

SCIENTIFIC & IMPLEMENTATION PLAN





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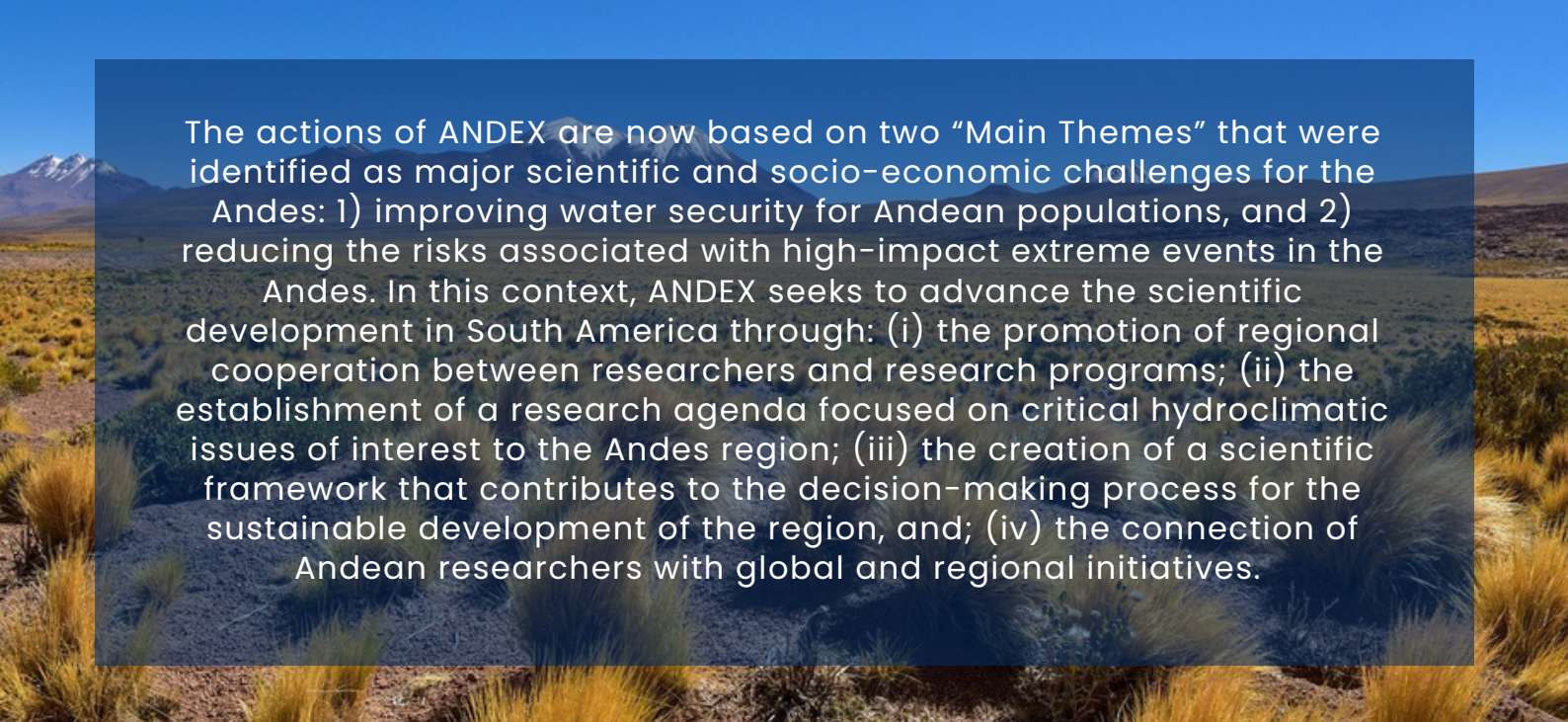


ABOUT ANDEX

Institutionalisation and timeline

ANDEX is an initiating Regional Hydroclimate Project (RHP) of the Hydroclimatology Panel of Global Energy and Water Exchanges (GEWEX), one of the core projects of World Climate Research Programme (WCRP). The program was founded in late 2017 with the objectives of understanding, modelling and predicting the dynamics of the water and energy cycles over the Andes cordillera, at a wide range of temporal and spatial scales, and their linkages with the surrounding oceans, land surface and major river basins.

Over the years, the objectives of ANDEX have broadened to include a transdisciplinary perspective where the outcomes of the hydroclimatic assessments can be incorporated into the decision-making process to support a sustainable development of the Andean countries.



The actions of ANDEX are now based on two “Main Themes” that were identified as major scientific and socio-economic challenges for the Andes: 1) improving water security for Andean populations, and 2) reducing the risks associated with high-impact extreme events in the Andes. In this context, ANDEX seeks to advance the scientific development in South America through: (i) the promotion of regional cooperation between researchers and research programs; (ii) the establishment of a research agenda focused on critical hydroclimatic issues of interest to the Andes region; (iii) the creation of a scientific framework that contributes to the decision-making process for the sustainable development of the region, and; (iv) the connection of Andean researchers with global and regional initiatives.

ANDEX was formed by a relatively small team of scientists who, with the help of the GEWEX International Project Office (IPO), have carried out diverse activities that have led to the present implementation plan, including: (1) six in-person meetings (Medellin, Colombia 2017; Santiago, Chile 2018; Quito, Ecuador 2019, Buenos Aires, Argentina 2022, Santiago, Chile 2023 and Lima, Perú 2024), (2) a collection of eight review papers dealing with the state-of-the-art of the Andean hydroclimate that served as a solid foundation for the ANDEX Implementation Plan*, (3) the assembly of an ANDEX virtual group (ListANDEX) that includes more than 300 colleagues in Latin America and beyond, (4) the assembly of an early-career virtual group (JovenANDEX) with more than 100 young scientists in Latin America and beyond,

(5) special sessions focused on the Andean hydroclimate at the 2019 AGU Fall Meeting, and at the 2020 and 2021 EGU Meetings, and many other virtual meetings, (6) a series of webinars ‘From the science to the policy in the Andes’ in 2022-23 and (7) implementation of the [ANDEX web page](#).

During these years, the ANDEX team has grown from 10-12 scientists at the initial meetings to a current network of more than 60 researchers working on Andean hydroclimate and related issues. In addition, strong connections have been established with national and international institutions such as IAI, IRD, SAAG-NCAR, the ANDES-C2H network, IGP, INAIGEM, AccelNet ACCORD project and PUCP, among others.

*These papers were included in a special issue of the journal *Frontiers in Earth Science*, titled “Connecting Mountain Hydroclimate Through the American Cordilleras”. Subsequently, in 2024, the ANDEX team published two review papers on advancements in atmospheric modeling and plans to publish a review on hydrological modeling in 2025. (Martinez et al., 2024; Juncquas et al., 2024).

Organisation, pillars, mission and vision

ANDEX is a scientific network organised into disciplinary teams, transversal lines, and integrative services which follow the two “Main Themes” mentioned in the previous section.



Figure 1. ANDEX structure.

Disciplinary Teams

TEAMS OF SCIENTISTS INTERACTING UNDER SIMILAR RESEARCH INTERESTS AND EXPERTISE THAT BROADLY RELATE TO THE ANDEX MAIN THEMES BUT TACKLE THE STUDY OF THE ANDEAN HYDROCLIMATE FROM DIFFERENT AND COMPLEMENTARY PERSPECTIVES.

Climatic Processes and Drivers:

This team deals with different atmospheric phenomena and processes that affect the Andean hydroclimatology, considering their interaction with the components of the climate system (biosphere, cryosphere, hydrosphere). It addresses a range of spatial scales, from global phenomena (e.g. climate change, El Niño-Southern Oscillation) and regional (e.g. Andes-Amazon interaction) to local factors (valley breezes, glaciers, topographic effects, cities, among others).

Environmental and Ecological Changes:

This team analyses the alterations that have occurred in the Andean environment and ecosystems from paleoclimatic scales to the observational period (last 50-100 years), and their relationship with global changes (e.g. climate change) and anthropogenic activities (e.g. deforestation, urbanisation). It addresses projections of Andean ecosystem dynamics based on possible future climate changes and human interventions.

Water Resources and Cryosphere:

This team addresses various hydrological and cryospheric processes in the Andes and their interaction with neighbouring regions within the framework of the hydrological cycle. It considers different processes that modulate water availability for Andean populations and ecosystems that could help improve the understanding and forecasting of high-impact events (e.g., mass movements, floods, droughts). The team is also interested in facilitating the dissemination and access of available hydroclimatic and cryospheric studies and data from the Andes cordillera.

