

Environmental services and management of water resources using the WEAP model: case studies in Ibero-America

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Abstract: This study identifies the experiences of Ibero-American countries that have implemented bioeconomy through environmental services (ES) for hydrological regulation and water quality, as part of water resource management in response to the impacts of climate change. A review of documents and case studies on Payment for Environmental Services (PES) schemes in Latin America and the Caribbean (LAC) was conducted. Furthermore, the application of the hydrological model WEAP (Water Evaluation and Planning System) is introduced as a tool for water resources management. This paper reviews applications of this hydrological model across LAC; the model enables the estimation of water-related environmental services and their relationship with land use and climate change.

Key words: bioeconomy; environmental services; payment for environmental services; hydrological resources management; hydrological model WEAP

1 Introduction

The integration of economic development and environmental protection—broadly conceptualized as sustainable development—is one of today's major global challenges. The need to implement public policies that foster economic growth and well-being while ensuring the sustainability of natural resources is giving rise to new conceptual frameworks, such as the bioeconomy. This concept is gradually gaining ground and points toward a new paradigm of economic, social, and environmental development.

The first and currently most widely used definition of bioeconomy was developed by the Organization for Economic Co-operation and Development (OECD, 2006), which defined bioeconomy as "the set of economic activities of a society that harness the latent value contained in biological products and processes to achieve new growth and deliver benefits for citizens and nations" (OCDE, 2006).

Its holistic approach matures and consolidates in subsequent documents on the Knowledge Based Bioeconomy (KBBE) (EU Commission, 2007, 2010). In these publications, bioeconomy is no longer understood as a process to extract benefits from biological resources, nor as an alternative form of sustainable economy, nor a political project aimed at reshaping the relationship between science, economy and politics. On the contrary, it is presented as an interpretive framework for reality itself: an articulated vision of what the good society is and ought to be, the commons, and the most

appropriate ways in which we should relate to one another, to nature and to society, Pavone (2012).

In a broad sense, bioeconomy encompasses all economic sectors that utilize biomass and biological processes in any of their possible forms. It rests on the premise that diversification and greater efficiency in the use of natural resources are necessary (Trigo, 2013).

This concept emerges in response to a set of global challenges that necessitate a shift in behavior—a context in which the agricultural sector is called upon to play a strategic role.

In this regard, ALCUENET has identified different productive pathways within bioeconomy: exploitation of biodiversity resources, eco-intensification, applications of biotechnology, biorefineries and bioproducts, improvement of value chain efficiency, and ecosystem services (Trigo, 2013).

This paper describes the ecosystem services pathway, which refers to the services generated by ecosystems. These services can be supporting services (e.g., soil formation, erosion reduction, biodiversity conservation and maintenance), provisioning services (e.g., water for human consumption or irrigation, genetic material), regulating services (e.g., carbon sequestration, gas mitigation, water purification), and cultural services (scenic beauty or ecotourism, recreational, spiritual, and cultural heritage services).

Maintaining the generation of ecosystem services is a concern for many citizens and policymakers. This article reviews interventions that enable the maintenance or restoration of ecosystem services related to water resource management.

2 Ecosystem services and payment for environmental services

Ecosystem services are the benefits that societies obtain from ecosystems. These benefits are numerous and varied, and include services that improve the quality of land, air and water.

Water, timber and medicinal substances are examples of environmental goods; they are nature's products directly used by humans. In contrast, environmental services refer to those ecosystem functions that generate benefits and well-being for individuals and communities (Hueting et al., 1998).

Environmental services are neither transformed nor consumed during use by consumers. This is their main characteristic that differentiates them from environmental goods, which are used as inputs in production systems and become transformed and depleted in that process.

The concept of Environmental Services (ES) is relatively new, and its application and development remain heavily debated regarding how they may positively or negatively impact ecosystems and communities.

In the case of water regulation and water quality, ES are associated with water resources that society uses to meet its needs (municipal supply, industrial supply, hydropower generation, irrigation supply, etc.).

Water regulation occurs when an ecosystem can manage or control water over time. In other words, it can store water during rainy seasons and release it gradually or in a regulated manner during dry seasons, maintaining a balance in streamflow between wet and dry periods (Logreira, 2009).

As outlined above, the water regulation ES provided by a watershed focus on both the volume of water available throughout the year (especially during the dry season) and the runoff generated by the watershed during torrential events (reduction of flood peaks). This ES is strongly linked to land use and management practices. PES directly targets land use to maintain or improve this ES. Accordingly, changes in the biophysical processes (driven by land cover or land-use change) that govern the hydrological cycle will also alter the ES. (Logreira, 2009).

