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Strategies for monitoring and evaluation of climate change adaptation: localizing global approaches into Andean realities

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While there is increasing progress made at the global scale on understanding climate change (CC) impacts and implementing adaptation solutions, there is still a major gap in documenting and assessing the effectiveness of monitoring and evaluation (M&E) systems for CC adaptation. This is particularly challenging if we consider the diversity of local perceptions and interpretations of what CC adaptation concretely means and how to measure it. We evaluate how global approaches on M&E to CC adaptation are being localized in the design and implementation of public policies and territorial strategies for CC adaptation in the Andes in four national and local case studies in Colombia, Ecuador, Peru and Bolivia. The analysis is based on a review of the status of national programs for M&E of CC adaptation and the implementation in those countries of the project "Adaptation to Climate Change Impacts in Water Resources in the Andes" (AICCA). The M&E systems in the four case studies differed widely in the way in which global M&E approaches are localized, reflecting the diversity of conceptions, goals, strategies and contexts in which adaptation is being implemented as well as power relations among actors and scales. Despite the diversity of implementation contexts and the complexity of monitoring the responses of socio-ecological systems, the M&E proposals share a focus on biophysical indicators over sociopolitical and institutional indicators. In addition, this study emphasizes the need to further implement participatory M&E systems from the community, to improve the territorial articulation of M&E proposals in the Andean region.

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INTRODUCTION

In recentyears, many resources and efforts have been invested internationally and nationally in the development and implementation of climate change adaptation measures. There are great advances in modeling and assessing climate change impacts and in the definition and analysis of the climate threats to which social and ecological systems are exposed[1]. Moreover, there is greater awareness that the effective adaptation of local communities to climate change will depend on the broader political, economic, social and environmental context in which such measures are implemented and how they relate to different power dynamics at multiple scales[2,3].

However, the monitoring and evaluation (M&E) of the impacts of the interventions to reduce the vulnerability of socio-ecosystems has lagged behind, especially in the case of the Andes[4]. One of the main information gaps that have been identified for the adaptive management of climate change in the Andes regards M&E of adaptation strategies being implemented at the national and local scales, as well as the identification of the most relevant approaches, methods and tools that could allow determining the effectiveness and impact of such actions[2,4–7].

Another challenge relates to the various interpretations and perceptions that coexist locally about what adaptation to climate change concretely means, in addition to what is understood by successful or effective adaptation and 'maladaptation'[8–10]. The difficulty in adopting a shared definition and understanding of what CC adaptation actions stand for also complicates the formulation and evaluation of indicators to measure their real impact at the local scale[11]. The challenges for measuring CC adaptation efforts often rely on different knowledge systems and the domination of expert knowledge in defining M&E mechanisms. This diversity also limits the possibility to develop comparative analyses across initiatives that address different aspects of adaptation across regions and scales. Therefore, it is necessary to analyze adaptation to CC and development as a social construction that involves a plurality of perceptions and interpretations depending on the types of actors, their interests, their power relations and their scales of action[12,13].

Following these considerations, this paper examines how global approaches for monitoring and evaluating climate change adaptation are being implemented in public policies and territorial strategies in the Andes. First, we identify the different conceptual and methodological approaches used globally, and especially in the Andes, for monitoring and evaluating the effectiveness and determining the impact of adaptation measures to the effects of climate change, with emphasis on water resources. The three main approaches that we identified are: M&E based on internationally funded project, participatory M&E from the community, and M&E of national public policies. Second, we analyze and discuss the localization process of these global approaches in four Andean countries. These case studies are articulated to the AICCA project (Adaptation to Climate Change Impacts in Water Resources in the Andes), conducted between 2018 and 2023, financed by the Global Environment Facility (GEF/GEF), implemented by the Development Bank of Latin America (CAF), and executed by the Consortium for the Sustainable Development of the Andean Ecoregion (CONDESAN).

The countries where the AICCA project was implemented share not only a common historical background, but also similar topographic and geographic characteristics[14,15]. While the four Andean countries are highly vulnerable to climate change, they are also promoting resilience of their economies and ecosystems[4,7]. In addition, there is robust evidence that climate change will seriously affect the availability, access and use of freshwater

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resources[1]. Simultaneously, water demand is rising in all parts of the world, boosted by population growth, increased water consumption in important economic sectors, and improved water supply in cities[16]. The Andean region is no exception to this[17,18]. Furthermore, climate change is affecting regional water cycles, with glaciers receding dramatically along the Andean cordillera producing more severe downpours followed by longer dry seasons, and varying evapotranspiration conditions, all of which alter the water balance of any given basin and challenge the economies and ecosystems that are built around them[19–23].

Finally, we conclude with lessons learned and key aspects that should be considered when designing and implementing locally M&E systems of adaptation measures for water security in the Andes. One of the main results of this analysis is to show the heterogeneity of the M&E approaches adopted in the four Andean countries, which reflects the diversity of strategies and local contexts where adaptation is implemented, even within a single regional project designed around a common goal. Most of the time, these countries integrated more than one approach, demonstrating their transversality in practice as well as the different conceptions, goals and scales of implementation of adaptation measures. Additionally, monitoring systems often focus on indicators based on biophysical elements over socio-political and institutional elements, without fully considering the high level of complexity of monitoring systems in the Andes[24]. Finally, this study emphasizes the need to further implement participatory M&E systems from the community, to improve the territorial articulation of M&E proposals in the Andean region.

This paper draws from a theoretical framework based on the concept of 'localization', which describes "the active construction (through discourse, framing, grafting, and cultural selection) of foreign ideas by local actors, which results in the former developing significant congruence with local beliefs and practices"[25] (245). This conceptual approach sheds light on how the diffusion of ideas, norms and narratives involves dynamics of contention over social values and natural capital, such as land, forests, water and mining resources[26]. Global norms diffusion involves power struggles over different understandings of norms, challenging local practices, and reinterpreting foreign norms to fit into different cultural frames. Therefore, the localization of global norms may lead to dynamics of negotiation, adaptation or resistance to fit into the local contexts and possibly divergent perceptions and values of locally rooted actors.

