STRENGTHENING CLIMATE RESILIENCE IN URBAN AMAZONIA

Experiences from Tarapoto and the Cumbaza Watershed in San Martín, Peru

About the Project

This document is part of the 'Strengthening climate resilient development in urban-rural landscapes' project implemented by Global Canopy, in partnership with the Centre for Development and Research in Upper Amazonia (CEDISA), the Water Competence Centre (CCA), and the Cumbaza Watershed Management Committee (CGMC) in Peru.

This project is part of the Climate Resilient Cities in Latin America initiative.

About Global Canopy

Global Canopy is an innovative environmental organisation that targets the market forces destroying tropical forests. Our mission is to accelerate progress towards a deforestation-free global economy - through improved transparency, innovative finance and strategic communications. Since 2001, we have catalysed new thinking and action by leading governments, companies and investors worldwide.

SUMMARY

This brief presents a Water-Energy-Food (WEF) nexus[1] case study of the Cumbaza River watershed in San Martin, Peru.

The dynamic socio-ecological pressures and complex water-energy-food system interdependencies that exist in increasingly urbanized Amazon landscapes are discussed.

This case study provides further evidence of the key role of forest ecosystems in strengthening urban and rural resilience capacity, and the need for coherent policy responses that maintain socio-ecological sustainability.

A systems approach such as the WEF nexus can be an important framework to inform such efforts.

RESEARCH INSIGHTS

- 11 priority Water-Energy-Food (WEF) nexus interactions, such as water demand for food production, are quantified.

- Economic development, population growth, land use and climate change projections are used to generate future resource demand-supply WEF scenarios and identify natural resource thresholds in the Cumbaza watershed.

- Differentiated vulnerabilities and resource risks across rural and urban households are highlighted, for example water scarcity for smallholder irrigation agriculture and the impact of increased sediment loads on urban water treatment capacity.

- The fundamental role of forest ecosystem services in underpinning key WEF securities in the watershed, in particular erosion prevention, water retention and biomass provision, is highlighted.

POLICY RECOMMENDATIONS

- Prioritising green infrastructure will be critical for WEF nexus resilience in the Cumbaza watershed, in particular for meeting urban and agriculture water demands.

- Risk mitigation actions and resilience strategies will need to account for local and regional level dependencies, in particular on growing food and energy import demands from urban centres and transportation infrastructure.

- Integrating watershed management platforms at scale, in this case for the Cumbaza-Mayo river watersheds, will be required to meet local and regional energy and food security objectives.

- Improved institutional information exchanges and coordination on cross-cutting WEF nexus interactions are required. This will enable more systematic WEF nexus assessments and effective monitoring of socio-ecological changes.

INTRODUCTION

In Amazonia, the forest ecosystem services that underpin water-energy-food (WEF) security are under increasing strain from urbanization, migratory flows, agriculture expansion and infrastructure development[2]. Climate change and climate extremes (e.g. temperature fluctuations, droughts and heavy rainfall) act as risk multipliers by exacerbating pressure on key forest ecosystem services, including water regulation and recycling, upon which both urban and rural populations depend[3].

In the next decades, regional development trends and climate-induced pressures, such as migration from the Andes-Amazon regions[4], are expected to continue driving urbanization and market integration that will affect local resource use dynamics. In Latin America, it is expected that the urban population will reach 90% of overall population by 2050, from 80% now. Most of that growth will occur in small and medium cities, many of which are located in Amazonia[5].

Tarapoto, the third largest urban centre in the Peruvian Amazon, is a prime example of the risks that environmental degradation poses for water, energy and food security. In the surrounding Cumbaza river watershed, 58% of forest cover was lost between 1977-2005 alone, which has affected the capacity of forests to deliver key ecosystem services, especially in relation to water. Higher sedimentation loads and precipitation variability, coupled with inefficient grey infrastructure, are already affecting the water security of urban households and smallholder farmers in the watershed.

The capacity to cope, respond and recover to these changing dynamics and their associated stresses will be paramount. Improving our understanding of how underlying socio-ecological factors affect water, energy and food security will be essential in strengthening climate resilience[6].

This brief outlines ongoing efforts to shed light on the complex WEF nexus interactions across urban Tarapoto and the surrounding Cumbaza watershed. It considers how this information can improve natural resource governance decision-making and inform the development of climate resilience strategies.