Faced with severe resource degradation, climate change phenomena, and especially projections of future water scarcity in many regions, new financing mechanisms have been and continue to be sought to promote conservation. These

are compensation, payment or reward mechanisms for the provision of ecosystem services, whereby the service buyers or beneficiaries cover the costs arising from land-use change in upper watersheds or carbon sequestration projects.

Insufficient investment in the protection and management of forests and other natural resources leads to the depletion of natural vegetation cover and soils, the degradation of watersheds, and species extinction. These impacts often result in substantial economic and social losses.

Economic and market-based instruments have been used for decades in pollution prevention and ecosystem conservation. Most of them aim to mitigate negative environmental externalities (such as pollution or habitat destruction) through taxes or ecological rights, alongside other tools grounded in the "polluter pays" principle.

In the 1990s, new approaches focused on acknowledging the generation of positive environmental externalities through economic incentives, mostly linked to subsidies and other environmental programmes. Among these new instruments, payment for environmental services has attracted growing attention owing to its potential to deliver social, economic and environmental sustainability (Encalada, 2006).

Payment for environmental services (PES) schemes constitute one approach to address the problems associated with natural resource degradation. Such systems take into account the component of environmental services that carries market value.

Payment for environmental services (PES) is an economic compensation mechanism whereby the beneficiaries or users of a service make payments to its providers or custodians. The environmental services involved can be very tangible, such as a steady freshwater flow, reduced erosion and sedimentation, or the reliable supply of firewood. In other cases, environmental services may be more abstract or global in scope: carbon sequestration and scenic beauty, for instance (Moreno & Renner, 2007).

PES usually involve the establishment of market-based mechanisms to compensate upstream landowners, in order to maintain or adjust a specific land use that affects the availability and/or quality of the resource to be conserved or managed.

Usually, this compensation comes from payments made by downstream water users. The fundamental idea of PES systems is to create a market for an environmental good that normally lacks commercial valuation. From an economic perspective, PES systems require the allocation of *de jure* or *de facto* property rights over environmental externalities that generate benefits for third parties (environmental service). In other words, the system starts by identifying economic agents responsible for the "positive" environmental externality — the service "providers" — as well as the beneficiary agents (or users). In the case of watersheds, it requires establishing causal relationships between upstream land use and downstream water resource conditions. Additionally, PES systems aim to build an information flow between providers and users, so that market exchange can emerge between these two types of agents (FAO, 2004).

The PES scheme is a voluntary, negotiated agreement, not a command-and-control measure. Potential service providers must have real land-use options, among which the supplied service is not the preferred land use. Similarly, what is being purchased must be clearly defined; in this case, dry-season water volume, sediment reduction, reduction in flood peak flows, etc. (Logreira, 2009).

It is important to note that the payment does not necessarily have to take the form of a monetary transaction. It can also consist of infrastructure improvements (roads, water reservoirs, etc.), services (health clinics, schools, etc.), or rural extension support (workshops, equipment, seeds, etc.). Compensation mechanisms can range from direct periodic payments to individual providers to the creation of a trust fund managed by a board including representatives from providers, users, the private sector, civil society and the state.

The design of a PES scheme requires biophysical, socioeconomic and institutional analyses. Without these analyses, it

is difficult to achieve a sound design.

According to Moreno and Renner, 2007, PES schemes constitute a valuable instrument to:

Achieve the sustainability of natural resources within watersheds.

Link stakeholders from the different geographical areas encompassed by the watershed.

Facilitate the pedagogy of natural resource sustainability and integrated watershed management.

According to Logreira (2009), a payments for environmental services (PES) scheme for water regulation or water quality would comprise 4 fundamental steps: The first step consists of the biophysical analysis of the watershed, which involves the collection of the watershed's hydrometeorological information (precipitation, evaporation, streamflow, relative humidity, solar brightness, etc.), as well as data on vegetation cover, slopes and soil types.

The second step consists of inventories of environmental service users and their respective water concessions or volumes of water consumed (for water regulation cases), alongside the identification of environmental service "providers", their land practices and potential improvements.

The third step involves applying a hydrological model that links land use and/or land cover to the environmental service. This model supports decision-making for maintaining or enhancing environmental services within the watershed.

Finally, to verify the effectiveness of implemented measures, a monitoring plan is established. Monitoring initially focuses on the actions recommended to service "providers", and subsequently targets the environmental service itself.