Another complementary approach to deal with the local implementation of global environmental norms is the one of 'translation'[27]. Various studies point out the tensions and challenges faced by top-down mechanisms in the design and implementation of global environmental initiatives. The concept of translation offers a way of conceptualizing these difficulties and their practical effects. By translation, Sanders et al. [27] refer to "what happens in- between the formulation of international goals and the results of implementation, and more specifically, relations and negotiations within this broader process" (68). Authors highlight the importance of local actors' participation in the design and implementation of global environmental initiatives and programs, as well as the need for international cooperation projects to focus on long-term impacts in societies and the communities beyond short-term goals[27,28].

RESULTS

Approaches for Monitoring and Evaluation (M&E) of climate change adaptation designed and used globally

Based on the literature review, three global major M&E approaches to CC adaptation that are used and promoted ay were identified: M&E based on internationally funded project, M&E based on national public policies, and participatory M&E from the community. We present below a brief analysis of the three approaches, the actors that promote them, their objectives, their tools, and main indicators (see Fig. 1 and Table 1).

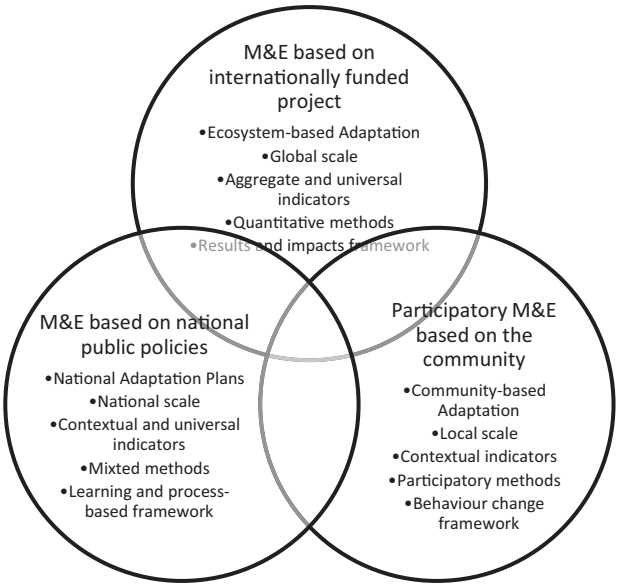

Fig. 1 Synthesis of the three M&E approaches to adaptation to climate change (Authors).

The first approach to *M&E based on internationally funded project* adopts conceptual frameworks of Ecosystem-based Adaptation (EbA) and Nature-based Solutions (NbS)[29,30]. We found in our empirical cases that the internationally funded project approach tends to be more often associated in the documents analyzed in this study with EbA/NbS frameworks as they often are the preferred conceptual frameworks for climate change adaptation as promoted by international cooperation actors at the center of this approach. This approach is articulated and conceptualized around a global/regional scale as it often responds to donor requirements and large-scale projects developed by international cooperation actors. While this approach also applies to projects implemented at the regional and national level, there is a need to be accountable to donors who fund various projects at the global level. In terms of indicators, the internationally funded project approach to M&E tends to favor aggregate and universal indicators that allow macro analysis across multiple climate change adaptation projects in different regions of the world. These indicators are often designed globally with the aim of applying them uniformly in various national or local contexts. Therefore, this approach uses mostly quantitative methods related to disciplines such as economy to analyze a large number of indicators through the collection of statistical data. Finally, the main objective of this approach is to measure results and impacts of adaptation to climate change as implemented by the projects. Impacts are assessed at the level of progress in project goals and, to a lesser extent, at the level of projects' impacts on livelihoods of the populations and the ecosystem services that are the object of the adaptation measures implemented. The main values behind M&E based on project management are related to efficiency and effectiveness in improving the capacities of humans and ecosystems to adapt to climate change.

The second *M&E approach based on national public policies* has greater relevance at the national level since it is typically implemented by decision-makers from national governments, in accordance with their international commitments to climate goals towards the United Nations Framework Convention on Climate Change (UNFCCC). This approach adopts both universal indicators based on the lines developed by the UNFCCC and contextual ones

Table 1. M&E approaches for climate change adaptation used globally (Authors).