Governance and Policy (not yet established):

This team will largely focus on the science-policy relationship, proposing strategies to make scientific work more effective concerning the needs of the Andean populations and decision-making. It will also seek to define tools that help decision-making based on scientific knowledge and the co-construction of priority research topics.



Transversal Lines

INTERDISCIPLINARY GROUPS OF SPECIALISTS INTERACTING AND COLLABORATING WITH THE DISCIPLINARY TEAMS TO INTEGRATE, FACILITATE, AND GUIDE THEIR TASKS AND RESULTS WITHIN THE FRAMEWORK OF THE TWO MAJOR CHALLENGES IDENTIFIED FOR THE ANDES.



Science Underpinning Sustainable Development

This line works with the Disciplinary Teams to develop a science based on sustainable development principles. It addresses a range of natural, social, and engineering fields on sustainability, its political dimensions, and possible solutions. The team focuses on understanding how the current and future well-being of the Andean populations can be achieved within the limits of the planet's sustainability.

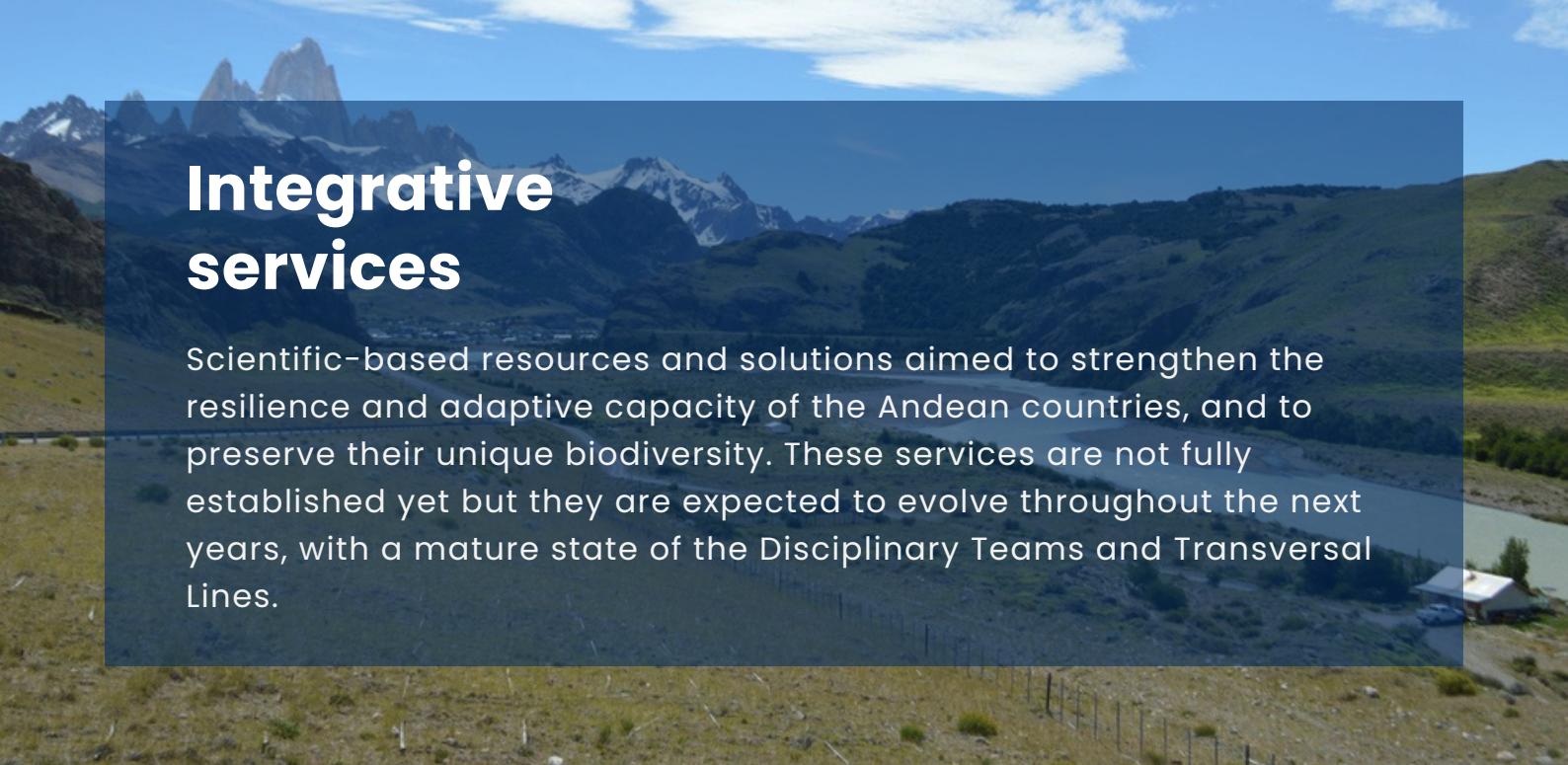
Observations and Data

This line of work deals with the challenges and possible solutions to make hydroclimatic data available throughout the Andean countries. It discusses policies and strategies for the compilation and publication of existing datasets and observational networks based on the needs and resources of the Disciplinary Teams.

Hydroclimatic Modelling

This line articulates with the Disciplinary Teams with a focus on their numerical modelling needs to answer their scientific questions and their interface with decision-making. It proposes policies and strategies for coordinated modelling approaches in the Andean region. The group addresses different spatial and temporal scales, including modelling of the Earth system as a whole (atmospheric, hydrological, hydrogeological, glaciological modelling) and its interactions (e.g. coupled atmosphere-ocean, biosphere-atmosphere, hydro-glacier models).





Integrative services

Scientific-based resources and solutions aimed to strengthen the resilience and adaptive capacity of the Andean countries, and to preserve their unique biodiversity. These services are not fully established yet but they are expected to evolve throughout the next years, with a mature state of the Disciplinary Teams and Transversal Lines.

Information and data exchange platform

This group will develop a web platform to provide free, open, and integrated access to the large variety of hydro-climatic, cryospheric, vegetation and land cover datasets that currently exist for the Andean region. The platform will also facilitate comprehensive and organised access to the new datasets and simulations developed by the different ANDEX Disciplinary Teams and Transversal Lines.

Capacity Building / Communication

This service constitutes a fundamental component of the program. Its objective is to disseminate and transfer the main ANDEX results, findings and data to society and decision-makers. It works closely with JovenANDEX to identify the priorities, gaps, and training needs of early-career scientists in the Andes, fostering their active engagement in research and science communication. In parallel, it collaborates with the Climate Science Observatory, led by the Geophysical Institute of Peru, to transform scientific results into clear and accessible language, promoting their assimilation by decision-makers and society in general.

Knowledge co-production

Seeks to implement collaborative processes of knowledge production, which incorporate the visions, needs and priorities of different actors of society in the design and execution of the objectives and work of ANDEX's Disciplinary Teams and Transversal Lines. Initially, in Peru and in collaboration with the Climate Science Observatory, the scientific literature is jointly interpreted with researchers from around the world. The Observatory also provides technical support to the Regional Governments of Peru to promote the incorporation of this scientific evidence into public decision making.

Communicational Resources

ANDEX Website

ListANDEX

ListANDEX is a key platform for interaction and dissemination of relevant information among ANDEX members, JovenANDEX, and the Scientific Committee. Through virtual discussions, the community analyzes hydroclimatic phenomena and their impact on the region, becoming a crucial space for idea exchange and access to important research project calls, etc.



JovenANDEX

The JovenANDEX network, a space for young researchers interested in Andean hydroclimatology and related topics, has 170 members as of December 2024, actively promoting scientific collaboration and professional development in the region. The network organizes three "Journal Clubs" focused on glaciology and water resources, climate system modeling, and continental hydrology.

The ANDEX website presents basic information about the program. The News section features summaries of selected relevant scientific articles which are prepared by the corresponding authors. The studies are selected from a dedicated reference list on hydroclimatic topics in the Andes which is updated monthly and made freely available to ListANDEX subscribers.

These communication channels are essential for ANDEX, as they facilitate the interaction among members, promote scientific collaboration, and ensure the dissemination of key information on hydroclimatological issues in the Andean region. Altogether, these tools support ANDEX's mission of strengthening science and knowledge within the community.

ANDEX Governance

ANDEX is led by two co-chairs and a Scientific Committee, which until recently had 12 members. In June 2024, three new members joined the Scientific Committee: Drs. Gulizia, Llambí and Cappelletti (see below). In March 2025, Dr. Lopez also joined the team replacing Dr. Anna Steward-Ibarra as a representative of the IAI. These researchers come from the different Andean countries and are leaders in their respective scientific fields.

