of the global warming potential of methane and offsetting the consumption of unsustainably produced wood and charcoal.

Sludge briquettes can reduce deforestation by reducing the demand for firewood and charcoal. Further- more, a citywide desludging program in Malindi would prevent pit latrines from overflowing during heavy rains and the unregulated dumping of fecal sludge into the environment. Aside from the significant public health benefits of reducing such incidents, maintaining a pristine environment is especially important in a community whose local economy relies on tourism.

Drinking Water

Rwanda

After neonatal disorders, pneumonia and diarrhoeal disease are the two leading killers of children under five years of age in Rwanda [100]. Unsafe drinking water is the leading cause of diarrhoeal disease and cooking indoors on open-fire stoves with fuels such as wood and charcoal has been linked to pneumonia, low birth weight, and impaired development in children [101]. Given the extent of reliance on firewood and the lack of access to safe drinking water, as well as to opportunities and mechanisms to engage directly with national and local government entities, a number of project developers have moved forward with carbon-financed drinking water projects in Rwanda at varying levels and scales. Here, we will highlight programs implemented at the household, community, and institutional levels. In 2007, several of the authors led the development and implementation of the first-ever United Nations Clean Development Mechanism program earning carbon credits for water delivery, followed in 2010 by the first-ever Gold Standard voluntary program. Through these programs, tens of millions of dollars of private financing was leveraged to deliver household water filters to millions of people in Rwanda and Kenya, with revenue from carbon credits largely re-invested into education, repairs, and replacements and resulting in significant health, economic, and environmental benefits [102, 103, 104, 105, 101].

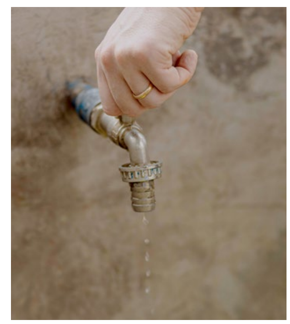
The Tubeho Neza Program, launched in 2012, paired household water filters with improved cookstoves in order to reduce emissions and improve health, especially for children younger than five. Following certification by the Rwanda Standards Board, project developer DelAgua and the Rwanda Ministry of Health selected the Vestergaard Frandsen LifeStraw Family 2.0 household water filter and the EcoZoom Dura portable wood-burning cookstove for implementation. Working with the Rwanda National Police and the Ministry of Health, DelAgua reached more than 101,000 households with these water filters and cookstoves. In 2015 they distributed an additional 250,000 cookstoves to serve nearly a million more people. Community health workers advised communities and households about proper use of these products and subsequently visited each household regularly for a year to encourage adoption and to perform any repairs that were needed. From 2012 to 2016, the London School of Hygiene and Tropical Medicine and Emory University evaluated the program. They looked at the design, the adoption rate, and at the impacts on water quality, air quality, respiratory disease and diarrhoea. They also considered the carbon credit financing mechanism. Their study was published in 2019 and showed promising results. Among children under five, the intervention reduced the seven-day prevalence of reported diarrhoea by 29 percent and acute respiratory infection by 25 percent [101]. Beyond the directly measured health impacts, researchers also analyzed the overall program costs and benefits. There were savings in wood fuel of an estimated 65,000 tonnes, enough to reverse deforestation in the region for a few years. The total program cost over five years was nearly $12 million, while the total benefit was estimated at more than $66 million. These results suggest that the program was cost-effective in reducing wood fuel use, improving drinking water quality, and reducing the risk of diarrhoea and respiratory illness among children under the age of five [103].

More recently, the Rwandan social enterprise Water Access Rwanda has been leveraging carbon markets in combination with other funding sources to rapidly reach scale through community water supply. Their first project, Water for Climate, was launched in 2017 and was focused on providing safe drinking water at the community level through hand pumps and piped water networks. To date, they have installed or rehabilitated about 50 hand pumps and 10 piped water networks, resulting in an estimated 70,000 tonnes of reduced CO_2 emissions. Under this project, community members do not pay to access water from hand pumps and pay a small fee for water delivered

> To date, they have installed or rehabilitated about 50 hand pumps and 10 piped water networks, resulting in an estimated 70,000 tonnes of reduced CO_2 emissions.

through piped networks. Water Access Rwanda was able to provide these subsidies using funds from the up-front sale of carbon credits to Spadel, a Belgian bottled water provider. The proceeds also paid for ongoing monitoring and maintenance of the supply systems. Based on the success of Water for Climate, Water Access Rwanda began to explore how to utilize carbon financing in their other projects, in combination with grants and private financing. In 2020, Water Access Rwanda launched Inuma Safe Water, which focuses on distributing water through "mini-grids", or small, piped networks reliant on solar-powered pumps. The objective is not to fully cover costs through the sale of carbon credits but rather to recoup initial investments and be able to attract more private financing. To that end, they negotiated a floor price with EKI Energy Services; the two entities will split the difference if a higher price is obtained when the credits are sold. Executive Director Christelle Kwizera anticipates that Water Access Rwanda will be able to leverage the $7.5 million they have raised in 2023 and, through re-investing the revenue from the sale of carbon credits in their water services, achieve up to $14 million in total investment to be able to serve 360,000 people.

At the institutional level, project developer Virridy launched a program in July 2023 aimed at providing safe drinking water in 1,000 schools. This program will implement ultrafiltration drinking-water treatment technologies in rural primary and secondary schools that serve at least 400 students, are public or government-aided, are not connected to the public water utility, and are reliant on drinking water sources that test positive for microbiological contamination. District-level governments sign collaboration agreements prior to implementation, as do school headmasters prior to treatment installation. School administrators commit to making staff available for ongoing operation and maintenance, while Virridy staff commit to installing treatment systems, training school staff in operations and maintenance, educating students on water sanitation and hygiene, and providing ongoing monitoring and maintenance visits and remote support for the duration of the program.