	M&E based on internationally funded project
Preferred CC adaptation conceptual framework and types of actors involved	Ecosystem-based Adaptation (GIZ 2020) Climate Change Adaptation and Development (GIZ 2013) Nature-Based Solutions for Adaptation (CI 2021) International cooperation actors, non-governmental organizations
Key documents analyzed	GIZ/UNEP: Guidebook for Monitoring and Evaluating Ecosystem-based Adaptation Interventions GIZ: Adaptation made to measure Conservation International: "Guidelines for designing, implementing and monitoring nature-based solutions for adaptation" Global Environmental Fund (GEF): "Adaptation Monitoring and Assessment Tool" (AMAT); Climate-Eval Comunidad de Prácticas Adaptation Fund "Results Framework and Baseline Guidance" WRI/GIZ: "Making Adaptation Count" UKCIP: "toolkit AdaptME"
Objectives and tools	Effectiveness/efficiency Inclusion of local beneficiaries Aggregate and project-level information Results-Based Management Framework (or impacts) Theory of Change (TOC) Assessments based on Resources-Products-Impacts
Examples of indicators	*Project management indicators* Number of people trained to identify, prioritize, implement, monitor and evaluate adaptation strategies and measures Number of direct beneficiaries Number of people/geographic area with access to improved weather- related early warning information *Impact indicators* Soil condition and status, vegetation cover, pollinators, biodiversity Income levels, employment, food security Institutional capacity, decision-making structures, distribution of costs and benefits
	M&E based on national public policies
Preferred CC adaptation conceptual framework and types of actors involved	Focused on the evaluation of official national adaptation plans, programs and policies Decision makers at the national and subnational level
Key documents analyzed	UNFCCC: "Assessing the Costs and Benefits of Adaptation Options" IPCC: 6th Assessment Report UNESCO: "Análisis de decisiones basadas en el riesgo climático" (CRIDA) GEF: "Strengthening Monitoring and Evaluation of Climate Change Adaptation" IIED: "Tracking Adaptation and Measuring Development" (TAMD) IDS: "Learning to ADAPT" OECD: "National Climate Change Adaptation" PNUD: "Adaptation Policy Framework" GIZ: "Developing National Adaptation Monitoring and Evaluation Systems"
Objectives and tools	Process-based M&E, continuous and flexible learning Integration of sectoral policies Mixed methods (participatory workshops, analysis of quantitative indicators, etc.)
Examples of indicators	Project management indicators Integration of climate change in institutional planning Impact indicators Resilience of people and systems to anticipate, avoid, plan for, cope with, recover from, and adapt to stresses and shocks Livelihoods as a result of climate-related shocks and stresses and other aspects of human well-being that could be undermined by climate change Identify and track trends and variations in climate hazards that can complicate the interpretation of well-being indicators
	Participatory M&E based on the community
Preferred CC adaptation conceptual framework and types of actors involved	Community-Based Adaptation Vulnerabilities at the individual and household level Non-governmental organizations, local communities
Key documents analyzed	IISD: "Community-based Risk Screening Tool" CARE: "Participatory Monitoring, Evaluation, Reflection and Learning for Community-based Adaptation" UNDP: "The Community-Based Resilience Assessment" (CoBRA)
Objectives and tools	Consider the particularities of contexts Participatory methods (communities, local NGOs); Assessment and mapping of behavior changes self-monitoring; dialogs; visual documentation; gender analysis

Table 1 continued	
	Participatory M&E based on the community
Examples of indicators	*Project management indicators* Capacity building (adaptive capacity of the community in access to information on climate and risk management; local government institutions and civil society that better support adaptation efforts) Empowerment to address the underlying causes of vulnerability (poor governance, gender inequality, excessive use of resources or limited access to basic services) *Impact indicators* Climate resilient livelihoods (diversification of land use and income sources)

reflecting differences in the national contexts regarding climate change impacts and vulnerability[31]. Given these two types of indicators, mixed methods for the collection of quantitative and qualitative data are generally used, in accordance with disciplines such as political science. The main objective of this M&E approach is to measure progress in public policies or the concrete practices of the actors in terms of both processes and learning, to reflect the importance not only of achieving impacts that may take time to manifest themselves, but also of improving the processes of adaptation to climate change that are starting or consolidating. Another key objective is to generate continuous learning through adaptive management approaches to change or improve the M&E approach itself in the face of the variability and dynamics of climate change, its impacts, and the vulnerabilities of socio-ecosystems at the national and local levels[32]. The main values associated with this M&E system are adaptative capacities of institutions (especially governments) and flexibility considering the variability of national contexts and climate impacts.

The third *participatory M&E approach from the community* is based on the conceptual framework of Community-based Adaptation (CbA) and has been developed to be applied above all at the local and sub-regional scale by involving the direct beneficiaries of climate change adaptation projects as key actors (e.g., vulnerable populations, communities). Due to the proximity to the beneficiaries, this approach uses contextual M&E indicators that are adapted to each local reality and that are often designed by the local actors themselves based on their knowledge and experiences, through participatory methods developed in disciplines such as anthropology or sociology (e.g., focus groups, participatory mapping, life stories). The ultimate goal of the participatory M&E approach from the community is to achieve a progressive and lasting change in the behaviors, perceptions and adaptive capacity of populations vulnerable to the impacts of climate change[33]. In this sense, the ultimate goal is not only to measure in the target population changes in the vulnerability to some impact of climate change at a given moment, but to ensure a deeper and transformative change in the practices, visions and strategies of people and their organizations, which can provide the foundation towards more resilient means and ways of life. The main values associated with this approach are direct participation, inclusion and solidarity at the level of the community.

There are both differences and complementarities between these three global M&E approaches to climate change adaptation. On the one hand, it can be observed that each approach involves different actors, scales, methods and objectives that respond to different definitions and visions of what adaptation to climate change concretely means. For example, the conceptual framework on adaptation to climate change that is used in each approach varies according to the actor that is at the center of the measures (socio-ecosystems, governments and communities being the typical focus of each of the three approaches respectively) and the scale at which the M&E process is developed (global/regional, national, or local). On the other hand, these differences do not prevent transversality or complementarity between the three M&E approaches in practice, helping to fill gaps and consolidate strengths. For example, it is often necessary to combine quantitative and qualitative methods to take into account the complexity of adaptation processes to climate change and its impacts. In addition, all three approaches adopt a framework of results and impacts of climate change adaptation measures, even though it differs in their focal actors and scales of implementation. Therefore, in various projects there is a combination of project management indicators and concrete impacts or results for the adaptation of ecosystems and populations, taking elements from the three major approaches.

The localization of global M&E for climate change adaptation in four Andean countries

The four Andean countries considered in this study have experienced different levels of national reforms regarding M&E of climate change adaptation.

In Colombia, the process of designing the National Adaptation M&E system began in 2014[34], and since then the country has made progress in defining indicators and guidelines to monitor the objectives and progress of the National Climate Change Adaptation Plan (PNACC). As part of the PNACC implementation process, between 2015 and 2016, the country began to design the National System of Adaptation Indicators. A group of 34 indicators were selected and included in 7 categories: (i) biodiversity and ecosystem services (ii) water resources (iii) agriculture and food security (iv) infrastructure (v) energy (vi) human habitat and (vii) health.