In addition, Dr. Cappelletti acts as the representative of JovenANDEX, the network of young scientists created by our program. Eleonora González Porcel worked as the Coordinator and Communication Manager of ANDEX between November 2022 and August 2024. Nicole Reyes took over Eleonora's role in September 2024.

Co-chairs and Scientific Committee members

Jhan Carlo Espinoza – Institut de Recherche pour le Développement, Grenoble, Francia / Pontificia Universidad Católica del Perú
Co-Chair 2022-2026

Mariano Masiokas – Instituto Argentino de Nivología, Glaciología y Ciencias Ambientales (IANIGLA), CCT CONICET, Mendoza, Argentina
Co-Chair 2022-2026

Paola Arias – Universidad de Antioquia, Medellín, Colombia

René Garreaud – Universidad de Chile, Santiago, Chile

Jorge Molina – Universidad Mayor de San Andrés, La Paz, Bolivia

Daniel Pabón – Universidad Nacional de Colombia, Bogotá

Germán Poveda – Universidad Nacional de Colombia, Medellín, Colombia

Norma Salinas – Pontificia Universidad Católica del Perú, Lima, Perú

Isabel Moreno – Universidad Mayor de San Andrés, La Paz, Bolivia



Silvina Solman – Universidad de Buenos Aires, Buenos Aires,
Argentina

Omar López – Inter-American Institute for Global Change
Research, Panamá/Paraguay

Carla Gulizia – Universidad de Buenos Aires, Buenos Aires,
Argentina

Luis Daniel Llambí – Universidad de los Andes, Mérida,
Venezuela

Lucía Cappelletti – Universidad de Buenos Aires, Buenos
Aires, Argentina

Peter J. van Oevelen – International GEWEX Project Office,
Fairfax (VA), USA

The members of the Scientific Committee can suggest new potential incorporations, who will then be evaluated and approved through a simple majority vote. In the case of a tie, the co-chairs will have the final decision. The Scientific Committee should renew up to 30% of its members every four years. The representation of ANDEX scientific themes, countries, and gender balance are key issues in the program and should be taken into consideration when incorporating members into the Scientific Committee.

The co-chairs of ANDEX will be chosen from the members of the Scientific Committee through a simple majority vote. The co-chairs will serve for a 4-year term and can be renewed once consecutively. It is suggested that at least one co-chair is renewed every four years.



Pillars, Mission and Vision

IN 2023, ANDEX CONDUCTED SEVERAL VIRTUAL MEETINGS WITH THE AIM OF DEFINING ITS INSTITUTIONAL MISSION AND VISION, WHICH ARE BASED ON THE FIVE MAIN PILLARS SHOWN BELOW.



Figure 2. ANDEX pillars.

OUR MISSION

ANDEX is an interdisciplinary scientific network that seeks to strengthen the resilience of Andean societies through the production and dissemination of knowledge and information on regional hydroclimate and the impacts of environmental changes on Andean populations and ecosystems.

OUR VISION

ANDEX seeks to become a regional hydroclimatic program of reference, constituted by a consolidated and articulated scientific community that responds to the needs of society and contributes to planning and decision-making for the sustainable development of the Andean countries.





MOTIVATION AND SCIENCE OBJECTIVES

The Andes cordillera

The Andes cordillera runs along the west coast of South America from the Caribbean shore (11°N) to the southern tip of the continent (55°S) crossing through Venezuela, Colombia, Ecuador, Peru, Bolivia, Chile and Argentina. With more than 7000 km in length, the Andes is the longest mountain chain in the world. Tectonic forces over millions of years have raised the Andes to impressive heights, reaching over 6000 m above sea level in some tropical and subtropical sectors (Figure 3). Moving into midlatitudes, the Andes decrease in elevation but several peaks - including active volcanoes- still surpass 3000 m.

The Andes cordillera can be generally described as a narrow mountain range except for the region between ca. 14° and 23°S where it widens and holds the South American altiplano, a closed, high elevation (4000 m) plateau encompassed by the eastern and western cordilleras. The Andes also split into three main ranges to the north of the Equator that contain major river basins draining into the Caribbean Sea.

The wide latitudinal and altitudinal gradients of the Andes, and the sheer magnitude of this mountain range, produce noticeable atmospheric circulation patterns Martinez et al. (2024) that result in a unique diversity of hydro-climatic and environmental contrasts and conditions. The contrasts between the eastern and the western slopes are especially noticeable at the central Andes, where, for example, hyper arid conditions exist along the coastal desert of Peru and northern Chile to the west of the Andes, and very humid forests cover the western flank of the southern Amazon basin to the east. Farther south the precipitation gradient reverses, with very humid conditions along the western slopes of the Patagonian Andes that changes towards arid conditions only a few kms to the east in the vast Patagonian steppe (Espinoza et al., 2020; Arias et al., 2021; Tovar et al., 2022).

The Andes also contain an extensive and diverse cryosphere and an extremely rich biosphere that together provide vital services and resources (fresh water, extensive forested areas, fertile lands, minerals) for human populations all along western South America (Masiokas et al., 2020). Major civilizations developed in this rich, vast and rugged landscape during the Holocene, including the Inca empire that once encompassed from today's southern Colombia to central Chile (Poveda et al., 2020). Nowadays, the human population living in the Andes surpasses 100 million people, many of them concentrated in large cities such as Bogota, Quito, La Paz, and many others in Colombia, Ecuador, Peru, and Bolivia.

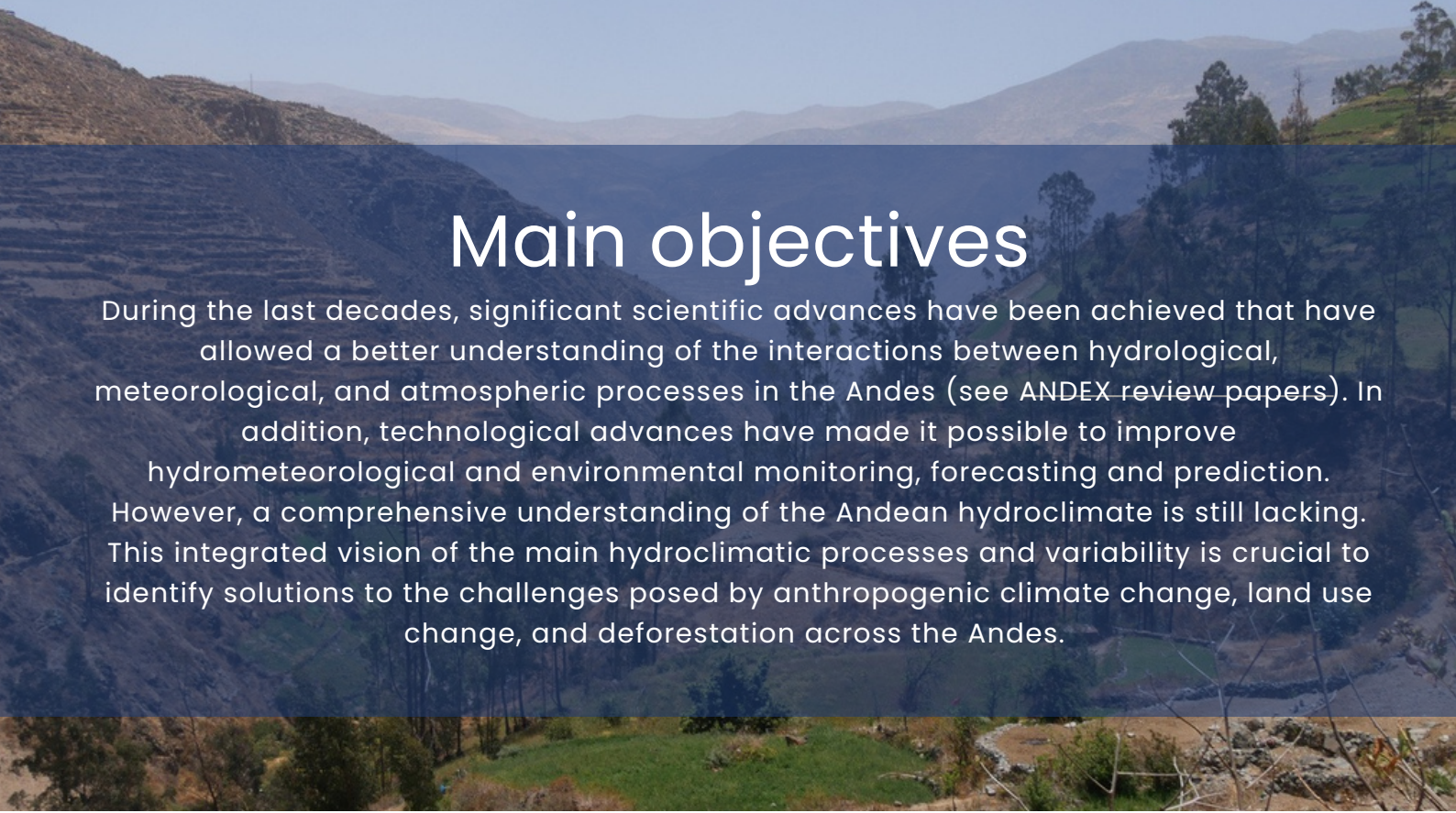
The multiple resources and services provided by the Andes also support human activities in the adjacent lowland areas, benefiting another ca. 30 million inhabitants of the Andean countries. This is clearly evident along the arid coast of Peru, in north-central Chile, and in central-western Argentina, where practically all the freshwater for human needs and activities originates in the upper watersheds in the Andes (Espinoza et al., 2020).