Fig. 1
Downtown Tarapoto in San Martin, Peru.
Photo credit: Simen Nuytemans

Tarapoto and the Cumbaza watershed

The Cumbaza watershed encompasses an area of 57,120 hectares and is located within the provinces of San Martín and Lamas in the San Martín region of Peru. The total registered population was 177,367 in 2016, 91% urban.
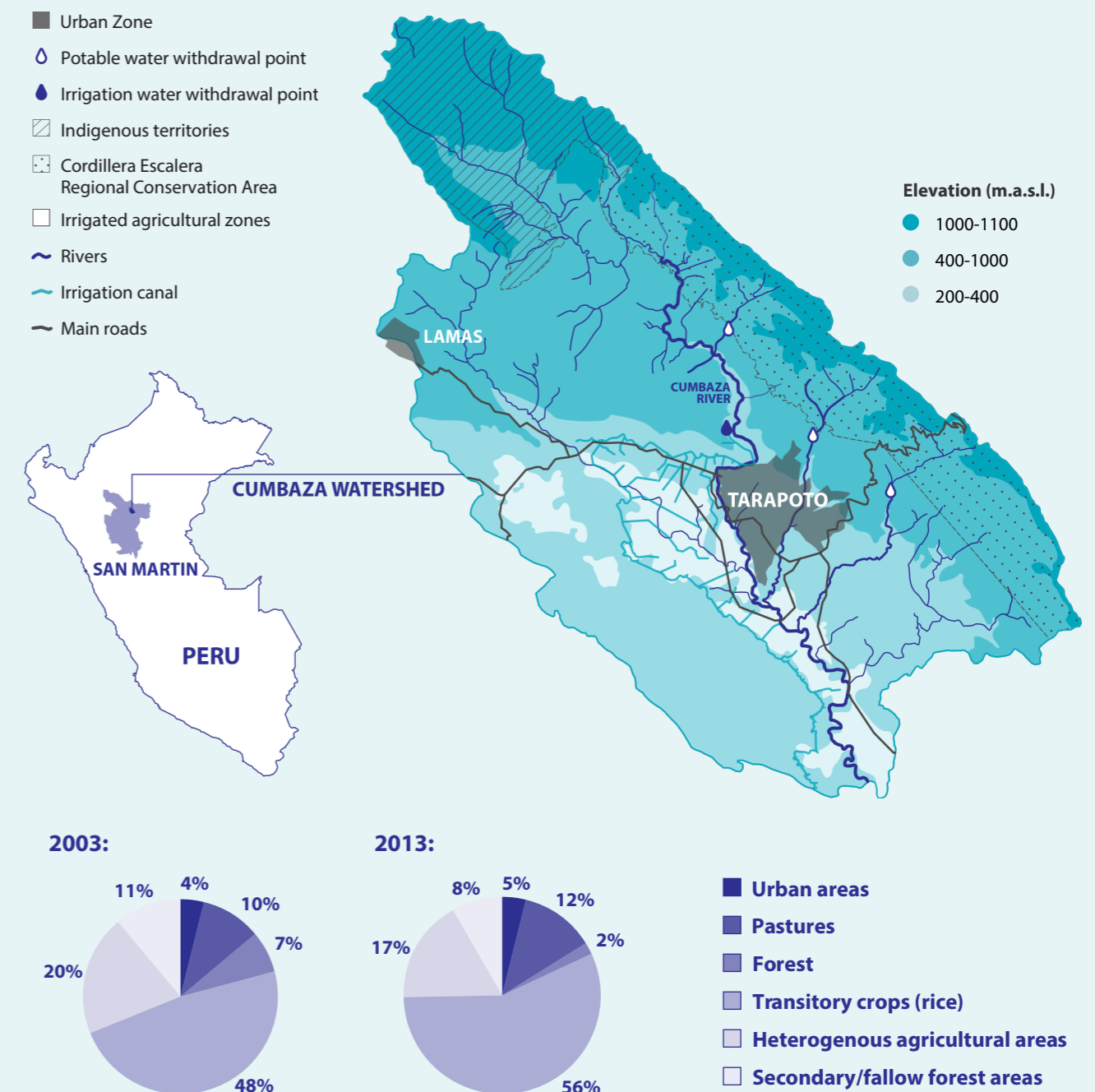
There are three main land use distinctions in the watershed: urban, agriculture and forest use.

Urban areas include Tarapoto and numerous satellite towns such as Lamas.

Agriculture is the main economic activity in the watershed. Smallholder rice farming and aquaculture exist in the lower part of the watershed. Corn, plantain, coffee and cocoa farming dominates the middle and upper part of the watershed.

The remaining forest areas lie within Cordillera Escalera Regional Conservation Area and four titled Kichwa-Lamas indigenous communities (Alto Shambuyacu, Aviación, Chirikyacu, Chunchiwi).

Figure. 2
Land use and land use change in the Cumbaza watershed.

Legend:
- Urban Zone
- Potable water withdrawal point
- Irrigation water withdrawal point
- Indigenous territories
- Cordillera Escalera Regional Conservation Area
- Irrigated agricultural zones
- Rivers
- Irrigation canal
- Main roads

Elevation (m.a.s.l.)
- 1000-1100
- 400-1000
- 200-400

2003: 4%, 10%, 7%, 48%, 20%, 11%

2013: 5%, 12%, 2%, 56%, 17%, 8%

- Urban areas
- Pastures
- Forest
- Transitory crops (rice)
- Heterogenous agricultural areas
- Secondary/fallow forest areas

Applying a WEF nexus approach

To date, WEF nexus based assessments in Amazonia have generated a better understanding of regional security risks and trade-offs (ASA and ECLAC for example), albeit with ongoing knowledge gaps surrounding the different levels of access to resources and inequalities across different social groups, as well as local quantified WEF system interactions.

In response to these gaps, and as part of efforts to advance WEF assessment methodologies, this qualitative and quantitative nexus-based study has applied a strong participatory-based approach, considering urban-rural and local-regional security dimensions[7].