While it is recognized in the PNACC that indicators are not the ultimate goal of M&E, tools to measure specific aspects and quantitative and qualitative instruments are still required (e.g., interviews, formal social science methods) to provide a national overview of the measures for climate change adaptation that are being implemented. In addition, Colombia has been consolidating an integrated framework for monitoring high Andean ecosystems[35], which can provide guidelines for promoting a transdisciplinary, multi-ecosystem and multi-scale perspective which explicitly considers the complex environmental and land-use transformation gradients that characterize tropical mountain landscapes[36].

In Ecuador, the construction of the National Climate Change Adaptation Plan[37] began in 2018 and was formally adopted in 2023 as a first step towards the future objective of designing a national M&E system for adaptation to climate change. The First NDC of Ecuador mentions the implementation of a national information system for the water sector as a tool to support the management, M&E of the effects of climate change. In addition, the Organic Environmental Code (COA) seeks to establish the legal and institutional framework for the planning, articulation, coordination and monitoring of public policies aimed at designing, managing and executing climate change adaptation actions at the local, regional and national level. The COA proposes the use of a transversal and participatory approach, coordinated and articulated with the international instruments ratified by the State and the principle of common but differentiated responsibility.

Table 2. Comparison of pilot M&E systems implemented within the framework of the AICCA project (Authors).

	Conceptual framework of climate change adaptation and central actors	CC Adaptation Measures Implemented	Key objective and solutions	Examples of indicators
Colombia	Ecosystem- based Adaptation Community- based Adaptation Regional and local governments Beneficiaries and communities	Water harvesting and irrigation Participatory Weather Monitoring Strengthening of the hydroclimatological monitoring network Phenological network for bird monitoring Ecological restoration Rural extension program Beekeeping production systems	Design and implementation of a monitoring system to assess the effectiveness of risk reduction practices and vulnerability to climate change in the Lake Tota Basin	Increased availability of water for production systems in times of drought and/or increased VC/CC phenomena. Improved livelihoods of families with high climate risks in the food security dimension related to extreme events linked with climate variability and change. Increased adaptive capacity of communities in relation to the use of meteorological data, integrated in the sectors of interest. Number of people trained in the identification of six bird species as bioindicators of climate change.
Ecuador	Adaptive capacity of hydroelectric generation under climate change scenarios Conservation Committee of the Machángara River Basin	- Sustainable agricultural production -Sustainable livestock production -Restoration -Drinking water systems -Biological monitoring - Microfinancing programs for implementing CC measures	Quantify the efficiency and effectiveness of adaptation measures to cope with climate change	Percentage of water sources protected. Percentage of monitoring stations within the sub-basin linked to the early warning system. Number of producers trained in irrigation issues and crops. Number of hectares of family plots beneficiaries/owners of the pastures/paddocks that have improved their performance and adaptive capacity.
Peru	Adaptive capacity of ecosystems, productive systems and hydrographic basins Ministry of Environment (MINAM)	- Agroclimatic information services -Climate change resilient business strategies -Capacity building for agricultural producers	Implementation of the Monitoring and Evaluation System (M&E) of climate change adaptation measures	Hectares prepared for planting and harvest water for water security. Number of agricultural producers who receive technical assistance. % of producers who diversify their production systems in crops and breeds with greater vulnerability to climate change. Number of agricultural producers trained in innovation technology adaptive to climate change in agrarian value chains.
Bolivia	Hydrological cycle Autonomous Municipal Government of Sacaba	Sustainable Urban Drainage Systems	Provide a procedural guide for representative monitoring of Sustainable Urban Drainage Systems (SUDS)	Indicators of hydrological impacts determined by changes in the processes of the hydrological cycle: Water flow, groundwater level and water quality.

Peru is implementing the System for Monitoring Adaptation and Mitigation Measures, within the framework of article 13 of the Paris Agreement and the Framework Law on Climate Change and its Regulations[38]. The objective is to monitor, report and evaluate the level of progress of the country´s NDC in its three components: adaptation, mitigation and climate financing. Peru is the only country part of the AICCA project that is actually fully implementing a national M&E system of CC adaptation.

In Bolivia, the construction of a national M&E system is still in an early design phase. The report on the progress of the implementation of the NDC in Bolivia mentions that institutional and technological capacities must be generated to monitor and report on the implementation of the NDC and thus be able to report to the UNFCCC[39]. In this sense, the Plurinational Authority of Mother Earth (APMT) is responsible for establishing the Plurinational System of Information and Comprehensive Monitoring of Mother Earth and Climate Change (SIMTCC).

In the following paragraphs, we analyze how the three major M&E approaches to climate change adaptation previously identified have been localized. Table 2 shows the key aspects of the pilot projects of M&E systems for adaptation to climate change in the four countries as implemented within the framework of the AICCA project. In terms of conceptual frameworks, Bolivia and Ecuador consider a specific climate change adaptation framework based on the hydrological cycle, while Colombia and Peru have a broader EbA approach. While in Bolivia, Colombia and Ecuador, the pilot projects have been developed at the sub-national scale, in Peru, the pilot project has been implemented at the national scale as a pre-requisite to then apply it at the local scale. Regarding the central actors of the M&E systems, in most cases, government authorities at the national and/or subnational level are considered, and sometimes more specific actors at the basin or community level. The objectives of these systems vary between evaluating effectiveness, representativeness or concrete implementation. Finally, the four countries consider indicators of impacts on the adaptive capacity of ecosystems, hydrological cycles, vulnerable populations, and the agriculture sector.

Colombia

CONDESAN, in collaboration with the Ministry of Environment and Sustainable Development (MADS), has supported the development of a M&E system for adaptation to climate change in the Lake Tota basin, in the department of Boyacá, a strategic production and food marketing area in the Cordillera Oriental of Colombia[40]. The implementation in Colombia had certain particularities, which respond to the context of adaptation in the country. Although the MADS provided guidelines and very close monitoring, it did not focus fully on the control of specific activities. Therefore, the implementation by CONDESAN responded to the established national climate change regulations, but also focused on a local implementation that responded to the adaptation needs of the population in the Lake Tota Basin.