Agriculture and pastoral activities are intense and widespread along the tropical and subtropical Andes. They include domestic-scale farms, where traditional practices are employed for local subsistence, as well as agro-businesses that use modern techniques and large production volumes destined to global markets. Coffee, maize, potatoes, and quinoa are the largest grown crops in the tropical Andes.

In the drier sectors of the subtropical Andes, the water originating in the mountains is used to irrigate the fertile lands of central Chile and central-western Argentina, which produce premium wines and a large variety of fruits and vegetables.

The Andes are also one of the greatest sources of mineral wealth in the world. Andean mines account for nearly half of the world's copper production, nearly 30 percent of the silver production, as well as significant amounts of lead, zinc, and gold. Recently, the production of lithium has taken a boost, as most of the world's reserves are held within the Lithium Triangle, an Andean region shared by Bolivia, Chile and Argentina. Mining is particularly intense in Chile, Peru and Bolivia. In addition to the land use, both mining and agriculture require vast quantities of fresh water and energy, and generate substantial waste, most of the time with conflicting demands with social and environmental uses.

Rapid rates of human encroachment, urbanisation, deforestation, and land use changes are taking place along the Andes and neighbouring regions, such as the Amazon (Pabón-Caicedo et al., 2020). These developments make the region and their populations highly vulnerable to extreme weather events and impose a huge toll in terms of socioeconomic, environmental and ecological impacts (e.g., Sierra et al., 2021; Junquas et al., 2024). The poor (or non-existent) preventive and adaptive capabilities of the local governments complicate things further and result in a fragile current situation where truly sustainable development measures are difficult to implement (Condom et al., 2020; Poveda et al., 2020).



Main objectives

During the last decades, significant scientific advances have been achieved that have allowed a better understanding of the interactions between hydrological, meteorological, and atmospheric processes in the Andes (see ANDEX-review papers). In addition, technological advances have made it possible to improve hydrometeorological and environmental monitoring, forecasting and prediction. However, a comprehensive understanding of the Andean hydroclimate is still lacking. This integrated vision of the main hydroclimatic processes and variability is crucial to identify solutions to the challenges posed by anthropogenic climate change, land use change, and deforestation across the Andes.

In this context and following the general framework of the two ANDEX “Main Themes” discussed above (improving water security for Andean populations, and reducing the risks associated with high-impact climate events in the Andes), we identified 17 projects and their corresponding scientific goals and research objectives (Table 1 and Figure 3). These goals and general objectives address key research gaps in the Andean region and overlap with the interests of the scientists involved in the program. The identification of these 17 projects was the result of a collective effort including a broad Andean community, developed through the last 2 years, particularly during the ANDEX annual meetings in Santiago (2023) and Lima (2024). The research goals are also intended to foster the scientific capacity building in the region by involving a new generation of scientists

while cementing an effective collaboration among research institutions, hydrometeorological operational centres, stakeholders, and the broader community. In this context, ANDEX activities will include open science and in-person conferences, regular assessments, coordination of monitoring and modelling activities, and the creation of public access inventories and databases based on current observing systems (see Implementation program strategy below). We also anticipate that ANDEX will embrace diverse field campaigns or new monitoring programs to address some hydroclimate processes that are poorly observed and understood in the present.

Table 1. Main goals and objectives of ANDEX.

ED: Disciplinary Team. LT: Transversal Line.

ANDEX Teams and Lines	Goal to 2033	Main objectives to 2026
ED01 Climate and Meteorological Processes	Understand and attribute climatic and meteorological processes associated with hydroclimatic and hydrometeorological extreme events, slow onset events and tipping points in the Andean region, and project their changes in the 21st century.	1. Identify the main drivers of the socio-environmentally relevant climate factors, such as the coastal El-Niño and atmospheric blocking.
		2. Understand the orographic and micro-scale processes that control the precipitation in the Andes.
		3. Implement a framework for attributing extreme events that allows disentangling different contributions.
		4. Assess the possible climate changes in the Andean region under local and global drivers, including slow onset events and tipping points.
ED02 Environmental and Ecological Changes	Evaluate the feedback between Andean ecosystems, intensification of human activities and hydroclimatic changes at various scales (extreme and progressive events) and their repercussions on biodiversity, ecosystem functioning, water security, food and health.	1. Establish the state of the art in the knowledge of ecosystems and biogeographic evolution in the face of the hydroclimate of the Andes at various scales (short term/extreme events vs. centennial-millennial variability). Identify knowledge gaps but also recognize understudied areas, understanding processes.
		2. Establish the variables of interest based on current knowledge (i.e. learn from those already observed, key and/or representative sites).
		3. Optimise the observation of these variables: unify protocols, knowledge sharing, among others.
		4. Design a participatory methodology throughout the Andes to observe these ecosystem variables (uncertainty if it is for 2026 or later).
ED03 Water Resources and Cryosphere	Improve and integrate the existing knowledge on the hydrology and cryosphere of the different regions of the Andes, in order to improve local capacities to assess and predict water availability and risks associated with extreme events (droughts, floods) in a context of climate change and growing anthropic pressures on water resources.	1. Compile and integrate existing data, information and knowledge related to the cryosphere and the water resources at different latitudes along the Andes. Identify regions with similar cryospheric and hydrological characteristics and detect gaps in current monitoring networks.
		2. Improve the regional capacities to monitor and assess the seasonal variations in cryospheric and hydrological variables throughout the Andes, incorporating ground observations, remote sensing data, and modelling products.
		3. Identify and understand the main hydrological processes that determine the availability of water resources and the occurrence of extreme events (droughts, floods) in the different regions of the Andes.
		4. Improve the forecasting capacities of short-term (intra-annual) to long-term (multi-decadal) river flows and water budget components in relevant Andean watersheds using local and global instrumental datasets, remote sensing data, high resolution climate models outputs, and hydrological models of different complexities.

ANDEX Teams and Lines	Goal to 2033	Main objectives to 2026
LT01 Science as the Basis of Sustainable Development	Make ANDEX an interdisciplinary program of reference for the provision of information and knowledge in support of decision-making in hydroclimatic matters with the objectives of improving water security for the Andean populations.	1. Recruit social scientists to broaden the interdisciplinarity of ANDEX.
		2. Expand and organise the ANDEX community to cover the different IPCC topics, including (as far as possible) the issues of adaptation and mitigation.
		3. Survey the map of global and regional actors in hydrometeorology and related fields to identify current and potential synergies and vacancies (information, knowledge, HR, capacities, resources, etc.).
		4. Identify initiatives (projects) to respond to niches in the global, regional, and local demand for hydroclimatic knowledge that ANDEX would be able to satisfy, (i) for the socio-productive environment in general, and (ii) to provide specific climate services that could ensure financial sustainability.
		5. Increase the participation of the ANDEX community in the IPCC AR7.
LT02 Observations and Data	Facilitate autonomous and unrestricted access to a hydroclimatic database that allows for a better understanding of the physical processes of hydroclimatic events, as well as innovative and new observation systems useful for water security and disaster risk management.	6. Identify the academic offers and funding opportunities at the graduate level in hydroclimate-related sciences in Latin America.
		1. Produce a summary publication on hydroclimatic gridded databases in the Andean region of South America.
		2. Produce a summary publication on new hydroclimatic measurement technologies available in the Andean region.
		3. Generate a portal on hydroclimatic data at the scale of the Andes: climatology and real time, sustainable over time and with a strong link with the NMHSs (WMO) and associated scientific institutions.
LT03 Hydroclimatic Modelling	Identify the needs of products and tools for the modelling of the hydroclimatic cycle of the Tropical and Extratropical sectors of the Andes, in order to support water resources management	4. Generate and make available data that improve the understanding of the physical processes of hydroclimatic events in the Andes.
		1. Coordinate modelling exercises in different Andean regions based on individual hydroclimatic phenomena to identify deficiencies, shortcomings of the models and identify their usefulness and benefits for the identification of impacts.
		2. Improve/understand the benefits/limitations of the models in simulating the spatial distribution of precipitation over the Andes, according to its nature (convective or frontal) and relationships with mountain circulations.
		3. Study precipitation patterns/gradients from Convection Permitting (CP) climate models.