In Latin America, most of the still limited payment or compensation for environmental services initiatives have focused on schemes related to freshwater quality and freshwater provision within hydrological watersheds. Examples of small-scale local PES projects can be found in Peru, Costa Rica, Colombia, Mexico, Nicaragua, Honduras and El Salvador; these projects focus on water conservation through water resource management.

Currently, many PES projects integrate predictive hydrological models into their methodologies. Such models can link land-cover changes to the environmental service. Among the most widely used models for various applications are SWAT, MIKE-SHE, WEAP and HEC-HMS.

2.1 The WEAP model (Water Evaluation and Planning System), a tool for water resources management

Water is a vulnerable and finite resource, essential for sustaining life, development and the environment. It carries high social and economic value across diverse uses: agriculture, healthy ecosystems, and the livelihoods of human beings. Within this context, the coordinated management and development of water, land and related resources can equitably maximize the resulting social and economic welfare, without compromising environmental sustainability.

Integrated Water Resources Management (IWRM) is defined by the Technical Committee of the Global Water Partnership (GWP) as "a process which promotes the coordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of ecosystems".

Operationally, the IWRM approach involves the application of knowledge from multiple disciplines, as well as the perspectives of different stakeholders, to develop and implement efficient, equitable and sustainable solutions to water and development challenges. Therefore, IWRM is a tool for water development and management, balancing economic and social needs and ensuring the protection of ecosystems for future generations.

Water has a wide variety of uses — for agriculture, for healthy ecosystems, for people and their livelihoods — which require coordinated action. An IWRM approach is an open, flexible process that brings together decision-makers from different sectors that affect water resources, and brings all stakeholders to the table to establish balanced policies and decisions in response to the water challenges faced.

There are numerous models for carrying out basin analysis. They simulate the partial or overall response of a basin to a given water input, whether from precipitation, snowmelt or groundwater recharge, alongside other natural resource characteristics. Their objectives are to diagnose and/or forecast the relationships among the various variables incorporated into the model.

Among the different types of hydrological models are those designed for water resources management. These focus more on resource use, taking into account water availability, demand and water management (operational rules, existing infrastructure, resource competition among different uses, etc.). They therefore support water managers by simulating the impacts of various management measures. Most of these models already feature advanced user interfaces that allow operation by users without a hydrological technical background, such as WEAP.

The WEAP model was developed in 1988 by Jack Sieber with sponsorship from the Stockholm Environment Institute (SEI). It is an integrated water resources planning model operating on the water balance principle, applicable to agricultural and municipal systems, as well as small or large river basins. The model can simulate processes such as rainfall-runoff, baseflow, groundwater recharge, etc. Likewise, it supports sectoral analysis, water conservation, water rights, reservoir operation, hydropower generation, pollutant tracking, water quality, vulnerability assessment and maintenance of environmental flow requirements. It also includes a financial analysis module that enables benefit-cost comparisons of different projects or alternatives and the exploration of long-range alternative scenarios.

Application of this program requires information such as simulation period, spatial boundaries of the simulation, etc. As a planning model, it can consider development alternatives and assess impacts on policies, costs, hydrology, municipal and industrial water supply, and climate.

The model operates on a monthly mass balance; water is allocated to meet consumption requirements, subject to priority demands. Three simulation methods are available for processes such as runoff, infiltration and irrigation, depending on the required level of complexity.

The first major application of WEAP took place in the Aral Sea region in 1989. Over the years, WEAP has been applied in many countries and basins. The software has been disseminated to water resources planners worldwide.

The development of a WEAP model generally includes the following stages (UC and SEL, 2009).

1. Study definition: At this stage, the time frame, spatial boundaries, system components and problem configuration are established.

2. Information collection: At this stage, data are gathered according to the defined study type. This stage can be iterative and is generally divided into two parts: a general data collection phase, and a specific data collection phase once the model has been set up and additional information requirements have been identified.

3. Model development: At this stage, the schematic is built, data entry is performed, and initial model runs are carried out to observe its preliminary behaviour and eliminate potential inconsistencies and errors.

4. Calibration: Here, characterisation of the current water supply and demand, pollutant loads, resources and sources for the system is conducted.

5. Model use and scenario generation: Once the model is calibrated, the impacts of a set of hypothetical alternatives on future policies, costs and climate can be explored, for instance, on water demand, water supply, hydrology and pollution.