The objective of AICCA in Colombia was to generate and share relevant data, information and experiences, useful for the formulation of local and national policies with the productive sector, to include criteria for adaptation to climate variability and change, and to promote pilot investments in priority areas for the country. This activity is aimed at government authorities at the national and subnational levels, and civil society actors as beneficiaries. It is framed in two conceptual frameworks of EbA and CbA. Some examples of CC adaptation practices as promoted by CONDESAN with local organizations include harvesting water and irrigation, participatory weather monitoring, strengthening the hydro-climatological monitoring network, a phenological bird monitoring network, an ecological restoration program, a rural extension program, beekeeping production systems, sustainable tourism, and renaturation of riverbeds and riverside areas.

This system is based on the M&E approach focused on national public policies. Although policies are not explicitly addressed, the final aim is that the monitoring be oriented toward policies or decision-making processes that affect the region. The project expects that some of the strategies implemented locally can evolve into official programs and policies, and can inform the national M&E system for monitoring adaptation. The design of the M&E system for adaptation in the Lake Tota basin seeks to influence decision-making supported by information and to include climatic considerations in policies in environmental and sectoral planning with a long-term vision of the adaptive management of the Lake Tota basin, based on local learning, but aligned with both national and global guidelines for M&E of adaptation. This reflects a dynamic of localization from national environmental indicators toward the local reality of one particular basin, as well as the potential of local initiatives to scale-up and improve national public policies.

The project integrates continuous learning and process-based evaluation. The system seeks to take into account the complexity of adaptation to climate change and the need to demonstrate the efficiency of the implementation of actions aimed at reducing vulnerability and climate risk, considering a framework of results and project impacts. It also recognizes that adaptation processes are varied, occur at different scales of application, and in their own contexts. In this sense, the implementation actions are aligned with the needs of each productive sector and territory conceived in an integral and transversal way. For example, CONDESAN and the MADS, in the framework of the AICCA project, facilitated the formulation of four Development Plans in the municipalities of the Tota Lake basin, including the CC variability dimension to reach effective local public policies, as well as Efficient Use and Water Saving Plans in irrigation districts (3) within the basin. As a result, the local communities who live in the basin can plan water availability in every sector according to demand and offer, as well as face climate variability in their territory.

In addition, the tools used within the construction of the system are related to the participatory M&E approach from the community. The system proposes to identify and link the beneficiaries of the different adaptation strategies as progress is made in the development and application of the methodology. It is also proposed to carry out a series of participatory workshops that allowed the gathering of information. For example, the "Participatory ecological restoration" component seeks to improve the adaptive capacity of communities, through capacity-building processes. The "Participatory meteorological monitoring" component aims to increase the adaptive capacity of communities, through the monitoring of meteorological variables, which serve as an input for decision-making in agricultural and environmental systems. The "Monitoring of birds as a bioindicators" component seeks to improve the adaptive capacity of communities and resilience of local biodiversity, through monitoring phenological bioindicators and possible current and future impacts of climate change. These participatory methods reveal a dynamic of localization of M&E systems towards local beneficiaries of one particular territory, considering the involvement of planning tools and local actors to monitor and evaluate CC adaptation measures.

This localization dynamics is key to prevent and manage possible conflicts or tensions at the moment of implementing CC adaptation measures in communities. Following this objective, CONDESAN and the MADS developed and implemented a methodology for addressing water conflicts in the Lake Tota basin, involving the participation of local communities in applying CC adaptation measures at the local scale.

Finally, the next proposed step is to institutionalize the M&E pilot system in the Lake Tota basin so that it constitutes an important contribution to the PNACC, designating institutions and officials responsible for leading the process, documenting

progress and making agreements with those responsible for generating and reporting the information.

Ecuador

CONDESAN and the MAATE, together with the University of Cuenca, carried out a study to assess the vulnerability and climate risks of hydropower generation in the Machángara river sub-basin, in the provinces of Cañar and Azuay, including the identification of adaptation measures and a follow-up and monitoring mechanism for adaptive capacity[41]. Within the conceptual framework of the project, a monitoring mechanism has been designed and implemented for the adaptive capacity of hydroelectric generation under climate change scenarios, proposing an impact-based M&E system.

In Ecuador, as of 2019, more than 97% of renewable energy came from hydroelectric generation[42]. Climate variability presents a challenge for the sector as it could increase the probability of water scarcity in certain areas of the country, as well as the presence of more intense rains in other territories, causing possible damage to the hydroelectric infrastructure. The Machángara river basin supplies about 60% of drinking water to the city of Cuenca, one of the largest in Ecuador: it also generates 39.5 MW of hydroelectric power (Saucay and Saymirín power plants), and provides irrigation for 2900 users, covering a total of 1900 ha, dedicated to agricultural production.

This case study falls mainly within the M&E approach based on internationally funded project as described above. The main objective of the M&E mechanism is to quantify the efficiency and effectiveness of adaptation measures (e.g., percentage of water sources protected; percentage of monitoring stations within the sub-basin linked to the early warning system; number of producers trained in irrigation issues and crops; number of hectares of family plots beneficiaries/owners of the pastures/paddocks that have improved its performance and adaptive capacity) to cope with climate change. The mechanism aims to periodically assess the degree of compliance with the objectives and goals pursued by the adaptation measures identified. In addition, it identifies key performance or impact indicators focused on the climate threat, the exposed elements, the adaptation measures, the objective, and the expected results.

Among the contributions of AICCA in Ecuador, the systematization of the experience of the formation and management model of the Machángara River Basin Conservation Committee stands out[41]. The systematization is aimed at the actors who will manage the M&E system of adaptive capacity; in turn, it becomes a methodological guide to strengthen decision-making at the subnational scale which can also serve a pilot for replication at the national scale. In this sense, localization processes demonstrate their potential for scaling-up towards national M&E systems for climate change adaptation.