Current water, energy and food resource systems were quantified, taking into account demand, supply and access indicators of WEF security that were developed with an array of stakeholders of Cumbaza River watershed (see: Cumbaza watershed management committee CGMC).

To undertake the quantitative assessment, a comprehensive review and systematisation of existing literature and datasets on food, energy and water resources was undertaken. To fill key information gaps we complemented this database through focus group discussion, multi-stakeholder consultations and participatory workshops. These activities served to gather security perspectives, and identify and prioritise key WEF interactions (e.g. water for local agriculture production), and to validate the scope of the analysis, methodology, and results.

To better understand the dynamics and vulnerabilities of WEF systems to socio-ecological pressures and how these interactions change over time, varying land use, climate change, population growth, economic development projections were developed, modelling data for 2030, 2040 and 2050. This modelling was used to develop varying WEF resource demand-supply scenarios (see Annex 1).

Workshops and bi-lateral meetings were held throughout to discuss and validate future trends and identify critical thresholds and risks in the Cumbaza watershed.

See Annex 2 for the WEF nexus methodology.

Fig. 3
A view of Tarapoto and the Cordillera Escalera Regional Conservation Area.
Photo credit: Diario Voces

RESULTS

In the figure below we present the key interactions found across water, energy and food systems in the watershed. The quantifications of these interactions are based on estimates (millions) for 2016. The interactions were also standardised to allow comparisons across interaction: cubic meters (m3), Terajoule (TJ) and tons (TN).

Quantified WEF nexus resource flows for the Cumbaza watershed

Fig. 4
Quantification of local and imported WEF resource demands (2016)

Cubic meters (m³)
Terajoule (TJ)
Tons (TN)
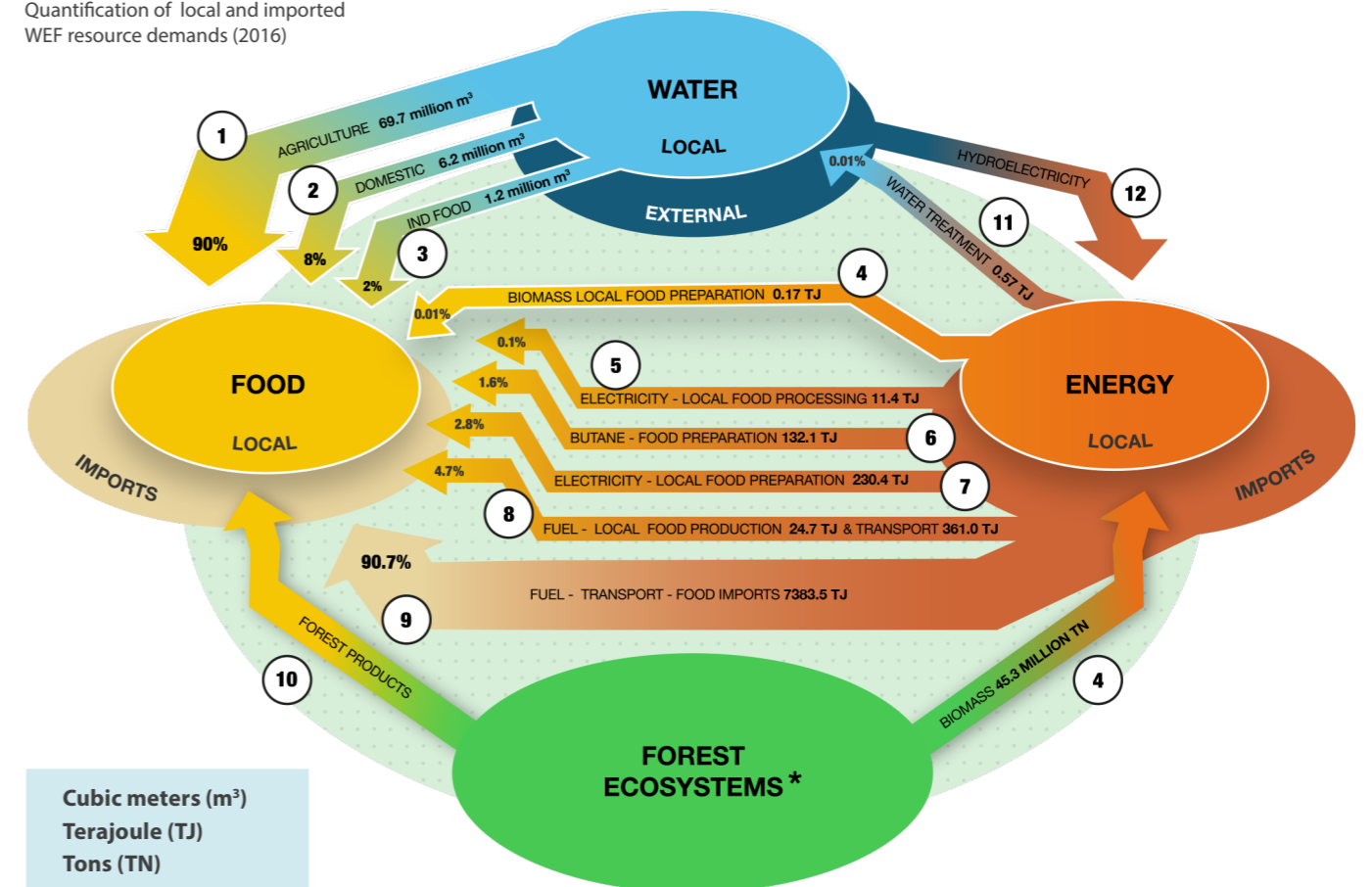
* We also include forest ecosystems as these underpin the water-energy-food nexus by providing important natural resources and services.