2.2 Applications of the WEAP model in LAC

According to Escobar et al. (2011), there are various applications of the WEAP model in LAC. Some of these were also carried out by the Stockholm Environment Institute-U.S. Center (SEI), available on its website [1], while others are currently under implementation. Most of these projects are related to large-scale agriculture and hydropower generation.

Agricultural studies reflect one of the world's fastest expansions in biofuel production in response to rising energy demand. This analysis indicates that in Central America and the Caribbean, agricultural areas allocated to biofuel crops will likely compete with other farmlands and water users under future development and climate change scenarios. In this context, the WEAP platform provides a suitable environment for assessing climate change adaptation measures at local or hydrological basin scale.

Below is a brief description of the applications by country and year or implementation period:

- Brazil: São Francisco River Basin. 2004–2008.

This project aims to plan and assess clusters of multi-purpose small reservoirs to improve livelihoods and food security for smallholder farmers, and it develops relevant tools and procedures. This project involved work in the São Francisco River Basin (Brazil), the Volta River Basin (Ghana), and the Limpopo River Basin (Southern Africa), on the planning and evaluation of multi-purpose small reservoirs to improve livelihoods and food security for smallholder farmers. Tens of thousands of rural communities in Africa and Latin America rely on water from multi-purpose small reservoirs for household use, livestock and irrigation schemes. In collaboration with local and regional stakeholders, tools for the analysis and design of small dams are being developed, methods for institutional, financial and economic analysis are being improved, and confidence is being built in a science-based approach to planning dam systems. Building on this foundation, decision-makers at basin and national levels, together with local communities, will work together to ensure the long-term sustainability of local water supply and adequate downstream flow. Well-located, multi-functional dams that make water accessible to smallholder farmers are essential, as they enable smallholder farmers to achieve the ultimate goals of increasing food production, reducing poverty, safeguarding human health and improving rural livelihoods.

- Chile 2008-2009

Limarí Basin, Chile: a model developed to calculate the impacts of climate change on a semi-arid, snowmelt-dominated basin.

Implementation and use of the WEAP model in snow-fed basins of the IV Region for climate change analysis. The objective of this study is to analyze the effect of climate change on the water resources of the Elqui (at Algarrobal) and Hurtado (at San Agustín) snow-fed basins—located in the Coquimbo Region (IV Region)—using the WEAP model.

- Huasco Basin, Chile, 2012

Water Resources Modelling of the Huasco River Basin. Develop a water resources allocation model for the Huasco River Basin on the WEAP platform, to simulate water supply and demand in the basin under scenarios that implement environmental flow, and to assess its impact on water users in the basin.

- Ecuador, 2009

Paute Basin, Ecuador: The model was developed for a basin that generates 50% of the country's electricity, and was used to assess the impact of climate change.

Pastaza River Basin (Upper and Middle), Ecuador: The WEAP model was applied to understand the hydrological behaviour of the Pastaza River Basin, located in the Andean Amazon region. This made it possible to forecast changes in water availability according to the climate change scenarios set out in the study. The project was developed jointly by the Escuela Politécnica Nacional (EPN), the Municipality of Pastaza and the GLOWS programme (Global Water for Sustainability Program).

- Peru 2008-2009

Adaptation in water management for glacier loss in the Peruvian Andes: this project focuses on assessing potential

changes in the hydrological basins of the Peruvian Andes related to glacier loss driven by climate change. Work is underway to develop a module within WEAP to represent glacier evolution under different future climate scenarios. This module will be used to build WEAP applications in three Peruvian hydrological basins: the Santa, Rimac and Mantaro basins. These applications will be run using regionally developed climate scenarios to investigate the water-management implications of glacier loss and possible adaptations in water governance.

- Santa River Basin, Peru

It was developed under the project "Assessment of Climate Change Impacts on Mountain Hydrology: Development of a Methodology through a Case Study in Peru". This project was sponsored by IRD, SEI-US and the World Bank. The WEAP model for the Santa River includes basin hydrological modelling and the integration of a glacier modelling module within WEAP.

- Rimac River, Peru

Integrated water resource management for drinking water in Metropolitan Lima: This study involves the modelling of the complex water system, including the Rimac River basin, upper Mantaro, Chillón River and Lurín River, as well as available water collection, storage and distribution infrastructure. The aim is to analyse and evaluate the performance of the current and future water system, with new water sources incorporated, to meet drinking water requirements for Metropolitan Lima in the short, medium and long term.