To generate long-term sustained processes, CONDESAN, the MAATE and the University of Cuenca involved the local populations of these basins, strengthening their capacities so that they can adapt to the changing climate, through the Machángara River Basin Conservation Committee. This reflects a dynamic of localization showing the importance of local actors' inclusion for sustaining climate change adaptation M&E processes in territories. The Committee is made up of 9 institutions and organizations, among them: the Municipal Public Telecommunications, Drinking Water, Sewerage and Sanitation Company of Cuenca (ETAPA- EP), the company Electro Generadora del Austro ELECAUSTRO S.A., the University of Cuenca, the Government Decentralized Autonomous Government (GAD) of Azuay, the Ministry of the Environment, Water and Ecological Transition (MAATE), the Ministry of Agriculture and Livestock (MAG), the Machángara Irrigation and Drainage Board, the Checa Parish GAD, and the Parish GAD of Chiquintad. The mission of the Committee is to strengthen the integrated management of water resources and territorial planning as the articulation axis of the climate adaptation mechanism, in addition to the conservation of strategic ecosystems in the region. This Committee is central to the process of localization through its capacity to adapt global and national climate policies to the specificities of the local context. Moreover, it is an innovative example of sub-regional governance and coordination for CC adaptation in the country.

The data and tools developed during the project are currently being used as inputs by the Machángara River Basin Committee to monitor the adaptation and territorial management measures being implemented in its Integral Management Plan for the Machángara River Basin including interinstitutional and intersectoral efforts. In the same way, the results of the M&E system will serve as inputs for the development of the national system of Measurement, Reporting and Verification (MRV) implemented by MAATE, as well as some activities related to the goals of the country´s First NDC.

Peru

CONDESAN and MINAM have supported the design and roadmap for the implementation of the national M&E system of climate change adaptation measures in the agriculture sector, in collaboration with key actors, such as the Climate Change Adaptation and Desertification Department (DACCD) of the Ministry of the Environment (MINAM). The NDC for Agriculture prioritized four subcomponents: soils, agricultural production systems, value chains, and water for agricultural use, identifying 24 adaptation measures. CONDESAN and MINAM focused on the design of indicators to measure the progress of the NDCs in the Agriculture sector, which are centered on the adaptive capacity of ecosystems, productive systems and hydrographic basins.

Irrigation in the Andes of Peru is key to ensuring family farming and different forms of livelihood for vulnerable populations in areas of poverty and extreme poverty, where the impacts of climate change affect access to water service, in terms of quality and quantity. In recent years, public investments in small and medium irrigation projects have increased as part of the National Agrarian Policy, since Peru is one of the Latin American countries most affected by climatic phenomena associated with El Niño, as well as one of the three countries with more climate risks worldwide[43]. Therefore, the inclusion of those vulnerable populations is key for localizing climate change adaptation M&E systems to the particularities of Andean ecosystems, culture and agriculture practices.

This activity is part of the M&E approach based on national public policies, due to its connection with the NDC. The Climate Change Law, in article 14 establishes the following: "The Ministry of the Environment is responsible for monitoring and evaluating the Nationally Determined Contributions, and report on their implementation to the Secretariat of the United Nations Framework Convention on Change Climate". In addition, Article 08 establishes the functions of the sectoral authorities, specifically to monitor, evaluate and report the level of progress in the implementation of adaptation and mitigation measures, while Article 32 establishes the creation of the System for the Monitoring of Measures of Adaptation and Mitigation. On the other hand, the National Competitiveness and Productivity Plan (PNCP) established the creation of a Platform for monitoring the implementation of the adaptation and mitigation NDCs, with the objective of providing updated information on compliance with the NDCs.

Whereas in Peru the project is mainly focused on national authorities, the process of localization still occurs through the involvement and participation of regional governments and local ancestral communities in some activities implemented. At the national level, for example, AICCA Peru updated the standard

technical sheet for investment projects in the irrigation sector. At the sub-national level, in the municipality of Independencia-Huaraz, in the regional government of Ancash, ancestral communities of Antonio Montero and Santiago Antunes de Mayolo received capacity-building to improve their knowledge of climate change impacts and adaptation measures in their territory.

As a final result, CONDESAN and MINAM contributed to the roadmap for M&E of adaptation measures (e.g., planting and harvesting water for water security; agricultural producers who receive technical assistance; producers who diversify their production systems in crops and breeds with greater vulnerability to climate change; agricultural producers trained in innovation technology adaptive to climate change in agrarian value chains). This has been achieved through three stages: (1) the development of sheets and indicators for all adaptation measures (24 in total, 17 for agriculture and 7 for water for agricultural use); (2) the development of M&E prototypes for 8 adaptation measures; and (3) the development of a pilot of the computer module for M&E of two adaptation measures. MINAM is responsible for the M&E system of adaptation measures; For this reason, the platform will be anchored in the MINAM system, and the Ministry of Agriculture (MIDAGRI) will also be able to access the platform to report the information.

Bolivia

In collaboration with CONDESAN, the Bolivian government has developed the Monitoring Program for Sustainable Urban Drainage Systems (SUDS). Its main objective is to provide procedural guidelines for a representative monitoring of SUDS to the Autonomous Municipal Government of Sacaba and to the institutions interested in replicating the methodology, considering the conceptual framework based on water cycles.

Cochabamba is one of the departments with the most areas prone to flooding and landslides. This is due to the accelerated urban growth, which generates settlements in places of risk and causes greater vulnerability of the region to the impacts of climate change[44]. CONDESAN and the MMAyA focused its work on flood prevention in key areas of the Kanata Metropolitan Region, in addition to the protection of water sources for human consumption. Priority was given to the improvement of territorial planning and environmental management to guarantee the safety of the population and the sustainability of water resources. The design and implementation of a pilot SUDS in Sacaba was one of the main climate change adaptation measures implemented by the project, along with restoration efforts and an environmental education program. Each of the project's actions were reinforced by the involvement and active participation of civil society, as well as capacity building of municipalities, as part of a dynamic of M&E systems' localization.