WATER-FOOD	FOOD-ENERGY	ENERGY-WATER
1. 70 million m³ of water per year (approx. 90%) destined for local agricultural production (mainly rice irrigation and aquaculture) withdrawn from the Cumbaza River.	**4.** 45.3 million tons of fuelwood and wood charcoal per year (230.6 TJ, 2.8%) utilized for local food preparation.	**11.** Electricity inputs (0.6 TJ, 0.01%) used for water treatment
2. 6.2 million m³ of water per year (8.2 %) for human consumption (including domestic, commercial and public sector uses) sourced from the Cachiyacu, Shilcayo and Ahuashiyacu tributaries.	**5.** 11.4 TJ (0.1%) of electricity used for local industrial food processing	**12.** Electricity inputs from the regional grid system originating primarily from hydropower but also thermoelectricity.
3. 1.4 million m³ of water per year (1.9%) for local industrial food processing.	**6.** 132 TJ (1.6%) of butane gas used for local food preparation	
	7. 230.38 TJ (2.8%) of electricity used for local food preparation.	
	8. 25 TJ (0.3%) and 362 TJ (4.4%) of fossil fuel energy used for local food production and internal transport respectively.	
	9. Fossil fuel energy consumption 7384 TJ (90.7%) for the transportation of various food imports which account for 47.2% of total food consumption in the watershed.	
	10. Extraction of non-timber forest products as part of local subsistence livelihoods.	

WEF nexus dimensions in the Cumbaza watershed

URBAN-RURAL

Between 1977-2005, 58% of forest cover was lost in the Cumbaza watershed. The remaining forest cover (an estimated 8500 hectares or 15% of the watershed[8]) and sources of fresh water - the Cumbaza river and its tributaries - are mainly concentrated in the upper fringes of the watershed, and in areas managed by four indigenous Kichwa-Lamas communities. They also make up part of the Cordillera Escalera Regional Conservation Area (see Figure 1).

In the lower part of the watershed, associations of smallholder rice and fish farmers - almost 4000 producers, covering 3500 ha - currently account for 90% of water withdrawals; followed by urban households (8%) and agro-industries[9] (2%) in Tarapoto (see Figure 4 above). These irrigation-fed agriculture systems are affected by inefficient water infrastructure and associated water loss, which accounts for almost 50% of total water withdrawn.

In urban areas (Tarapoto and Lamas) the supply and access to public water services (through EMAPA), in particular to good quality water, is largely determined by the sustainability of forest ecosystem services in the upper part of the watershed. Such areas are increasingly under stress from urbanization, migration and agricultural development in the San Martin region. The erosion that results from upstream deforestation, in particular during water level surges, has increased sedimentation loads in rivers. This in turn affects the water treatment facilities (run by EMAPA) for urban water consumption, and consequently increases energy use and treatment costs. This is particularly evident in the Shilcayo and Ayashiyacu river sub-basins of the Cumbaza river watershed.

In sum, higher sedimentation loads and precipitation variability, coupled with inefficient grey infrastructure, are affecting the water security of urban and rural households in the watershed.

Among indigenous communities in the rural and upper fringes of the watershed, forests are an essential source of drinking water and the use of fuelwood for food preparation occurs among 94% of households, compared to 23% in urban households. Forests also provide multiple sources of food through the collection of non-timber forest products (NTFPs), hunting, and agroforestry and subsistence farming systems[10]. Among these peri-urban indigenous communities, income from the sale of agricultural perennial cash crops like corn, plantain, coffee and cocoa, as well as fruits, vegetables and other traditional crops in local markets (Tarapoto and Lamas) is used to purchase food, making these crops an integral part of food security strategies.

LOCAL-REGIONAL

Food imports account for almost half (47%) of food consumption. Of this, 22% of these imports are agricultural products and 25% are processed foods. The energy demands linked to transportation of these imports from other regions (e.g. Lima, Chiclayo, Yurimaguas, Moyobamba, Tocache, etc.) total almost 50 million gallons (8 million TJ) of fossil fuel per year, equivalent to more than 90% of total energy demands in the watershed.

WEF nexus scenarios & impacts

The total population of the Cumbaza watershed is expected to reach 335,000 by 2050. Should the present annual population growth rate of 3.55% remain constant, and current economic development trends in key agricultural sectors continue, significant increases in the demand for natural resources, services and land can be expected. Among urban and rural areas, climate change impacts, precipitation variability and extreme climate events (droughts and intense rainfall) are already affecting smallholder farming and urban water security. Road infrastructure also generates economic and commercial disruptions. By 2030, an increase in maximum temperature from 0.7 °C to 1.2 °C is predicted, with further impacts on human wellbeing.