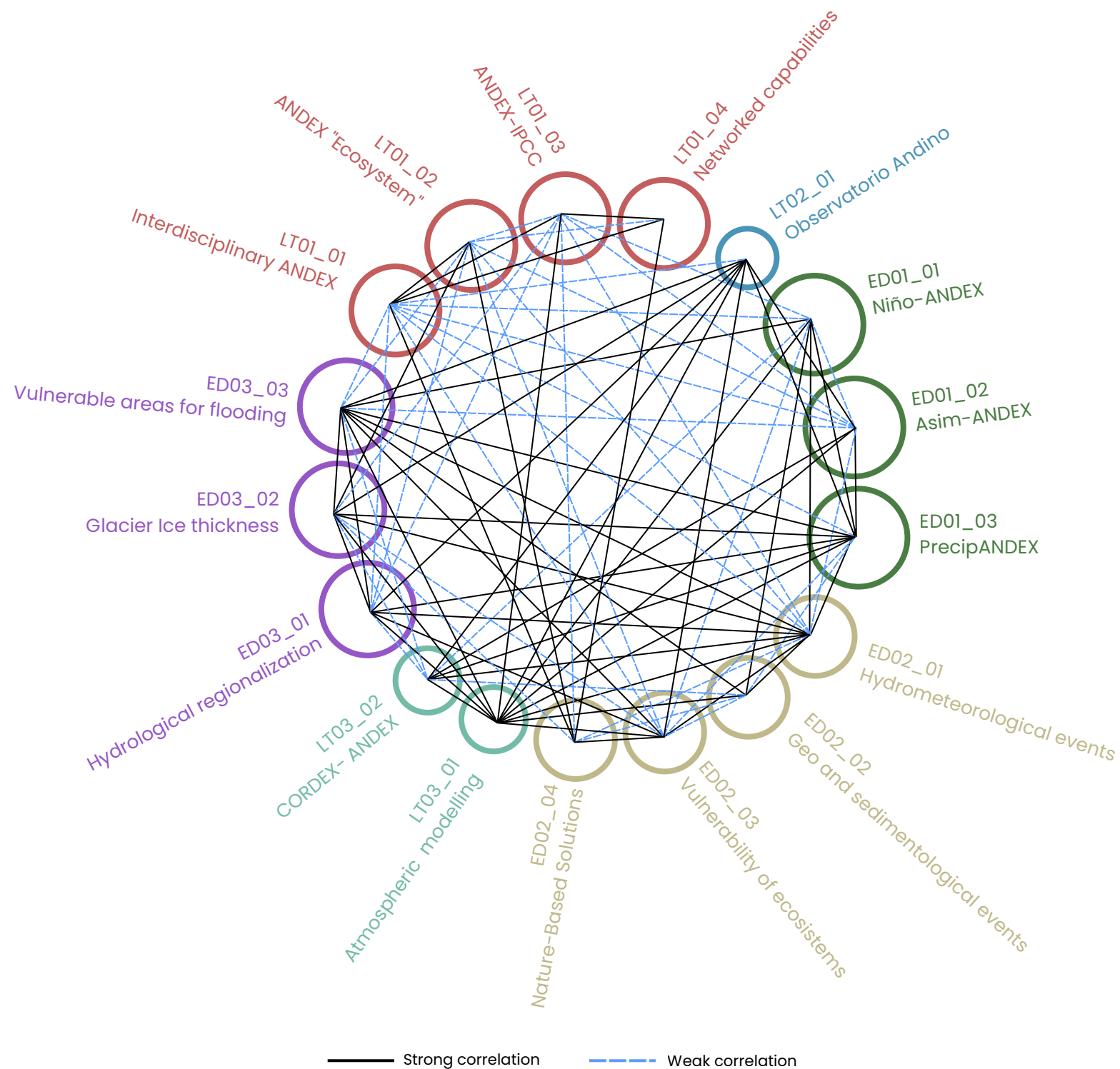


Figure 3. Degree of association between projects

Figure 3 shows the degree of association (strong or weak) within the projects. These interrelationships will be presented and discussed at the 2025 Annual Meeting, to be held in Mendoza, Argentina, to clarify the alignment and coordination of projects within the broader ten-year research program.



IMPLEMENTATION STRATEGY

After its approval as an initiating program in 2022, ANDEX worked on specifying its grand challenges, pillars, mission and vision to formulate and implement projects directed towards concrete goals. This project formulation process took place during 2023 with a 10- year time horizon, and was approached through the collaborative work of ANDEX specialists, in person and remotely, by applying a guiding instrument that resulted in a portfolio of initiatives outlined within a general structure.

The main goals and objectives, outlined in Table 1, were used as general guidelines to define a series of activities, timelines, and milestones associated with each ANDEX project. The teams also identified the project leader(s), the necessary resources, and potential funding mechanisms at the national, regional, and international levels.

A project clustering process has been initiated based on two main criteria:

- Criterion 1: Identification of project beneficiaries, grouped by specific categories (Figure 4).
- Criterion 2: Relationships between ANDEX projects, WMO, WCRP, and GEWEX initiatives (Figure 5).

The details of the items that together conform the structure of the Implementation Plan of our program are described in Annex 1.

Funding

Regarding science and technology investment in the Andean countries, the current outlook (year 2025) is worrisome and challenging. In Argentina, the president, Javier Milei, is pushing for radical free-market and austerity policies, leading to deep cuts in public spending on scientific research and education, potentially slowing long-term innovation and even triggering a brain drain as researchers seek better-funded environments.

Meanwhile, in Colombia, chronic underinvestment in science, technology, and innovation has long been a hurdle. During 2024, investment was reduced to 0,01% of the GDP, the lowest of the 21st century. With the government not increasing its spending, the country's innovation ecosystem faces structural challenges, from insufficient research and development infrastructure to weaker industry-academia linkages. For the broader Andean region, the challenge will be to attract and mobilize alternative sources of funding.

Currently, around 30% of the ANDEX projects have received initial funding, mainly from national scientific agencies (e.g. Peru, Chile, Colombia) and regional cooperation programs such as IAI, the French Embassy, IRD, NSF-USA, among others.

Some projects have also received contributions from universities and research institutions (UdeA- Colombia; PUCP-Peru, IANIGLA- Argentina, CR2-Chile). The funding for the remaining projects is expected to come from a mix of local, regional, national, and international sources and agencies operating in the Andean countries or with an interest in the topics addressed by our program. In most cases, the success of these initiatives will depend on the active participation and collaboration of ANDEX team members.

To secure additional financial support, obtaining the final approval of the Scientific Plan is essential, as it will facilitate presenting the ANDEX program to international funding institutions. In this context, a preliminary list of potential funding sources has been compiled, which will be maintained and updated by the members of the Scientific Committee, who can contribute further information on funding opportunities in their respective countries or research networks. Furthermore, the possibility of securing financial support from the private sector has been explored, given its increasing interest in science and research.

It is also worth noting the strategic role of IAI as an ally for ANDEX, not only because it could enhance access to diverse funding sources for regional projects, but also due to its ongoing collaboration with focal points in each country.

EXPECTED OUTCOMES AND BENEFICIARIES

ANDEX projects were formulated considering the beneficiaries or end/intermediate users of their results and impacts. Based on the information provided by the work teams when designing the proposals, the expected beneficiaries were classified into six clusters, as follows:

1. Academia (teaching, students, educational institutions).
2. ANDEX (transversality between disciplinary teams (ED) and transversal lines (LT)).
3. Science (research, Andean and international scientific community).
4. Communities (territories, people, organised civil society).
5. Private sector (productive sector, insurance sector).