- Chicama River Basin, Peru

Study of surface water resources in the Chicama River Basin: This study was developed to meet the following objectives: 1) simulate the hydrological basin as a whole; 2) define storage locations within the basin to determine water availability in reservoirs and the probable volumes that could be impounded; 3) implement a water balance model and hydrological simulation that can be updated for management purposes; 4) implement a simulation model that considers water volumes transferred from the Santa River for the special CHAVIMOCHIC and CHINECAS projects; and 5) quantitatively assess water availability and demand, establishing the water balance of the basin's water potential. Future water conditions were quantified and evaluated by considering basin water availability under four scenarios: a) baseline scenario; b) baseline plus groundwater abstraction; c) baseline plus groundwater abstraction plus Chavimochic transfer volumes (water imported from the Santa River); and d) baseline plus groundwater abstraction plus reservoirs within the hydrological basin.

- Chira–Piura System, Peru

Assessing the impact of bioenergy crop introduction on water resource availability in the Chira-Piura system, Peru: The study evaluated water resource sustainability for agricultural expansion (agricultural water demand) driven by the introduction of energy crops for biofuel (bioethanol) production in the Chira Valley. The assessment was based on four scenarios, which differed mainly in water demand and water availability within the Chira River Valley. These scenarios were described and evaluated regarding impacts from the perspectives of system reliability, supply coverage and system vulnerability. The scenarios were: Scenario 1 – baseline current conditions; Scenario 2 – increased sugarcane area; Scenario 3 – increased sorghum area; Scenario 4 – increased sugarcane area together with expansion of smallholder crops. System simulation and reliability assessment were carried out using the WEAP model. The analysis adopted an integrated approach, considering both water supply and demand. It provided a basis for evaluating the allocation of limited water resources among agricultural, municipal, industrial and environmental uses. Under current conditions, projections show that there is insufficient available water to support a planned expansion of 23,976 hectares of sugarcane for bioethanol production in the Chira Valley. Current water supply can only support an additional 10,000 hectares of sugarcane in the

valley. The results demonstrate an urgent need for land and water resources management in the Chira and Piura valleys. Furthermore, improvements in water productivity are feasible (0.7 kg rice per m³ of water under current conditions, and 1.34 kg per m³ for all crops in the valley), enabling higher food production with the same water volume and cultivated area.

- Colca- Sigwas System, Peru

Update of the water balance study for the Colca- Sigwas system for renewal and other purposes: This study assessed water availability in the Colca system to support water management in reservoirs. The assessment was based on the hydrological balance of the Colca system, considering agricultural water demand for the Pampa de Majes (23,000 ha) and Pampas de Sigwas (38,000 ha), as well as energy demand (400 MW) of the Tarucani, Lluta and Lluella hydropower plants. The water balance was evaluated in terms of system reliability, demand coverage and system vulnerability. The results show that the system can meet up to 1,070 Hm³ of agricultural water demand with a reliability of 75%. The available water of the Majes- Sigwas system is 1,101.36 Hm³ (107.68 Hm³ from the Sigwas basin, 698.76 Hm³ from the Colca basin and 294.92 Hm³ from the Apurimac basin) for agricultural and municipal uses. For hydropower generation at the Lluta and Lluella hydropower plants, the available annual volume can reach up to 993.7 Hm³.

- Pampas River Basin, Peru, 2010

The project "Evaluation of Surface Water Resources in the Pampas River Basin" was carried out. The objective of the study was to evaluate, quantify and simulate the temporal and volumetric behaviour of water resources in the Pampas River Basin and establish a basin- scale water balance. It provides the hydrological evidence required for decision- making, aiming to optimize the use of surface water resources in the Pampas River Basin within the framework of sustainable water resources development.

- Colombia: Upper Chinchina River Basin, 2010

A WEAP application was developed to define water scarcity indices based on water supply and demand, using this information to implement integrated water resources management in the upper Chinchina River Basin. The specific objectives achieved were: a) establish water supply and demand; b) analyse water balance at defined control points; c) prepare a proposal for stream flow allocation and corresponding actions; d) develop and operate the model; and e) define management scenarios for population growth and expansion of public water services in the study area. Model results indicate that during different drought periods, the system cannot guarantee sufficient water availability to meet increased municipal water demand or maintain environmental flows in rivers, which is a typical feature of Andean basins.

- Colombia: Barbas, Cestillal and Consota Rivers Basin, 2010

A WEAP application was developed to implement integrated water resources management for the Barbas, Cestillal and Consota river basins. The objective of this application was to build a model to provide a comprehensive, flexible and user- friendly framework for planning and support policy analysis for efficient water resources management. Model projections show that the whole system is under stress and cannot meet municipal water demand or maintain ecological flows for most of the time.