Nigeria

In Nigeria, there is both low access to safely managed drinking water and high reliance on the burning of biomass for cooking. Nationally, 11.7 percent of the population has access to piped water and 3.5 percent has piped water in the home [106]. Reliance on solid fuels for cooking is particularly high in rural areas, with 83 percent of rural populations relying on firewood and 3 percent using charcoal (compared to 42.1 percent and 11.8 percent, respectively, in urban areas) [107].

Impact Carbon's Improved Cookstove and Safe Water Program was launched in 2021 to provide safe drinking water in schools and other institutions in Nigeria through the implementation of low greenhouse gas water purification systems (WPS). The stated intent of the program is to "use carbon finance to support local partners engaged in operation, sales and distribution, and maintenance of various WPS technologies." [108] To date, Impact Carbon and its partners have implemented chlorination in approximately 20,000 schools in Nigeria.

This program, along with a parallel program in Kenya, was an expansion of Impact Carbon's successful project in Uganda, with both Nigeria and Kenya chosen based on market size. These efforts were made possible through an Emissions Reductions Purchase Agreement (ERPA) in which the Norwegian government committed to buying the credits produced by implementing clean water programs in approximately 30,000 schools in Nigeria and Kenya. The Norwegian government did not provide any funding up front, but the ERPA made it possible for Impact Carbon to raise money through impact investment.

Impact Carbon has worked to navigate uncertainty around corresponding adjustments under Article 6 of the Paris Agreement by cooperating directly with the Nigerian government through workshops for capacity building and partnership that were funded by a grant from ZdK (Foundation Future of the Carbon Market). Despite these efforts and the receptivity of the Nigerian government, the infrastructure is not yet in place to account for and issue corresponding adjustments.

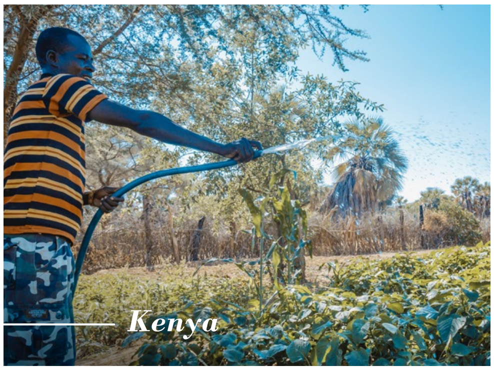
Kenya

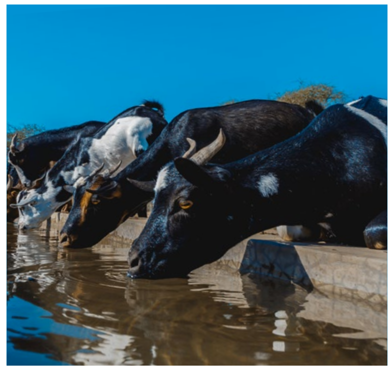
Kenya

Climate change-driven drought and challenges in maintaining emergency groundwater supplies has led to millions of people living in the arid regions of Kenya lacking safe, reliable, and affordable drinking water throughout the year [90, 109, 110, 111]. Typically, the response to drought has been reactive. Kenyan government and international emergency assistance is dispatched in extreme situations in a bid to save lives and livelihoods. This support then disappears when the immediate crisis dissipates. This reactive approach is the norm, despite drought in northern Kenya being cyclical and increasing.

> Kenyan government and international emergency assistance is dispatched in extreme situations in a bid to save lives and livelihoods.

In the past decades, millions of dollars have been spent throughout northern Kenya on the installation of borehole pumps so that people can access groundwater. However, evidence shows that local communities and regional governments are not yet able to manage the operations, maintenance, and service delivery of groundwater. This is because they lack funding and professional capacity, including maintenance training, asset management tools, supply chains, and financially viable service contracts [112, 113]. As a result, there have been a high number of water point failures. For example, about 35 percent of rural water points in Kenya were non-functional before the 2016 drought. This increased to roughly 55 percent during the drought because of mechanical failures or depleted groundwater [114].





Vietnam

In 2023, the World Bank announced a five-year $50 million Emission Reduction-Linked Bond that allows investors to earn returns linked to the generation of voluntary carbon credits tied to a water purifier project in Vietnam [115, 116, 117]. The Vietnamese Ministry of Education and Training will distribute the water purifiers to schools and institutions throughout the country. They are provided for free to the beneficiary kindergartens, nurseries, primary schools, secondary schools, high schools, and community homes, that were selected due to a prior lack of access to safe drinking water. The project aims to manufacture 300,000 water purifiers and distribute them to approximately 8,000 schools and institutions. It is expected to make clean water available to around two million children and to reduce greenhouse gas emissions by almost 3 million tonnes of carbon dioxide over 5 years.

The bond is an outcome-based financial instrument that mobilizes private capital to support the financing of a project with positive climate and development impacts, with outcomes measured by the generation of carbon credits. Through the transaction, investors are supporting the up-front financing required to manufacture and distribute the water purifiers, the use of which will reduce the burning of biomass traditionally employed in boiling water for safe consumption. In addition to reducing greenhouse gas emissions, use of the purifiers will help improve air quality, reduce associated health impacts, lower the fuel costs and effort previously required to purify water, and help reduce deforestation.

To interrupt this negative cycle, the Millennium Water Alliance, Virridy and the University of Colorado Boulder developed the Drought Resilience Impact Platform-Fixing Uptime Now and Decision Improvement (DRIP FUNDI), a USAID Bureau of Humanitarian Assistance (BHA)-funded program. DRIP FUNDI aims to secure reliable water supplies for 120,000 people living in Northern Kenya.

To address the underlying factor of inadequate finances for repair, MWA and Virridy, supported by the Autodesk Foundation, are in the process of registering the DRIP FUNDI program under the Gold Standard. The carbon credit revenue is slated to be used for continued borehole repair once the funding period for the program elapses in March 2025. Carbon credits will be produced from increased borehole uptime and, when needed, water treatment, which will reduce both the use and demand for communities to boil unsafe water with wood and fossil fuels. Over 70 percent of the revenue generated from the carbon credits will be used to deliver an on-going water pump maintenance service.