6. Public sector (NMHSS, national and subnational entities and officials responsible for environment, disaster risk management (DRM), climate change, water management, conservation and management, geological/geophysical services, among others).

Figure 4 below displays the ANDEX projects according to their main theme of reference, by cluster of beneficiaries/users. The number between parentheses indicates the total number of projects that mention stakeholders considered to be part of the corresponding cluster. A project may respond to more than one cluster. For a detail of the project associated with each identification (ID), see Annex 1.

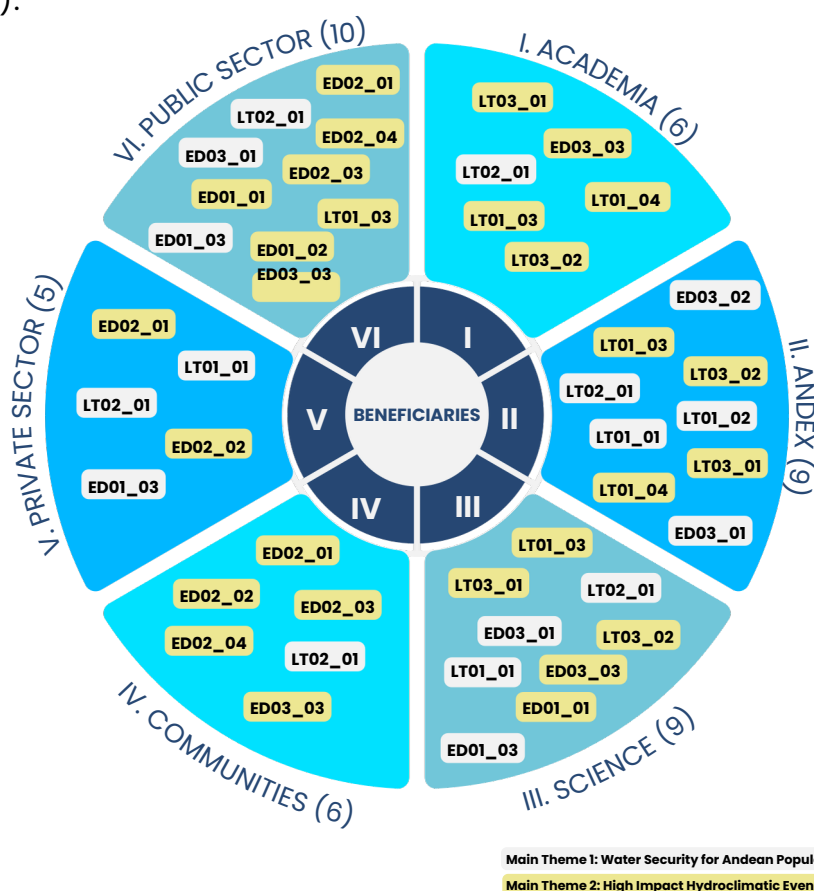


Figure 4. ANDEX projects organised by main theme and cluster of beneficiaries/users.

The central purpose of ANDEX is to generate original scientific knowledge, strengthen interdisciplinary and stakeholder cooperation, and enhance the collaboration with National Hydrometeorological Services (NHS). Critically, results from ANDEX will directly serve as inputs to improve operational practice in the future

Some ANDEX members are part of the region's National Hydrometeorological Services, forming a broad network of research institutions, which will facilitate the involvement of decision-makers during the implementation of this Scientific Plan.

Given each country's specificities, the connection between ANDEX, local stakeholders and NHS is likely to take different shapes. One ongoing example of the efforts to bring science closer to society, incorporating scientific evidence in managerial documents at national and regional levels is the project Observatory of Scientific Knowledge on Climate Change "Ciencia Climática".

This initiative, co-led by the Geophysical Institute of Peru and supported by the Peruvian Ministry of Environment, includes several members of ANDEX and JovenANDEX who have been actively participating in the generation of simple-language interpretations of related scientific publications relevant for the Andean region. The Andean Snow Observatory is a popular, open access website created by ANDEX members that is widely used to monitor real-time, daily snow cover variations over a wide latitudinal range in the Central Andes of Argentina and Chile.

In the long term, ANDEX seeks to increase its connection with stakeholders by making the program even more interdisciplinary. In this sense, the goal for the first three years is to increase the number of social scientists into the program.



RELATION TO GEWEX IMPERATIVES AND SCIENCE GOALS

The proposed activities and expected results identified in Table 1 and Annex 1 address six of the seven GEWEX Imperatives (namely, Datasets, Analysis, Processes, Modeling, Applications, and Capacity Building), offering a new original possibility for achieving these relevant scientific goals in the Andean region.

The structure of ANDEX, which combines teams of scientists with various backgrounds from the natural and the social sciences, will hopefully facilitate this process and strengthen the existing network of colleagues working on Andean hydroclimate and related issues. The seventh GEWEX Imperative (Technology Transfer) is not part of the key goals of our program but it will likely be partially achieved by the collective work of the ANDEX teams. This is because the new sets of observations, models and diagnostic tools developed by the program, together with our specific platforms for data management and publication, will form a solid information and technology basis that can certainly be transferred to operational applications in partnership with climate and hydrometeorological service providers. The GEWEX Science Goals are more specific and largely focused on the Earth's water and energy cycles. These goals are thus more directly related to the activities and results of the ANDEX teams dealing with atmospheric, meteorological, hydrological, cryospheric and ecological processes and models.

The outcomes of these teams will effectively provide original information and tools to better understand and predict the Andean water, energy and carbon cycle across different spatial and temporal scales.

The results will also allow a better understanding of the natural variability and the anthropogenic influences on the hydroclimate, water cycle and their impact along different portions of the Andean range, contributing to our understanding of hydroclimate in complex topography regions.

The degree of association between the different ANDEX project is shown in Figure 4. To further clarify the alignment between ANDEX projects and GEWEX scientific goals, an additional table has been included in the annex (Annex 2).

Finally, it should be noted that ANDEX also maintains variable degrees of association with the in-house activities of GHP. These include, among others, an active cooperation and participation in shared research initiatives with colleagues from the Crosscutting Project INARCH, and the Regional Hydroclimate Project Global Water Futures. There remains ample potential for further collaboration with other GHP programs and activities. These will likely grow as the ANDEX projects evolve and the program becomes a fully operational RHP.



COORDINATION WITH OTHER ENTITIES AND PROGRAMMES

The implementation projects of this Plan were outlined considering the possible linkages with other WMO, WCRP and GEWEX programs, projects or initiatives. Consequently, a series of coordination opportunities have been identified which, without exhausting all the possibilities, show a first panorama of articulation.

Figure 5 presents the links identified between ANDEX projects and WMO, WCRP and GEWEX initiatives. An ANDEX project may have been conceived as an opportunity to articulate with more than one initiative at a time. For details of the projects associated with each ID, see Annex 1.