On the one hand, this program partly responds to the M&E approach based on internationally funded project, since it seeks to establish techniques and procedures for monitoring the effectiveness of SUDS and water retention, based on internationally standardized hydrological practices (e.g., water monitoring for different planning, control, monitoring, evaluation or research purposes)[45]. This objective is reflected in the definition of hydrological impact indicators determined by the hydrological cycle processes, as well as variables related to the state and dynamics of water quality in its physicochemical and hydrobiological manifestations. The methodologies for data analysis include the comparison of variables with current regulations, water quality indicators and modeling. The adoption of international standards for water monitoring reveals a process of norms' localization involving sub-national public authorities. For example, CONDESAN contributed to the forestation and reforestation of 11 hectares in the Kanata Metropolitan Region, with the support of the Ministry of Water and Environment, the Municipal Government of Cochabamba and the participation of more than 500 people from local communities, institutions and education centers. The objective is to implement global best practices for hydrological control and planning to respond to concrete climate threats and impacts faced by this territory.

On the other hand, this pilot program is aimed at supporting subnational government authorities in charge of M&E. In addition, it seeks to identify the responsibilities and institutional roles for monitoring SUDS and water resources based on current regulations. For example, CONDESAN and the MMAyA carried out a training cycle on the proper management of household waste, emphasizing the reduction, recycling and reuse of solid waste. Workshops were held in the municipality of Cochabamba and encouraged women to join, turning them into multiplying agents of change through various initiatives that provide them with independence and additional resources. The focus on particularly vulnerable populations also considered as potential leaders of change is one other key characteristic of localization dynamics.

In the case of the M&E system of the SUDS, the municipality has the commitment to carry out the operation and maintenance of the project. The municipality has provided funds in the 2023 Annual Operating Plan to carry out the administration and achieve the operation of the components, and the technicians from the Municipality of Sacaba will be responsible for M&E processes. The results will be used to improve the operation of the SUDS and provide the information and data necessary to evaluate their efficiency. In addition, there is interest in developing agreements between the municipality and universities to carry out some research with the data information and records of the monitoring system.

DISCUSSION

There has been substantial progress made in understanding CC impacts and adaptation, but much less in the implementation of M&E of CC adaptation, particularly in the Andes[4]. In what follows, we discuss our findings related to the dynamics of localization of global approaches on M&E of CC adaptation in the Andes. We found that localization mainly occurs though a bidirectional process across scales: by adapting global norms to the local realities, and by considering local pilots' potential contribution to the scaling-up of M&E systems at the national scale.

At the level of national institutional frameworks, the four Andean countries have key documents that mention the need to move towards the design of national M&E systems for adaptation to climate change. In practice, Colombia, Ecuador and Peru have defined national systems of indicators for the M&E of climate change adaptation. In Bolivia, only pilot proposals are found at the local level, without these proposals yet being scaled-up at a national level. In general, these monitoring systems have not been fully implemented (with the only exception of Peru) and there are no published results, which makes it difficult to analyze their effectiveness up to now.

A key result of the analysis is the heterogeneity in the adoption of global M&E approaches in the different countries, which reflects the diversity of strategies and local contexts where adaptation occurs. In the four case studies, more than one approach is often being used, demonstrating their transversality in practice and application at different scales. This is due to the diversity of climate impacts and the adaptation measures proposed in each context, the multiple scales at which adaptation occurs, and the difficulty of separating adaptation and development in countries from the Global South[11,46].

In addition, it is also challenging to attribute impacts to projects or programs which may include many changes resulting from the broader context of implementation. This emphasizes the need for comprehensive monitoring approaches that are transdisciplinary, but at the same time cost- effective[24]. This learning stems from

the recognition that adaptation to climate change is not only based on measurable impacts and results in the short term, but also on continuous processes of governance and social development in the long term[47,48]. Therefore, monitoring indicators of changes in the adaptive capacity of human groups is key (e.g., knowledge, capacities, empowerment and participation), as emphasized in the analysis of localization dynamics in the four case studies. Additionally, localization processes highlight the importance to include the most vulnerable populations to climate impacts and their related knowledge in M&E systems to ensure their sustainability in the long-term.

In Colombia, two M&E approaches based on national public policies and participatory M&E from the community have been adopted, which demonstrate a high level of territorialization, which should then upscale into the design of Colombia´s national M&E system of CC adaptation. In Peru, there is a consolidated M&E system based on national public policies within the framework of its NDC for the agricultural sector under the UNFCCC, although the assessment of this monitoring framework remains an open challenge. Whereas the M&E of CC adaptation in Peru is mainly articulated around the national level, CONDESAN contributed to territorializing this system through capacity-building activities with ancestral communities, municipalities and regional governments in some regions of the country. In Ecuador, the National CC Adaptation Plan (NAP) has been adopted in 2023 as a key step towards the implementation of a M&E system for CC adaptation measures in the territory. CONDESAN, through implementing the AICCA project in the country, brings an important territorial milestone for the effective implementation of the PNA nationally. Finally, in Bolivia, the legal framework at the national level considers the need to create an M&E system for adaptation to climate change, but M&E remains at the level of projects located in certain territories or hydrographic basins. Hence, there is still the need to feed the conceptual and practical lessons derived from this local and sub-national experiences into a consolidated proposal at the national level.

In addition, from a norms' translation perspective, it is necessary to analyze how the socio- environmental specificities of the Andean context impose challenges and considerations that need to be incorporated into M&E systems in these countries in which mountain socio- ecosystems play a strategic role as providers of ecosystem services and living spaces for a substantial proportion of their rural and urban populations[24]. This includes aspects such as the connections between the high and low mountain areas and the ecosystem services that the high areas provide to the populations of the low areas, social vulnerability and isolation of rural mountain communities, fragility of mountain ecosystems and agroecosystems, high exposure of these systems to climate change impacts, and the lack of information on climate dynamics and impacts in the context of high climatic, environmental and social heterogeneity of the Andes[4,7].