Acknowledgements

This report was prepared by the Mortenson Center in Global Engineering at the University of Colorado Boulder and Castalia Advisors, and supported by the Autodesk Foundation, the Gold Standard, HSBC, the Moore Foundation, National Science Foundation (Award #P23-000295), Resilient Water Accelerator, the Voluntary Carbon Markets Integrity Initiative, Walton Family Foundation, and WaterAid. The views and opinions expressed in this report are only those of authors. We thank the expert stakeholders who participated in interviews and provided resources.

References

[1] World Health Organization, World Bank, and UNICEF. State of the World's Drinking Water. Technical report, 2023. URL https://www.unicef.org/reports/state-worlds-drinking-water.

[2] Mesfin M. Mekonnen and Arjen Y. Hoekstra. Sustainability: Four billion people facing severe water scarcity. *Science Advances*, 2(2), 2016. ISSN 23752548. doi: 10.1126/sciadv.1500323.

[3] Peter H. Gleick and Morgan Shimabuku. Water-related conflicts: definitions, data, and trends from the water conflict chronology. *Environmental Research Letters*, 18(3), 2023. ISSN 17489326. doi: 10.1088/1748-9326/acbb8f.

[4] Tomás Bredariol. Clean energy can help to ease the water crisis, 2023. URL https://www.iea.org/commentaries/clean-energy-can-help-to-ease-the-water-crisis.

[5] International Energy Agency. Water energy xexus- Excerpt from the world energy outlook 2016. *International Energy Agency*, 2016.

[6] GIZ. Stop Floating, Start Swimming Water and climate change – interlinkages and prospects for future action. Technical report, 2020. URL https://everydrop-counts.org/imglib/pdf/Water%20Climate%20Report%202020.pdf.

[7] International Energy Agency (IEA). Tracking Transport. Tracking *Transport*, (May 2019), 2019.

[8] World Wildlife Foundation. High Cost of Cheap Water: The True Value of Water and Freshwater Ecosystems to People and Planet. Technical report, 2023. URL https://wwfint.awsassets.panda.org/downloads/wwf-high-cost-of-cheap-water--final-lr-for-web-.pdf.

[9] Dustin E. Garrick, Michael Hanemann, and Cameron Hepburn. Rethinking the economics of water: An assessment. *Oxford Review of Economic Policy*, 36(1), 2020. ISSN 14602121. doi: 10.1093/oxrep/ grz035.

[10] Sophie Webber, Sara Nelson, Nate Millington, Gareth Bryant, and Patrick Bigger. Financing Reparative Climate Infrastructures: Capital Switching, Repair, and Decommodification. *Antipode*, 54(3), 2022. ISSN 14678330. doi: 10.1111/anti.12806.

[11] Samantha Kuzma, Marc F.P. Bierkens, Shivani Lakshman, Tianyi Luo, Liz Saccoccia, Edwin H. Sutanudjaja, and Rens Van Beek. Aqueduct 4.0: Updated Decision-Relevant Global Water Risk Indicators. *World Resources Institute*, 2023. doi: 10.46830/writn.23.00061.

[12] Ecosystem Marketplace. Ecosystem Marketplace Insights Report: Paying for Quality. State of the Voluntary Carbon Markets. Technical report, 2023. URL www.forest-trends.org.

[13] IEA. Unlocking the potential of direct air capture: Is scaling up through carbon markets possible? – Analysis - IEA, 5 2023. URL https://www.iea.org/commentaries/unlocking-the-potential-of-direct-air-capture-is-scaling-up-through-carbon-markets-possible.

[14] Alex H. Johnson and Joe S. Whitworth. Enabling ecological restoration through quantification. In *Broken Pumps and Promises: Incentivizing Impact in Environmental Health*. 2016. doi: 10.1007/978-3-319-28643-3{\ }7.

[15] The Gold Standard. Gold Standard Water Benefit Certificates, 2022. URL https://www.goldstandard.org/articles/gold-standard-water-benefit-certificates.

[16] Sylvera. The State of Carbon Credits 2023. Technical report, 2023. URL https://www.sylvera.com/resources/the-state-of-carbon-credits-report.

[17] Gold Standard. Gold Standard on LinkedIn: Gold Standard Issuances and retirements 2021-2023 , 11 2023. URL https://www.linkedin.com/posts/gold-standard_gold-standard-issuances-and-retirements-2021-ugcPost-7127656839147581440-2E3A/?utm_source=share&utm_medium=member_ios.

[18] Ernst and Young. Essential, expensive and evolving: The outlook for carbon credits and offsets An EY Net Zero Centre report. Technical report, 2022. URL https://assets.ey.com/content/dam/ey-sites/ey-com/en_au/topics/sustainability/ey-net-zero-centre-carbon-offset-publication-20220530.pdf.

[19] Ecosystem Marketplace. 2023 All in on Climate: The Role of Carbon Credits in Corporate Climate Strategies. Technical report, 2023. URL https://www.ecosystemmarketplace.com/publications/2023-em-all-in-on-climate-report/.

[20] European Investment Bank. *2022 Joint Report on Multilateral Development Banks' Climate Finance*. 2023. URL https://www.afdb.org/sites/default/files/documents/publications/joint_mdb_climate_finance_report_2022.pdf.

[21] Our World in Data. Carbon Intensity of Electricity and Global Burden of Disease. URL https://ourworldindata.org/grapher/carbon-intensity-electricity.

[22] World Bank. IBNET - waterdata. URL https://wbwaterdata.org/ibnet/.

[23] WHO/UNICEF JMP. JMP. URL https://washdata.org/data/household#!/.