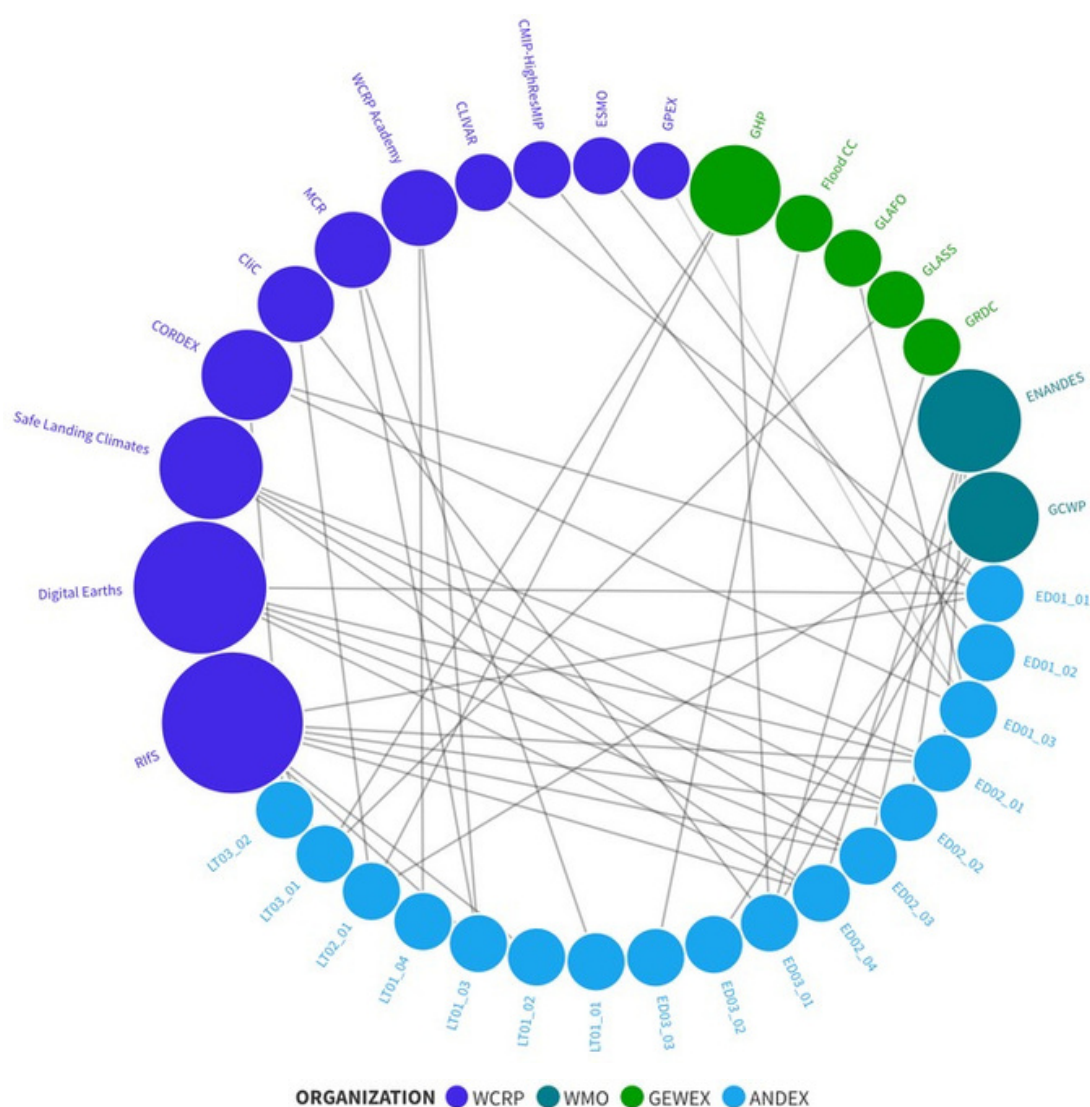


Figure 5. Linkages between ANDEX projects and WMO, WCRP and GEWEX initiatives.
ED: Disciplinary Team. LT: Transversal Line.

The researchers leaders of each project are listed in Annex 1. However, it is anticipated that, once the necessary financial support is secured, the number of participating institutions will likely increase depending on the nature of each project. This includes JovenANDEX member and/or other researchers that were not contemplated in the initial design of the projects (see Figure 6).

Importantly, collaboration with the IAI will promote significant integration between ANDEX members and the IAI focal points in the different countries, which will facilitate more efficient and effective execution of the scientific projects. In addition to the IAI, the participation of other institutions, such as the different affiliations of the team members and entities providing financial support, is anticipated.

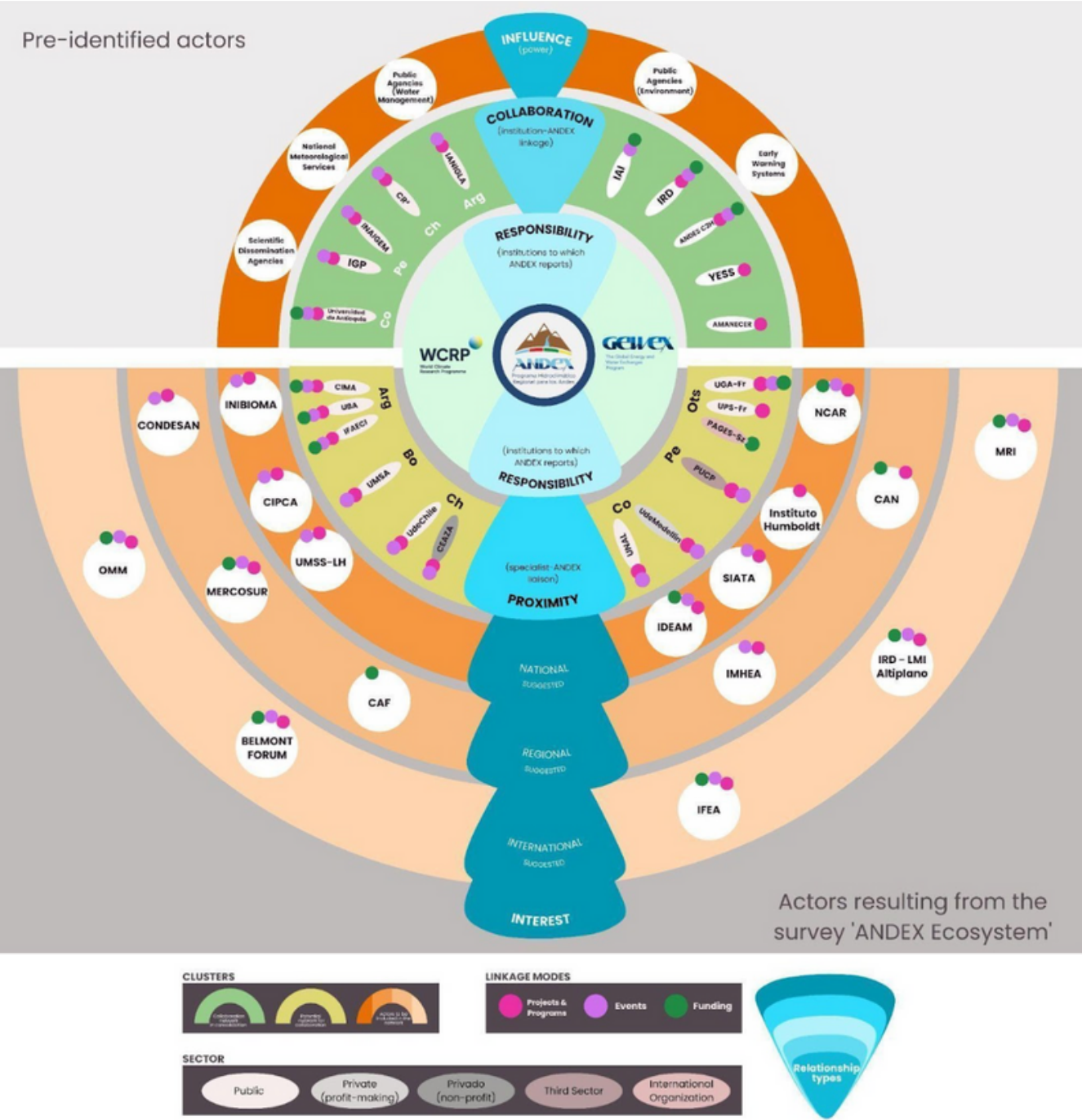


Figure 6. Initial ANDEX stakeholders' map.



Figure 6 was presented to the ANDEX team for consideration at the annual meeting held in Lima, Peru in 2024. It is the first advance that is currently being implemented by the Transversal Line Science Underpinning Sustainable Development. It illustrates the actors identified according to:

- Responsibility: Institutions to which ANDEX reports (regulations, policies or practices).
- Interest: Institutional relationships of trust and mutual collaboration.
- Influence: Institutions that have or will have the potential to influence ANDEX's ability to achieve its goals, whether their actions can boost or impede its performance.
- Proximity/representation: Institutions in which ANDEX is 'present' through its members. Classified according to location/scope (i.e. national, regional, others), sector (i.e. public, private, others) and modes of possible linkage (i.e. design and implementation of joint programs or projects; collaboration in organising events; funding of projects, meetings or publications, among others).

Accordingly, different clusters can be distinguished that respond to a network of collaboration in consolidation, a potential network of collaboration, and a series of actors to be included in the network.

MODELLING AND DATA SHARING STRATEGY

Some ANDEX teams have identified key research priorities that involve the development (or application) of different meteorological, climatological, hydrological and environmental models (see Table 1). It is expected that the outcomes of these specific efforts can provide, not only original information and knowledge to address the research questions and objectives identified by each team, but also serve as an additional tool for the other ANDEX teams that may benefit from these newly generated modelling results. The interaction and discussion of the model outcomes among the different teams will also likely enrich and strengthen their collective work and ultimately improve the quality of the products or results derived from these activities.