Monitoring the impacts of adaptation to climate change has a high level of complexity that is not fully reflected in the existing proposals for environmental and social monitoring across the Andes[24]. In the large majority of cases, regional long-term monitoring systems and networks focus on indicators based on biophysical elements over sociopolitical and institutional elements. For monitoring climate change impacts and their complex interactions with land-use changes it is necessary to make greater efforts in monitoring ecosystem services, governance processes and the changes in vulnerability and adaptive capacities of Andean populations. Currently, impact monitoring remains at a sectoral but not comprehensive level.

In addition, this study indicates the need to further implement participatory M&E systems from the community, as it provides an opportunity to improve the territorial connection of many M&E proposals in the Andean region. This gap reveals the remaining challenges for the localization of global M&E systems for CC adaptation to fit with local contexts, beliefs and values regarding CC adaptation. This constitutes a great opportunity to take advantage of climate change adaptation programs as local experiments or experiences. The systematization of these experiences could allow a better understanding of the relationship between management strategies, use and conservation of natural resources and changes in vulnerability and resilience of environmental and social systems in the face of climate change and land use change, particularly in the complex context of mountain landscapes[36].

M&E systems were designed in response to the needs and guidelines of the Ministries of the Environment of each country, with the exception of Colombia, which prioritized local monitoring in the Lake Tota Basin. Although CONDESAN as the executing agency gave recommendations based on its experiences of supporting regional networks of ecosystem monitoring and ecosystem services, it could not have any influence on what for the Ministries was a priority. The above described demonstrates how, indirectly, environmental authorities exercise their power regarding the localization of climate change adaptation in each country. When managing GEF resources, countries have the final say when deciding the implementation of resources. Currently, there are limitations in the dialog processes between science and politics in the region (although there has been progress in the last years in generating these spaces)[49], so international cooperation agencies must respond to what is asked of them, with a critical need for the consolidation of more formal spaces for reflection and collective construction (e.g., within the context of the Andean Mountain Initiative). For example, the climate change adaptation discourse is too sectorialized that recommending more comprehensive and landscape approaches still constitutes a major open challenge.

METHODS

Literature review

To identify the major M&E approaches to CC adaptation designed and used at the global level, we carried out a literature review of 40 documents (see Table 1) including 20 scientific publications and 20 synthesis reports on climate change adaptation M&E tools or methodologies in general as well as those with a specific focus on water security in the four prioritized subsectors of the AICCA project (water and basic sanitation, agriculture, minor irrigation, and hydropower). For practical reasons, we did not include all the existing global tools of CC adaptation M&E (i.e., Pilot Program on Climate Resilience; Least Developed Countries Fund; Building Resilience and Adaptation to Climate Extremes and Disasters; USAID resilience framing).

We refer to these approaches as global as they have been all created, promoted and used by key actors working in the field of international development and global climate policies. Moreover, they have been designed to be applicable in different contexts around the world, without an explicit reference to a particular territorial context or region. In addition, to provide context for each case study, we first reviewed the current status of the national systems of M&E of climate change adaptation (including the National Adaptation Plans-NAPs). The M&E systems of CC adaptation in these four countries are primarily within a design phase, and national plans are still not being implemented[3]. Hence, the implementation of M&E systems at a local scale in the different case studies could provide inputs to this process of designing national strategies.

Analysis of four national cases from the AICCA project

Then, we analyzed the M&E systems of the AICCA project in the four Andean countries where it was implemented in Colombia (M&E system for adaptation to climate change in the Lake Tota

basin), Ecuador (Vulnerability and climatic risk of hydropower generation in the Machángara river sub-basin), Peru (M&E System of national climate change adaptation measures for the agriculture sector) and Bolivia (Monitoring Program for Sustainable Urban Drainage Systems). Our objectives were to understand what the key actors in these four countries choose to monitor, how they adjust or integrate the different M&E approaches, and how they understand adaptation or vulnerability reduction to climate change. Another goal was to identify possible innovations at the national and local scales, as well as the pending challenges for the design and implementation of M&E systems for climate change adaptation in those countries. This analysis was carried out with the information obtained through the main project's products and consultations with key actors involved in M&E processes (i.e., final implementation reports, diagnoses, design of methodologies and indicators).

The AICCA project was designed by the Ministries of the Environment of Colombia, Ecuador, Peru and Bolivia in collaboration with the World Bank, later on, the Project design was transferred to CAF who finalized it. Although the focus of the project was adaptation to climate change and its impacts on water resources, each country prioritized its preferred sector and implementation site. In Ecuador, for example, a change was taking place in the country's energy matrix towards hydroenergy, so working with this sector was a priority. In Bolivia, the intensity of the winters was affecting high Andean cities such as Cochabamba with strong landslides and floods which were increasingly recurrent. For this reason, the Government prioritized the sanitation and drinking water sector. In the Andes of Peru, irrigation is essential to ensure the sustenance and development of vulnerable high Andean populations. In Colombia, for its part, the Department of Boyacá is one of the most important areas of food production and marketing. Thus, each country, depending on the circumstances it was going through, established the sector and site of intervention. Although CONDESAN recommended certain intervention actions that were more local or focused on conservation of ecosystem services, the implementation responded to what the environmental authorities of each country considered appropriate. This means that, in the end, the decisions about what to implement and how to do it were made by the Ministries of the Environment, and not by the executing or implementing agencies, which are chosen for their technical expertize.

Reporting summary

Further information on research design is available in the Nature Research Reporting Summary linked to this article.

DATA AVAILABILITY

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

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AUTHOR CONTRIBUTIONS

E.D. led the writing of the whole paper. A.G., L.D.L. and M.B. contributed to provide key data from the four case studies analyzed in this paper, and to the overall revision of the approach, content and structure of the paper.

COMPETING INTERESTS

The authors declare no competing interests.

ADDITIONAL INFORMATION

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