[24] Harmonized Grid Emission factor data set — UNFCCC, 7 2019. URL https://unfccc.int/documents/198197.

[25] Alan Wyatt and Mohammad Alshafey. Non-revenue water: Financial model for optimal man-agement in developing countries - Application in Aqaba, Jordan. *Water Science and Technology: Water Supply*, 12(4):451–462, 2012. ISSN 16069749. doi: 10.2166/WS.2012.014. URL https://www.researchgate.net/publication/263193365_Non-revenue_water_Financial_model_for_optimal_management_in_developing_countries_-_Application_in_Aqaba_Jordan.

[26] Guy Hutton and Mili Varughese. The Costs of Meeting the 2030 Sustainable Development Goal Targets on Drinking Water, Sanitation, and Hygiene. 2016. URL https://documents1.worldbank.org/curated/en/415441467988938343/pdf/103171-PUB-Box394556B-PUBLIC-EPI-K8543-ADD-SERIES.pdf.

[27] International Water Association. Leakage Emissions Initiative: Establishing a Standard Carbon Balance for Drinking Water Utilities. 4 2023. URL https://iwa-network.org/wp-content/uploads/2023/06/Water-Loss-SG-White-Paper-on-Leakage-Emissions-Initiative.pdf.

[28] ESMAP. A Primer on Energy Efficiency For Municipal Water and Wastewater Utilities Technical Report 0 0 1 / 1 2. Technical report, 2012. URL https://www.esmap.org/sites/default/files/esmap-files/FINAL_EECI-WWU_TR001-12_Resized.pdf.

[29] UNFCCC. CDM: Baseline methodology for water pumping efficiency improvements — Version 2.0, . URL https://cdm.unfccc.int/methodologies/DB/TH0MTJC0KYJYYMQLL9B71Q9QJHOPZ9.

[30] P. Jenicek, J. Kutil, O. Benes, V. Todt, J. Zabranska, and M. Dohanyos. Energy self-sufficient sewage wastewater treatment plants: is optimized anaerobic sludge digestion the key? *Water Science and Technology*, 68(8):1739–1744, 10 2013. ISSN 0273-1223. doi: 10.2166/WST.2013.423. URL http://iwaponline.com/wst/article-pdf/68/8/1739/472538/1739.pdf.

[31] IEA. Introduction to the water-energy nexus , 3 2020. URL https://www.iea.org/articles/introduction-to-the-water-energy-nexus.

[32] UNFCCC. CDM: Renewable electricity generation for captive use and mini-grid — Version 5.0, . URL https://cdm.unfccc.int/methodologies/DB/XKCRT4QQUUWXXZMQRXUGES0WON451M.

[33] Cara D. Beal, Thulo Ram Gurung, and Rodney A. Stewart. Demand-side management for supply- side efficiency: Modeling tailored strategies for reducing peak residential water demand. *Sustainable Production and Consumption*, 6:1–11, 4 2016. ISSN 2352-5509. doi: 10.1016/J.SPC.2015.11.005.

[34] Halidu Abu-Bakar, Leon Williams, and Stephen Henry Hallett. A review of household water demand management and consumption measurement. *Journal of Cleaner Production*, 292:125872, 4 2021. ISSN 0959-6526. doi: 10.1016/J.JCLEPRO.2021.125872.

[35] Mosisa Teferi Timotewos, Matthias Barjenbruch, and Beshah M. Behailu. Setting a Baseline Residential Water Demand Management Solution in Urban Towns of Ethiopia. *Water 2023*, Vol. 15, Page 930, 15(5):930, 2 2023. ISSN 2073-4441. doi: 10.3390/W15050930. URL https://www.mdpi.com/2073-4441/15/5/930.

[36] UNFCCC. CDM: Demand-side energy efficiency activities for installation of low-flow hot water savings devices — Version 2.0, . URL https://cdm.unfccc.int/methodologies/DB/748XBKQYSN13E836NPOU9IS4BHOSSJ.

[37] Global Methane Initiative. Municipal Wastewater Methane: Reducing Emissions, Advancing Recovery and Use Opportunities. 2013. URL www.globalmethane.org.

[38] McKinsey. Curbing methane emissions: How five industries can counter a major climate threat , 9 2021. URL https://www.mckinsey.com/capabilities/sustainability/our-insights/curbing-methane-emissions-how-five-industries-can-counter-a-major-climate-threat.

[39] Lena Höglund-Isaksson, Adriana Gómez-Sanabria, Zbigniew Klimont, Peter Rafaj, and Wolfgang Schöpp. Technical potentials and costs for reducing global anthropogenic methane emissions in the 2050 timeframe –results from the gains model. *Environmental Research Communications*, 2(2), 2020. ISSN 25157620. doi: 10.1088/2515-7620/ab7457.

[40] UNFCCC. CDM: Methane recovery in wastewater treatment — Version 19.0, . URL https://cdm.unfccc.int/methodologies/DB/K7FDTJ4FL3432I1UKRNKLDCUFAMBX7.

[41] UNFCCC. CDM: Avoidance of methane production in wastewater treatment through replacement of anaerobic systems by aerobic systems — Version 8.0, . URL https://cdm.unfccc.int/methodologies/DB/Z5A2LR9Q7XS906TDS4XDC8MKORZ63R.

[42] Jake Johnson, Fiona Zakaria, Allan G. Nkurunziza, Celia Way, Miller A. Camargo-Valero, and Barbara Evans. Whole-system analysis reveals high greenhouse-gas emissions from citywide sanitation in Kampala, Uganda. *Communications Earth & Environment 2022 3:1*, 3(1):1–10, 4 2022. ISSN 2662-4435. doi: 10.1038/s43247-022-00413-w. URL https://www.nature.com/articles/s43247-022-00413-w.

[43] Michiel R. J. Doorn, Sirintornthep Towprayoon, Sonia Maria Manso Vieira, William Irving, Craig Palmer, Riitta Pipatti, and Can Wang. *International Panel on Climate Change. "Chapter 6: Wastewater Treatment and Discharge"*,. 2006.