The ANDEX program is oriented towards a free and open data policy where all interested users can access the results and information generated by the different teams. In this context, the Data and Observations team will be in charge of compiling and presenting the datasets or the information compiled by the other groups. We intend to improve and enlarge an existing web platform named "Observatorio de Nieve en los Andes de Argentina y Chile" to incorporate not only snow covered area, but also many other relevant hydrometeorological variables and related datasets from the whole Andean countries. In addition, we will continue to improve our website, where news, datasets, papers, and all the information generated by the program members and useful for ANDEX will be made available online, free of charge.

MONITORING, EVALUATION AND EXIT PLAN

Monitoring and Evaluation (M&E) mechanism

Given the scope and number of projects proposed, the establishment of an office dedicated exclusively to scientific project coordination will be contingent upon the financial resources that ANDEX is able to secure following the approval of its Scientific Plan. Therefore, ANDEX, through its Scientific Committee, is committed to fostering an institutional culture of project monitoring and evaluation (M&E).

The evaluation, which is conducted annually, will involve assigning two to three projects per member to ensure a balanced workload. The interdisciplinary nature of the Committee members allows for thorough and rigorous evaluations, ensuring the effective achievement of expected results. During the annual meetings, structured opportunities will be provided to present project progress and prospects, fostering a comprehensive and collaborative understanding among Committee members.

Three fundamental principles for ANDEX regarding M&E are:

1. Transparency in data processing and dissemination (WCRP, 2017).
2. Transversal perspective of diversity, equity and inclusion in the design of results and impact indicators (UN Women, 2014).
3. Intercultural approach of the M&E criteria (UN Women, 2014).



ANDEX projects will be assessed primarily on their contribution to addressing the two major scientific challenges for the Andes: improving water security for Andean populations and reducing the risks associated with high-impact hydroclimatic events.

In addition to this overarching framework, each project will undergo a structured evaluation based on specific performance criteria, which will be reviewed by the Scientific Committee during the annual meetings (possible indicators discussed so far include: number of scientists involved in the project, number of publications, meetings conducted with stakeholders, etc). This evaluation process will include not only a comprehensive analysis of progress and results, but also a case-by-case assessment of potential limitations and identification of adjustments needed to ensure success and alignment with the overall program objectives.

Risk management will be incorporated into this process by systematically identifying barriers to implementation and developing mitigation strategies. This approach will allow ANDEX to adapt its projects as needed, ensuring their long-term viability and impact.

The project formulation tool designed for ANDEX is inspired by the Logical Framework Approach in its CEPAL-ILPES line (Ortegón et al., 2005), considering the Latin American context in which the Program works. In addition, it lays the foundations for an M&E mechanism that seeks to measure both the results in quantitative terms of objective achievement and impacts in terms of the effects of the implemented projects on beneficiaries, when applicable. The specific evaluation indicators for each project are designed collaboratively with the leaders and teams involved, according to implementation priorities.

ANDEX's M&E mechanism seeks to measure results regarding its grand challenges and objectives, the WCRP Scientific Objectives and the GEWEX's Imperatives and Science Goals. In turn, it aims to measure impacts in coordination with the stakeholders benefiting from ANDEX actions to ensure that scientific advances in the understanding and prediction of climate and hydrology along the Andes cordillera reach the decision-making levels of the seven countries involved.

The M&E of results and impacts implies an integral perspective of the consequences of ANDEX interventions on its environment and also means a challenge concerning the available resources. For this reason, the Program establishes its long-term goals (10 years) but formulates its scientific projects in three years and its management projects in one year. Thus, it applies an annual short-term monitoring mechanism and a three-year mid-term evaluation, which allows it to make decisions on the continuity or reformulation of existing projects according to their results and impacts. The mid-term evaluations and the third three-year assessment will be inputs for the ANDEX Exit Plan (Figure 6).

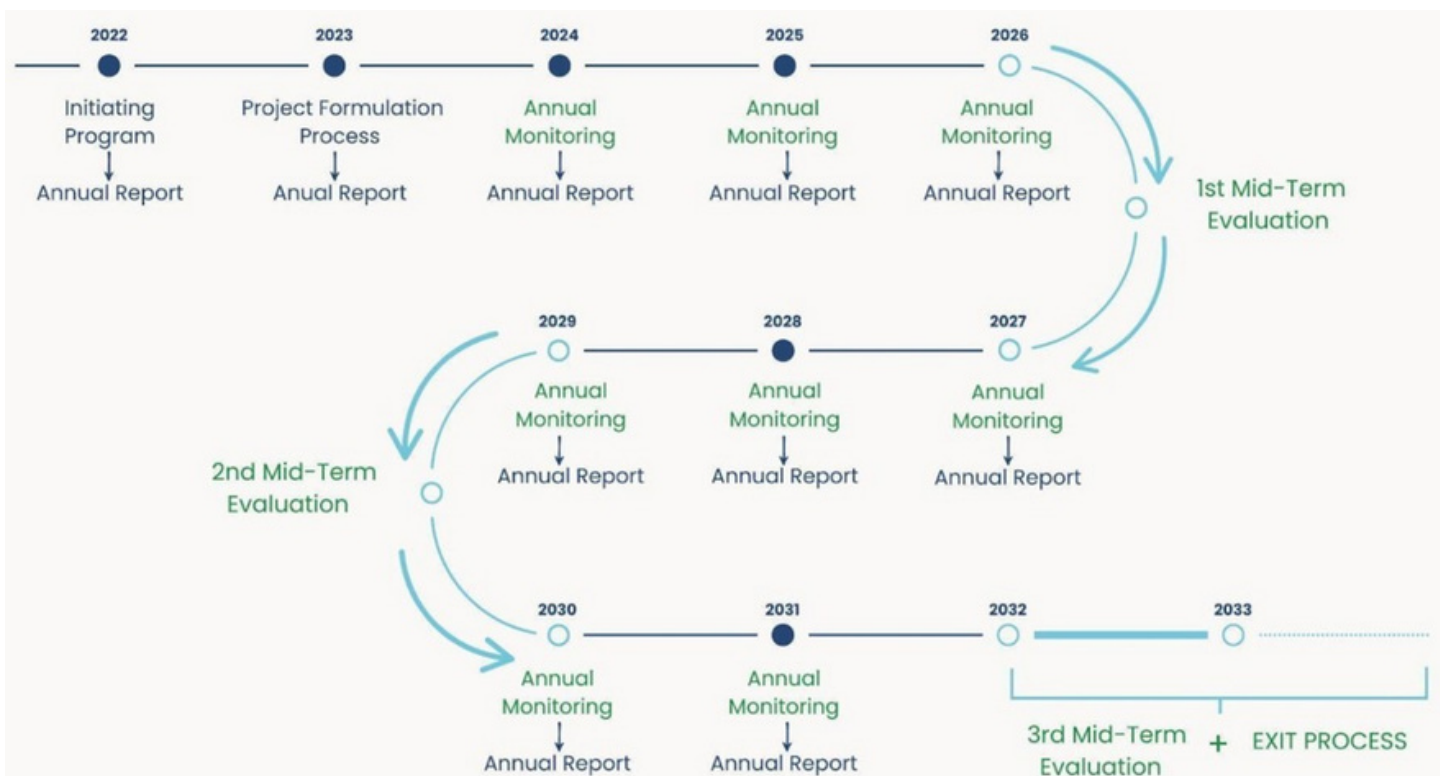


Figure 6. ANDEX M&E roadmap.



ANDEX Exit Plan

The ANDEX exit evaluation will occur in 2032 and 2033, with a final presentation to the reporting institutions in 2033. The two key sections of the exit plan include the development and presentation of the scientific and applications synthesis of the program and the data archiving procedure.

Regarding the first section, the findings resulting from the internal M&E mechanism will provide the basis for the program's final report on the scientific developments achieved during the implementation of this Plan.

In addition, a narrative and technical synthesis of applications and capacity building will also contribute to an organised exit strategy. Concerning the data archiving procedure, the program's official web page serves as the first stage of classification, categorization and digital storage of available data while providing access to updated scientific resources. The servers hosting the site are the first technical backup. The periodic monitoring and evaluation reports constitute an integrated archive.

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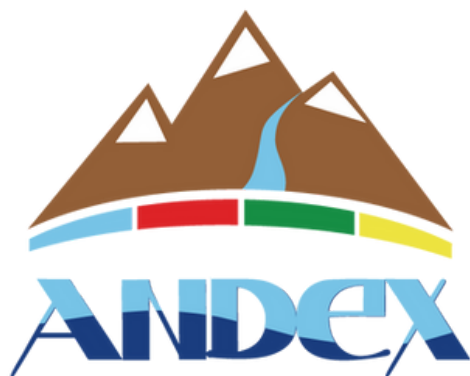
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