- Cuba, 2013–2015

Within the framework of the project "Environmental Bases for Local Food Sustainability (BASAL)", and in close collaboration between the Cuban project team and the Joint Research Centre (JRC) of the European Commission, a water management modelling system (MASPA) is being developed. Its objectives are to improve understanding of the impacts of climate variability and land- use change on water availability and food production, and to provide a decision- support tool for water resources management to guarantee sustainable food production. The WEAP model is used to develop this

modelling system. In its first phase, the project operates in three intervention municipalities: Güira de Melena, Los Palacios and Jimaguayú. Their main activities are rice production, multi-crop cultivation and livestock farming respectively, which are key components of national food production.

- Dominican Republic, 2007

Haina River Basin, Dominican Republic: The model was developed for a WEAP training workshop session.

Yaque del Sur Basin, Dominican Republic: A WEAP application was developed for the Yaque del Sur River Basin to support the National Hydrological Programme. This application is an integrated assessment to represent the main water demand sites in the basin, including agriculture and urban users. The modelled infrastructure includes a reservoir for agricultural use and a set of canals that deliver water to demand sites inside and outside the hydrological basin. Two scenarios were modelled: one representing increased agricultural water demand caused by the expansion of irrigated areas, and another representing the implementation of a new reservoir within the basin.

- Guatemala, 2007

San José and El Naranjo River Basins, Guatemala: Models were developed to calculate climate change vulnerability as part of the NCAP-funded project.

- Mexico, 2004

Water planning in Mexico: WEAP was translated into Spanish and used for integrated water resources planning in several river basins in Mexico.

- San Juan River Basin, Mexico, 1993–1994

Water and environment in the San Juan River: WEAP was applied for an integrated water resources assessment in the San Juan River Basin, Mexico, including the industrial centre of Monterrey. The study included developing a water supply-demand balance for the hydrological basin and identifying alternative water development strategies together with their environmental implications. The analysis also calculated the true cost of water in the region, reflecting opportunity costs, marginal costs and scarcity costs.

- Rio Grande / Bravo River Basin, Mexico- United States

The Physical Assessment Project: The "Physical Assessment" project consists of a consortium of US and Mexican universities, NGOs and government agencies. It analyses water-management alternatives for the Río Grande/Bravo system to address growing pressure on this vital water resource. The project develops and applies a full-basin hydrological-planning model for this shared transboundary river system. It enables public water managers, private stakeholders and other actors to identify hydrologically feasible system-improvement options that deliver mutual benefits for affected parties across the whole basin. Alternatives passing the hydrological screening will undergo economic, legal and institutional feasibility analyses in subsequent project phases. The resulting viable alternatives represent clear "success cases" for future implementation (<http://www.riogrande.org>).

- Jiboa River Basin, El Salvador, 2007

The hydrological behaviour of the Jiboa River Basin system was characterized using the WEAP model, to support the development of water-resources management plans in view of the impending impacts of climate change.

3 Final considerations

Important progress has been observed in Latin America and the Caribbean (LAC) in applying the bioeconomy concept, especially for environmental services such as hydrological regulation and water-quality maintenance. In this context, the region possesses substantial water-resource potential, which opens opportunities to redirect economies

towards sustainable water-resources management.

The implementation of Payment for Environmental Services (PES, PSA in Spanish) mechanisms is one pathway for achieving sustainability and conservation of water resources. Climate change is projected to bring rising water demand together with constraints on water availability and water quality in parts of the LAC region. PES represents an innovative approach built on recognizing the value of natural-resource assets. Intensive multidisciplinary research is required to assess hydrological, geographical, biological as well as socio-economic drivers. This means considering not only the commercial aspects of a PES scheme, but all dimensions linked to water-resource regulation and conservation.

Faced with new development outlooks, population growth, and high ecosystem vulnerability under climate-change impacts, water-resources management stands among the most critical environmental challenges for LAC in this century. Predictive simulation models constitute highly useful tools for water-resources management, widely applied at present. They support biophysical characterisation, the development of forecasting scenarios, and underpin policy design and decision-making.

This paper presents several completed and ongoing sustainable-development studies and projects based on the WEAP model in Latin America, mainly related to large-scale agriculture and hydropower generation.

Conflicts of interest

The author declares no conflicts of interest regarding the publication of this paper.

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