The table below presents current (2016) and future (2050) resource demand scenarios, that consider current (business-as-usual) land use and climate change, population growth and economic development trends (see Annex 1 and 2 for complete methodology and results). Key risks and impacts of these socio-ecological pressures on WEF security are also presented.

Fig. 5
WEF nexus scenarios and risks table

SECTOR	CONTEXT	SCENARIO (Business-as -usual)	RISKS & IMPACTS
WATER	• Agriculture accounts for 90% of water demand; followed by urban (8%) and industrial (2%) use.	• Total projected water demands could reach 151 million m³ per year by 2050 (see Figure 4 in annex) of water demand; followed by urban (8%) and industrial (2%) use.	• Significant water loss from poor infrastructure coupled with seasonal water level fluctuations, pose risks for the rice and aquaculture supply chains and broader agriculture sector. • Urban water access and treatment capacity for EMAPA (from the Ayashiyacu and Shilcayo tributaries) is affected by sedimentation fluctuations linked to seasonal water level surges and deforestation-induced erosion.
ENERGY	• External energy inputs (hydrocarbons and electricity) make up 99% of energy sources. • Fuelwood and wood charcoal are the only local energy source, accounting for 94% of rural household energy needs.	• By 2050, 61% more energy for transportation and agricultural production will be required to meet food demands.	• The basin remains highly dependent on external energy inputs (hydrocarbons and electricity) to meet energy and food security and regional market price fluctuations could impact water and food security in the basin. • Climate-induced events outside the basin could impact the road and the energy infrastructure supply network[14]. • Policy decisions outside of the basin will impact local energy and food supply networks and prices.
FOOD	• 8.9 million tons of food are consumed per year in the watershed (47 % are food imports). • Among urban populations, processed foods account for 57% of consumption and 34% among rural households.	• By 2050 (BAU) 75% more food will be demanded (17.4 million tons), which in turn will demand 61% more energy for transportation and agricultural production[15]. • Demand for local food products will outstrip supply over the next 10 years.	• Changing urban consumption patterns (e.g. demand for processed and imported food products), and shifts from subsistence to cash crop farming among rural actors, will change access to food systems and vulnerabilities to market dynamics and infrastructure. • Achieving food security will be increasingly determined by favourable local market dynamics, adequate access to road infrastructure and transport costs.
FORESTS	• Between 1977 and 2005 the watershed saw a reduction in forest area from 20,429 ha to 8,500 ha of forest. • 45.3 million tons of fuelwood and wood charcoal are consumed per year[16].	• Biomass demands (firewood and wood charcoal), are projected to double to 96 million tons per year in 2050.	• Forest loss resulting from land use change significantly impact ecosystem services linked to rural and urban water and food security. • In rural areas, the loss of forest resources jeopardizes local indigenous Kichwa livelihoods that rely on forests as an important source of energy (fuelwood), of food (through agroforestry systems, the collection of non-timber forest products and hunting) as well as drinking water.

Strengthening resilience in the Cumbaza

This WEF nexus assessment has generated a deeper understanding of current resource supply-demands and access to water, energy and food systems in the Cumbaza watershed. More importantly, it considers important variations across economic sectors and urban-rural environments in the Cumbaza watershed, as well as regional links.

The results also highlight the role of forest ecosystem services in underpinning water-energy-food systems for both urban and rural populations, in particular around water security. As such, it will be important that efforts to build resilience in the Cumbaza watershed acknowledge the role and contributions of existing forest-based livelihoods and local community resource management regimes in determining the sustainability of forest ecosystems – which, as we have seen, influences access to vital water resources among downstream urban dwellers and smallholder farmers.

The evidence generated through this study provides valuable inputs for identifying priority areas for optimization, investment, management and policy articulation. Among some of the initial risk-mitigation responses and policy recommendations identified are the following:

- Promote water resource use efficiency and infrastructure investments in the agriculture sector, and develop less water-intensive agricultural production systems – supporting a shift towards agroforestry systems.
- Increase rural access to the energy grid, and use of efficient wood stoves or clean energy alternatives in food preparation, to help reduce pressures on forest resources.
- Expand green infrastructure projects to maintain important water ecosystem services. Prioritising restoration by reforesting 1500 ha in the Ahuashiyacu and Shilcayo river sub-basins, and a total of 3000 ha for the broader Cumbaza watershed through agroforestry systems by 2050, should be considered to maintain the sustainability of water ecosystem services.
- Promote multi-level governance mechanisms, including through multiscale watershed management platforms for identifying food and energy resource supply risks and integrating regional infrastructure planning.

Existing public green investment policy incentives and mechanisms being pursued in the region (water PES scheme[11], PIP Cumbaza[12]), could support the implementation of forest-based and locally-owned risk mitigation activities and provide the right incentives to link urban-rural actors and economic sectors in efforts to maintaining key forest ecosystems.

The interventions identified above will be developed, discussed and validated through different multi-stakeholder engagement activities which consider important gender and rural-urban dimensions. This further analysis will form a key part of the roadmap and portfolio of activities that seek to strengthen climate resilience in the Cumbaza basin.

Improving nexus governance

Nexus governance capacity, in terms of institutions and knowledge processes for coherent policy design, implementation and coordination across multiple sectors and levels[13], will be a critical variable in determining resilience.