[44] JMP. Sanitation . URL https://washdata.org/monitoring/sanitation.

[45] CRS. SFD Report – Greater Tamale, Ghana - Resources • SuSanA, 2021. URL https://www.susana.org/en/knowledge-hub/resources-and-publications/library/details/5053#.

[46] Lugali Yvonne, Zziwa Ahamada, Banadda Noble, Wanyama Joshua, Kabenge Isa, Kambugu Robert, and Tumutegyereize Peter. Modeling sludge accumulation rates in lined pit latrines in slum areas of Kampala City, Uganda. *African Journal of Environmental Science and Technology,* 10(8):253–262, 8 2016. doi: 10.5897/AJEST2016.2106.

[47] Mphethe Tongwane, Stuart Piketh, Luanne Stevens, and Teke Ramotubei. Greenhouse gas emissions from road transport in South Africa and Lesotho between 2000 and 2009. *Transportation Research Part D: Transport and Environment*, 37:1–13, 6 2015. ISSN 1361-9209. doi: 10.1016/J.TRD.2015.02.017.

[48] Global Water Intelligence. Mapping Water's Carbon Footprint, 2022. URL https://www.globalwaterintel.com/water-without-carbon.

[49] World Bank. Market-Based Models and Public-Private Partnership Options for Non-Sewered Sanitation in Selected Cities and Towns in Kenya, 2022. URL http://hdl.handle.net/10986/38559.

[50] Conservation International, Friends of Ocean Action, ORRAA, Salesforce, The Nature Conservancy, and Meridian institute. High-Quality Blue Carbon Principles and Guidance A Triple-Benefit Investment for People, Nature, and Climate. Technical report, 2022. URL https://merid.org/wp-content/uploads/2022/11/HQBC-PG_FINAL_11.8.2022.pdf.

[51] Peter I. Macreadie, Micheli D.P. Costa, Trisha B. Atwood, Daniel A. Friess, Jeffrey J. Kelleway, Hilary Kennedy, Catherine E. Lovelock, Oscar Serrano, and Carlos M. Duarte. Blue carbon as a natural climate solution, 2021. ISSN 2662138X.

[52] Yiwen Zeng, Daniel A. Friess, Tasya Vadya Sarira, Kelly Siman, and Lian Pin Koh. Global potential and limits of mangrove blue carbon for climate change mitigation. *Current Biology*, 31(8), 2021. ISSN 18790445. doi: 10.1016/j.cub.2021.01.070.

[53] Daniel A. Friess, Jen Howard, Mark Huxham, Peter I. Macreadie, and Finnley Ross. Capitalizing on the global financial interest in blue carbon. *PLOS Climate*, 1(8), 2022. doi: 10.1371/journal.pclm.0000061.

[54] Verra. Update on Methodologies for REDD Projects that Include Wetlands - Verra, 8 2023. URL https://verra.org/update-on-methodologies-for-redd-projects-that-include-wetlands/.

[55] EPA. Energy Efficiency for Water Utilities, 2016. URL https://www.epa.gov/sustainable-water- infrastructure/energy-efficiency-water-utilities.

[56] F. Y. Cheng, K. J. Van Meter, D. K. Byrnes, and N. B. Basu. Maximizing US nitrate removal through wetland protection and restoration. *Nature*, 588(7839), 2020. ISSN 14764687. doi: 10.1038/s41586- 020-03042-5.

[57] Braden Limb, Jason Quinn, Alex Johnson, Robert Sowby, Zia Mehrabi, and Evan Thomas. Greening America's Rivers: The Potential of Climate Financing for Nature-Based Water Quality Improvement. *Nature Communications Energy and Environment (in review)*, 2023.

[58] Ghislaine Rosa and Thomas Clasen. Estimating the scope of household water treatment in low- and medium-income countries. *American Journal of Tropical Medicine and Hygiene*, 82(2), 2010. ISSN 00029637. doi: 10.4269/ajtmh.2010.09-0382.

[59] Evan Thomas. Leveraging Carbon Financing to Enable Accountable Water Treatment Programs. Technical report, 2012. URL https://globalwaterforum.org/2012/09/23/leveraging-carbon-financing-to-enable-accountable-water-treatment-programs/.

[60] J Hodge and Thomas Clasen. Carbon Financing of Household Water Treatment: Background, Operation and Recommendations to Improve Potential for Health Gains. *Environmental Science and Technology*, 48(21):12509–12515, 2014.

[61] Sarah K. Summers, Rochelle Rainey, Maneet Kaur, and Jay P. Graham. CO2 and H2O: Understanding different stakeholder perspectives on the use of carbon credits to finance household water treatment projects. *PLoS ONE*, 10(4), 2015. ISSN 19326203. doi: 10.1371/journal.pone.0122894.

[62] Amy J. Pickering, Benjamin F. Arnold, Holly N. Dentz, John M. Colford, and Clair Null. Climate and health co-benefits in low-income countries: A case study of carbon financed water filters in Kenya and a call for independent monitoring, 2017. ISSN 15529924.

[63] Mark Williams and Sharmila Murthy. Reconciling the carbon market and the human right to water: the role of suppressed demand under Clean Development Mechanism and the Gold Standard. *Environmental Law*, 43(3), 2013. ISSN 00462276.

[64] UNCTAD. Smallest footprints, largest impacts: Least developed countries need a just sustainable transition, 2022. URL https://unctad.org/topic/least-developed-countries/chart-october-2021#:~:text=Despite%20recent%20 increases%2C%20in%202019,9%25%20of%20the%20world's% 20average.

[65] Evan Thomas and Joe Brown. Using Feedback to Improve Accountability in Global Environmental Health and Engineering. *Environmental Science and Technology*, 0(0), 12 2020. doi: 10.1021/acs. est.0c04115. URL https://pubs. acs.org/doi/10.1021/acs.est.0c04115.