Information generated through WEF nexus approaches can provide valuable evidence for developing a range of coherent policy responses, risk-mitigation actions and incentives for building climate resilience. However, integrating this information into planning and decision-making processes at various levels of governance has been affected by broader land rights conflicts and complex social-ecological trade-offs.

The next step in this research-action project will be to analyse the governance structures, roles and gaps in (inter)institutional capacity that affect efforts to build resilience, and build understanding of how institutions, policies, and underlying power relations shape decisions and outcomes around WEF security.

In parallel, further nexus dialogues for prioritising issues and identifying adequate and effective interventions, measures and actions will take place. This will help to identify solutions for addressing governance gaps and strengthen resilience capacity. This valuable insight will inform the development of a clear response strategy.

The final road map will incorporate differentiated actor risk perceptions and vulnerabilities and locally-owned mitigation responses. A series of bilateral meetings will be undertaken in efforts to integrate this into government agendas and annual operational plans, as part of this roadmap towards strengthening climate resilience in the Cumbaza basin.

CONCLUSION

This case-study has generated important insights into, and awareness of, water, energy and food security interdependencies across urban and rural environments, and local-regional elements of risk and resilience.

In addition, it highlights the critical role of forest ecosystem services for long-term sustainability, and the usefulness of the WEF nexus approach for improving natural resource governance and developing integrated and coherent policy responses and risk-mitigation actions.

Accounting for these complex interdependencies and development-conservation trade-offs will be paramount in strengthening climate resilience in urban Amazonian landscapes.

Fig. 6
Lamas-Kichwa community members
Credits: Guillermo Carlos (CEDISA)

ENDNOTES

1. Over the last years the Water-Energy-Food (WEF) nexus concept has emerged in response to challenges of achieving food, energy and water security in the face of natural resources pressures and climate change (Hoff 2011). It provides a framework to consider the complex and interdependent resource flows that exist between food, energy and water systems, and the ecosystems/environment, and the presence of linkages and feedbacks across different temporal and spatial scales (Stringer el al., 2014; Meza et al., 2015; De Strasser et al., Stringer et al. 2014).
2. Yurimaguas-Tingo Maria IRRSA highway expansion. See: Padoch et al., 2008
3. Mardas et al. 2013
4. In the department of San Martín, 65% of the population is urban and migration from the Andes is an ongoing trend http://www.cepes.org.pe/apc-aa/archivos-aa/a8799f3db81457e2c81aac97d67afe96/Publicacion_Cedisa.pdf
5. Most of the projected urban population growth by 2050 in Latin America will occur in small and medium cities. http://documents.worldbank.org/curated/en/779851468011741367/pdf/844410BRI0REPL00Box382123B00PUBLIC0.pdf
6. The capacity of a system to withstand, respond and recover/adapt and positively transform from a range of shocks, changes, pressures and uncertainties, whether economic or demographic (Lloyds 2015; Mitchel 2013; WWF 2016; Stringer et al. 2014: 7; OECD 2014)
7. Gender dimensions have also been considered and will be analysed and discussed in subsequent publications.
8. Alvarado, et al. 2007; PEHCBM 2007
9. Other activities that support the economy of the watershed are terrestrial and air transport, trade and tourism (PEHCBM, 2014).
10. PEHCBM, 2008
11. This is an ongoing payment for water ecosystem services mechanism with rice producers that compensates upstream communities for sustainable natural resource management and conservation activities.
12. Peru's first green public investment project (PIP Cumbaza) will direct S/. 46.5 million for the conservation and restoration of forest ecosystem services (GIZ 2016).
13. Scott, A. 2017
14. Climate extreme events have already impacted the road infrastructure (e.g. Lima - La Oroya - Tingo María - Tarapoto) causing economic losses and commercial disruptions.
15. Under the scenarios presented (that consider demand variations for processed and imported food demands, population growth, transport costs, energy efficiency) we project a constant growth in energy for transport.
16. Sale of firewood and charcoal is also registered

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ANNEXES

Annex 1. WEF Nexus scenario (BAU)