[66] The Gold Standard. METHODOLOGY FOR EMISSION REDUCTIONS FROM SAFE DRINKING WATER SUPPLY. Technical report, 2021. URL https://globalgoals.goldstandard.org/standards/429_V1.0_EE_SWS_Emission-reductions-from-Safe-Drinking-Water-Supply.pdf.

[67] UNFCCC. CDM-MP92-A07 Development of default values for fraction of non-renewable biomass. Technical report, 2023. URL https://cdm.unfccc.int/sunsetcms/storage/contents/stored-file-20231012184345703/MP92_EA07_ Information%20Note_fNRB%20values_collated.pdf.

[68] WHO. Global health observatory data repository: Population using solid fuels (estimates): data by country. Technical report, 2015.

[69] FAO. Land use in agriculture by the numbers, 2020.

[70] Ivan Lombardich and Akhil Unnikrishnan. Global assessment of the energy footprint of irrigated agriculture. *POLITesi - Archivio digitale delle tesi di laurea e di dottorato*, 2021. URL https://www.politesi.polimi.it/handle/10589/174218.

[71] Robert B. Sowby and Emily Dicataldo. The energy footprint of U.S. irrigation: A first estimate from open data. *Energy Nexus*, 6, 2022. ISSN 27724271. doi: 10.1016/j.nexus.2022.100066.

[72] Benjamin McCarthy, Robert Anex, Yong Wang, Anthony D. Kendall, Annick Anctil, Erin M.K. Haacker, and David W. Hyndman. Trends in Water Use, Energy Consumption, and Carbon Emis- sions from Irrigation: Role of Shifting Technologies and Energy Sources. *Environmental Science and Technology*, 54(23), 2020. ISSN 15205851. doi: 10.1021/acs.est.0c02897.

[73] Netafim. Carbon Credits Initiative for Rice Growers at COP27 — Netafim, 2022. URL https://www.netafim.com/en/ news-and-events/news/orbias-precision-agriculture-business-netafim-reveals-first-carbon-credits-initiative-for-global-rice-growers-at-cop27/.

[74] Reiner Wassmann and Milkha S. Aulakh. The role of rice plants in regulating mechanisms of methane missions. *Biology and Fertility of Soils*, 31(1):20–29, 2000. ISSN 01782762. doi: 10.1007/ S003740050619/METRICS. URL https://link.springer.com/article/10.1007/s003740050619.

[75] FAO. FAOSTAT, 2020. URL https://www.fao.org/faostat/en/#data/QCL.

[76] Tim Searchinger and Richard Waite. More Rice, Less Methane, 12 2014. URL https://www.wri.org/insights/more-rice-less-methane.

[77] Gold Standard. Methane Emission Reduction by Adjusted Water Management Practice in Rice Cultivation – Gold Standard for the Global Goals, 2023. URL https://globalgoals.goldstandard.org/437-luf-agr-methane-emission-reduction-awm-practice-in-rice/.

[78] Verra. VM0042 Methodology for Improved Agricultural Land Management, v2.0 - Verra, . URL https://verra.org/ methodologies/vm0042-methodology-for-improved-agricultural-land-management-v2-0/.

[79] Gold Standard. SDG Tool Guidance — The Gold Standard. URL https://www.goldstandard.org/ blog-item/sdg-tool-guidance.

[80] Verra. SD VISta Program Details - Verra, . URL https://verra.org/programs/sd-verified-impact-standard/sd-program-details/.

[81] Brett Cohen, Annette Cowie, Mustafa Babiker, Adrian Leip, and Pete Smith. Co-benefits and trade-offs of climate change mitigation actions and the Sustainable Development Goals. *Sustainable Production and Consumption*, 26:805–813, 4 2021. ISSN 2352-5509. doi: 10.1016/J.SPC.2020.12.034.

[82] Science Based Targets Network. Freshwater – Science Based Targets Network. URL https://sciencebasedtargetsnetwork.org/our-mission/issue-hubs/water/.

[83] Matthew C. Reid, Kaiyu Guan, Fabian Wagner, and Denise L. Mauzerall. Global methane emissions from pit latrines. *Environmental Science and Technology*, 48(15), 2014. ISSN 15205851. doi: 10.1021/ es501549h.

[84] Anna Libey, Marieke Adank, and Evan Thomas. Who pays for water? Comparing life cycle costs of water services among several low, medium and high-income utilities. *World Development*, 136, 2020. doi: https://doi.org/10.1016/j.worlddev.2020.105155.

[85] VCMI. VCMI Claims Code of Practice — Additional guidance launching 28th November, 6 2023. URL https://vcmintegrity.org/vcmi-claims-code-of-practice/.

[86] Gold Standard. Public Consultation Draft Guidance Document on Digitising Methodologies for Climate Markets. 2022. URL https://www.goldstandard.org/sites/default/files/public_consultation_draft_general_guidance_for_digitising_methodologies.pdf.

[87] Asian Development Bank. Digital Technologies for Climate Action, Disaster Resilience, and Environmental Sustainability. Technical report, Asian Development Bank, Manila, Philippines, 10 2021. URL https://www.adb.org/publications/digital-technologies-climate-change.

[88] E A Thomas, S Tellez-Sanchez, C Wick, M Kirby, L Zambrano, G Abadie Rosa, T F Clasen, and C Nagel. Behavioral Reactivity Associated with Electronic Monitoring of Environmental Health Interventions–A Cluster Randomized Trial with Water Filters and Cookstoves. *Environ Sci Technol*, 50(7):3773–3780, 2016. ISSN 1520-5851. doi: 10.1021/acs.est.6b00161. URL https://www.ncbi.nlm.nih.gov/pubmed/26986617.