Scenario - B-SNC1

Annex 2. WEF Nexus methodology
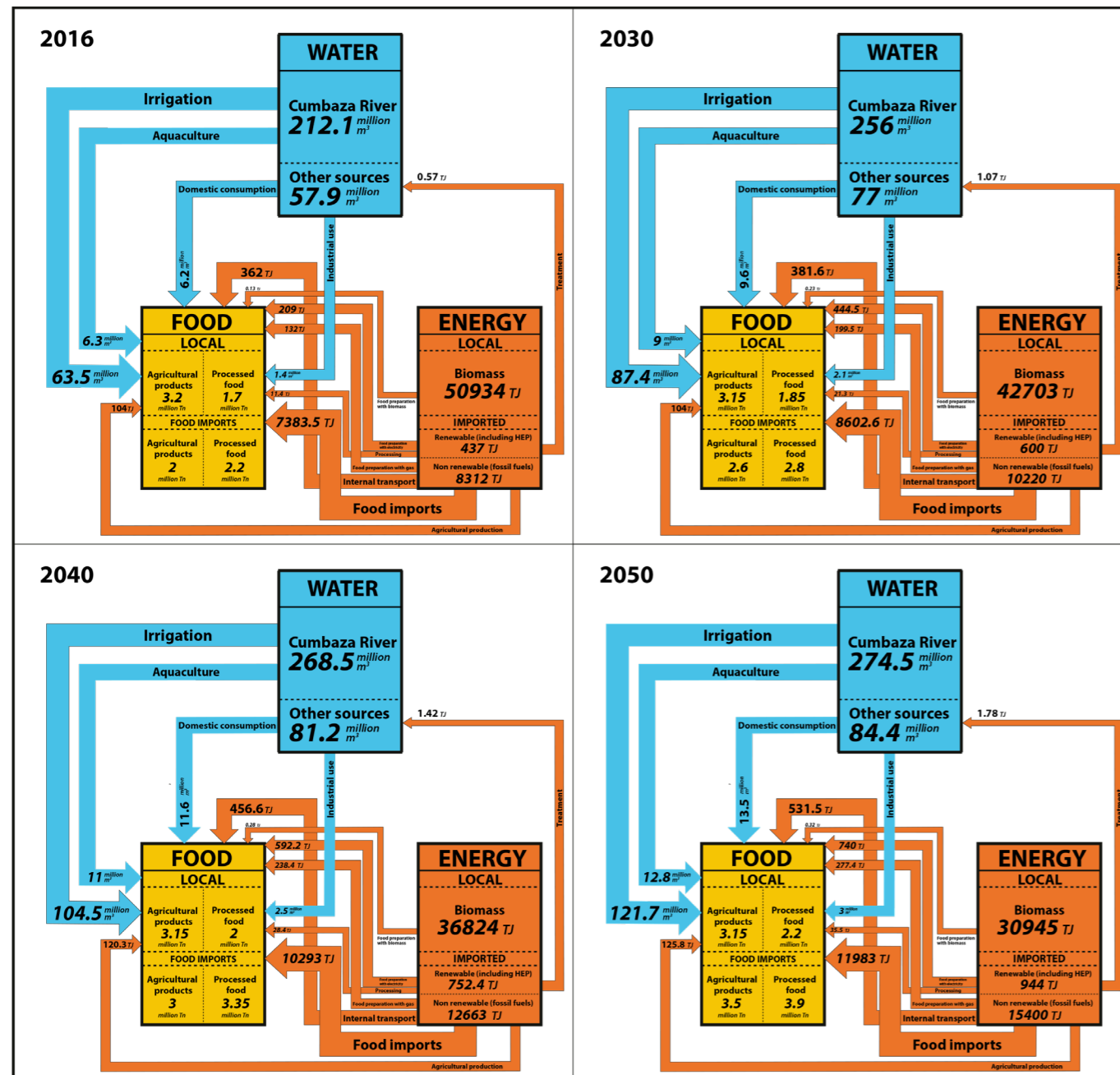
The methodology adopted for this WEF analysis draws on the key procedural steps in contextualizing and engaging stakeholders on nexus thinking developed by De Strasser et al. (2016); the conceptual diagrams developed by Meza et al. (2015) for visualising the interactions of the nexus; and the approach by Ferroukhi et al. (2015) in using resource demand percentages to quantitatively evidence the interactions between the Nexus over time.

QUALITATIVE ANALYSIS

As part of the qualitative assessment, we developed conceptual diagrams of the WEF nexus and forest ecosystem interactions in the watershed, based on an initial rapid socio-ecological analysis that identified general natural resource flows and governance regimes. These results were analysed and validated through participatory workshops with key actors responsible for managing water, energy and food resources in the watershed. These actors were identified through a stakeholder mapping exercise that assessed their role as facilitators, communicators and decision-makers within the governance of the nexus. Consequently, a technical working group was consolidated to follow the study closely and input into the different stages and activities developed.

QUANTIFICATION

As part of the quantification of the WEF nexus, we gathered secondary information through a comprehensive review and systematization of existing literature and data sets from government, private sector and civil society institutions. The collection of information for the quantification of the WEF nexus was dependent on several factors such as the availability or existence of data, accessibility to the data, and the temporal and spatial uniformity of the information[a]. Focus group discussions with rural communities and bi-lateral meetings with key government institutions were also undertaken to fill key information gaps (on water and biomass consumption for example) and to validate the data analysed, the scope of the analysis and the dimensions of the Nexus interactions.

Drawing from previous definitions of WEF security (Ferroukhi et al., 2015; UNECE, 2015; FAO, 2014; Bizikova et al., 2013; Ortiz et al., 2013; Carletto et al., 2013; Martchamadol & Kumar, 2012; Sovacool y Mukherjee, 2011; Kruyt et al., 2009; Milman & Short, 2008), we focused on three main dimensions and related indicators, which included resource supply, access and demand.

- Supply - total amount of food, energy and water resources available in the watershed;
- Access - net resource use and loss;
- Demand - total and unitary demand as well as service tariff or price per unit.