[89] Katie Fankhauser, Denis Macharia, Jeremy Coyle, Styvers Kathuni, Amy McNally, Kimberly Slinski, and Evan Thomas. Estimating groundwater use and demand in arid Kenya through assimilation of satellite data and in-situ sensors with machine learning toward drought early action. *Science of the Total Environment*, 831, 2022. ISSN 18791026. doi: 10.1016/j.scitotenv.2022.154453.

[90] Evan A. Thomas, Joseph Needoba, Doris Kaberia, John Butterworth, Emily C. Adams, Phoebe Oduor, Denis Macharia, Faith Mitheu, Robinson Mugo, and Corey Nagel. Quantifying increased groundwater demand from prolonged drought in the East African Rift Valley. *Science of the Total Environment*, 2019. ISSN 18791026. doi: 10.1016/j.scitotenv.2019.02.206.

[91] Corey Nagel, Jack Beach, Chantal Iribagiza, and Evan A Thomas. Evaluating Cellular Instrumentation on Rural Handpumps to Improve Service Delivery-A Longitudinal Study in Rural Rwanda. *Environmental Science and Technology*, 49(24):14292–14300, 2015. ISSN 15205851. doi: 10.1021/acs. est.5b04077.

[92] World Bank. Digital Monitoring, Reporting, and Verification Systems and Their Application in Future Carbon Markets Climate Warehouse Acknowledgements Disclaimer. Technical report, World Bank, Washington, DC, 2022. URL www.worldbank.org.

[93] Livelihoods Funds. INDIA (Sundarbans): 16 million mangrove trees to protect local communities – Livelihoods Funds. URL https://livelihoods.eu/portfolio/news-india/.

[94] Livelihoods. Launch of a new Livelihoods Carbon Fund – Livelihoods Funds, 6 2021. URL https://livelihoods.eu/launch-of-a-new-livelihoods-carbon-fund-lcf3/.

[95] ESMAP. Good Practices in City Energy Efficiency, Yerevan, Armenia-Water and Sewerage Management Contract, 2011.

[96] Verra. Yunshui Wastewater Treatment Plant Project in Guangdong Province, . URL https://registry.verra.org/app/projectDetail/VCS/2938.

[97] WSUP. Towards a cleaner and more productive Malindi and Watamu – WSUP, 2021. URL https://www.wsup.com/insights/towards-a-cleaner-and-more-productive-malindi-and-watamu/.

[98] USEPA. Greenhouse Gas Equivalencies Calculator — US EPA. URL https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator.

[99] Sanivation. Waste-to-Value Faecal Sludge Treatment Plant (FSTP). Technical report, Sanivation, 2021.

[100] Institute for Health Metrics and Evaluation. GBD Compare — IHME Viz Hub, 2016. ISSN 0022-3492.

[101] Miles A. Kirby, Corey L. Nagel, Ghislaine Rosa, Laura D. Zambrano, Jean de Dieu Ngirabega, Jeanine Condo, Evan A. Thomas, and Thomas F. Clasen. Effects of a large-scale distribution of water filters on water quality and diarrhoea: a cluster randomized controlled trial in Western Province, Rwanda. *PLOS Medicine*, pages 1–24, 2019. URL https://doi.org/10.1371/journal.pmed.1002812.

[102] C K Barstow, C L Nagel, T F Clasen, and E A Thomas. Process evaluation and assessment of use of a large scale water filter and cookstove program in Rwanda. *BMC Public Health*, 16:584, 2016. ISSN 1471- 2458. doi: 10.1186/s12889-016-3237-0. URL https://www.ncbi.nlm.nih.gov/pubmed/27421646.

[103] Christina Barstow, Randall Bluffstone, Kyle Silon, Karl Linden, and Evan Thomas. A cost-benefit analysis of livelihood, environmental and health benefits of a large scale water filter and cookstove distribution in Rwanda. *Development Engineering*, 2019. ISSN 23527285. doi: 10.1016/j.deveng.2019. 100043.

[104] Christina Barstow, Thomas F Clasen, Miles Kirby, and Evan Thomas. Health, livelihood, and environmental impacts of the distribution of a carbon-credit-financed, large-scale water filter and im- proved cookstove programme in Rwanda. Lancet Planetary Health, 2018. ISSN 25425196. doi: 10.1016/S2542-5196(18)30116-5.

[105] Ghislaine Rosa, Fiona Majorin, Sophie Boisson, Christina Barstow, Michael Johnson, Miles Kirby, Fidele Ngabo, Evan Thomas, and Thomas Clasen. Assessing the impact of water filters and improved cook stoves on drinking water quality and household air pollution: A randomised controlled trial in Rwanda. *PLoS ONE*, 9(3):1–9, 2014. ISSN 19326203. doi: 10.1371/journal.pone.0091011.

[106] National Population Commission (NPC) [Nigeria] and ICF. Nigeria Demographic Health Survey 2018. *The DHS Program ICF Rockville, Maryland*, USA, 2019.

[107] UNICEF NBS. Nigeria Multiple Indicator Cluster Survey 2016-17 Survey Finding Report. *Survey Findings Report. Abuja, Nigeria: National Bureau of Statistics and United Nations Children's Fund*, 5, 2017.

[108] SustainCert. GS11263 Improved Cookstove and Safe Water Programme – Nigeria – VPA 05 . URL https://platform.sustain-cert.com/public-project/2491.

[109] Chris Funk, Shraddhanand Shukla, Andy Hoell, and Ben Livneh. Assessing the contributions of east African and west pacific warming to the 2014 boreal spring east African drought, 2015. ISSN 00030007.

[110] Ali Ahmadalipour and Hamid Moradkhani. Multi-dimensional assessment of drought vulnerability in Africa: 1960–2100. *Science of the Total Environment*, 2018. ISSN 18791026. doi: 10.1016/j.scitotenv. 2018.07.023.

[111] I. Masih, S. Maskey, F. E.F. Mussá, and P. Trambauer. A review of droughts on the African continent: A geospatial and long-term perspective, 2014. ISSN 16077938.

[112] Rob Hope, Tim Foster, and Patrick Thomson. Reducing risks to rural water security in Africa. *Ambio*, 2012. ISSN 00447447. doi: 10.1007/s13280-012-0337-7.

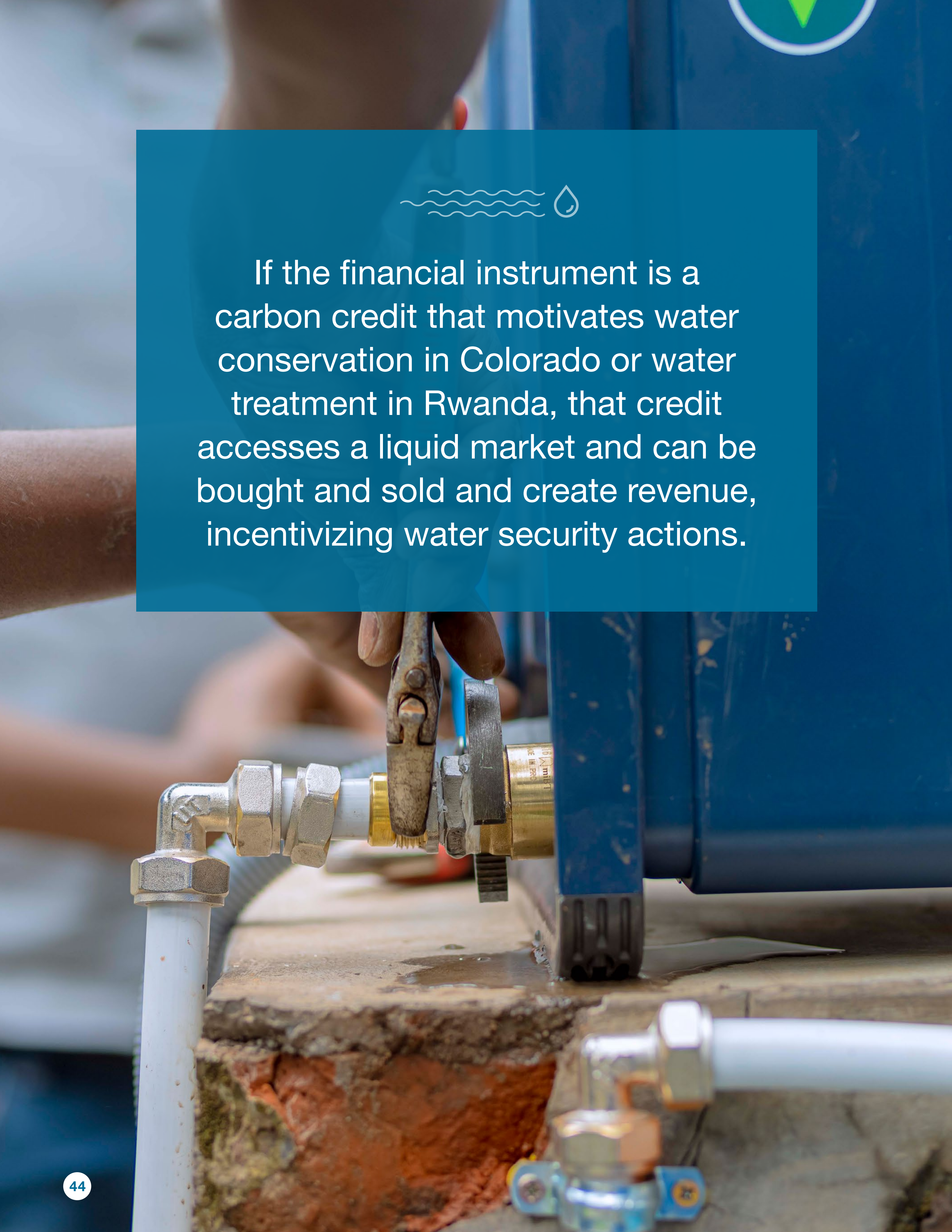
[113] Patrick Moriarty, Stef Smits, John Butterworth, and Richard Franceys. Trends in rural water supply: Towards a service delivery approach. *Water Alternatives*, 2013. ISSN 19650175. doi: 10.1111/j.1365- 2923.2008.03137.x.

[114] UNICEF. Kenya Humanitarian Situation Report. Technical report, UNICEF, 2017. URL https://reliefweb.int/sites/reliefweb.int/files/resources/UNICEFKenyaHumanitarianSitRep-20February2017.pdf.

[115] World Bank. World Bank Emission Reduction-Linked Bond Uses Voluntary Carbon Market to Provide Clean Water to Children in Vietnam, . URL https://thedocs.worldbank.org/en/doc/a550207090350837a902c49e00e93568-0340022023/original/World-Bank-IBRD-Emission-Reduction-Linked-Bond-Q-A-Final.pdf.

[116] World Bank. Emission Reduction-Linked Bond Helps Provide Clean Drinking Water to Two Million Children in Vietnam, 2 2023. URL https://www.worldbank.org/en/news/press-release/2023/02/14/emission-reduction-linked-bond-helps-provide-clean-drinking-water-to-two-million-children-in-vietnam#:~:text=The%20project%20aims%20to%20manufacture,carbon%20dioxide%20over%205%20years.

[117] Verra. Grouped projects for water purifiers for climate and community action, . URL https://registry.verra.org/app/projectDetail/VCS/2557.



If the financial instrument is a carbon credit that motivates water conservation in Colorado or water treatment in Rwanda, that credit accesses a liquid market and can be bought and sold and create revenue, incentivizing water security actions.

March 2024

Decarbonizing Water: Applying *the* Voluntary Carbon Market *toward* Global Water Security

Mortenson Center
in Global Engineering & Resilience
UNIVERSITY OF COLORADO **BOULDER**

CASTALIA