Disaggregated nexus diagrams were developed in order to visualise the three dimensions and indicators for water, energy and food. This followed three sequential steps working from right to left (see Figure 1):

- Identification and quantification of all resource uses or demands (input-output flows) by the different sectors (e.g. irrigation, drinking water, etc.);
- identification of the sub-sectors associated with each sector and the process or means by which each resource is accessed, this considers infrastructure or spaces for acquiring such resources (e.g. local markets, public water network, irrigation channel, etc.), and also considers loss linked to these processes; and lastly;
- Identification of the end users or consumers of each resource (e.g., domestic, commercial or industrial use) and the amount consumed. This process was repeated for each nexus component to generate an aggregated diagram of the interactions. The size of the spheres is presented as a percentage of the total amount of resource available.

This process was repeated for each nexus component to generate an aggregated diagram of the interactions. The size of the spheres is presented as a percentage of the total amount of resource available.

Nexus conceptual diagrams for quantification
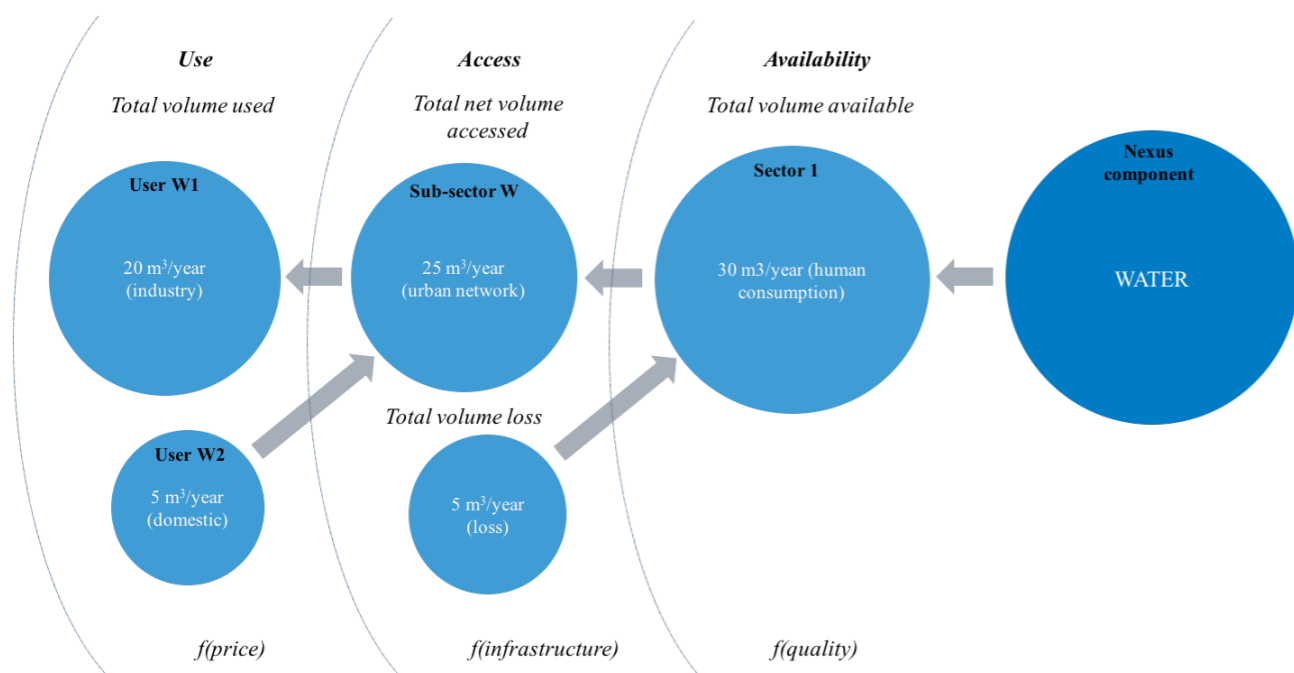
Based on data availability and critical resource flows prioritised by stakeholders, and given the particular development context found in the region, a total of eleven nexus resource input-output interactions were quantified:

TABLE 1. WEF NEXUS INTERACTIONS	
WATER-FOOD	1. Water for human consumption[c]
	2. Water for local agriculture (irrigation) production
	3. Water for local aquaculture production
	4. Water for local industrial food processing
FOOD-ENERGY	5. Energy for importing processed products
	6. Energy for importing agricultural products
	7. Use of hydrocarbons, biomass and electricity for the preparation of food[d]
	8. Use of electricity for processing of food
	9. Energy for food preparation[e]
	10. Use of hydrocarbons for local food production[f]
ENERGY-WATER	11. Use of electricity for the process of obtaining and/or distribution of drinking water

The quantifications of these interactions are based on estimates for 2016. The interactions were also standardised to allow comparisons across interaction: cubic meters (m3), Terajoule (TJ) and tons (TN).

Subsequently, bilateral and multi-stakeholder group meetings were held to gather feedback on various adapted visual representations of these interactions, and discuss and adjust the quantifications produced.

NEXUS SCENARIOS

Population growth, economic development, climate change and land use change variables were selected for the development of future water, energy and food resource nexus demand and supply scenarios. These variables were selected considering the availability and relevance (indicators) of data and multistakeholder interests and priorities (e.g. around water resources). Projections were elaborated considering a temporal scale of 2030, 2040 and 2050.

These variables include:

Population growth (number of inhabitants), based on historical growth trends and projections from census data (INEI 2007; INEI 2015), these are further divided into urban and rural populations. A 3.55% annual population increase is estimated.
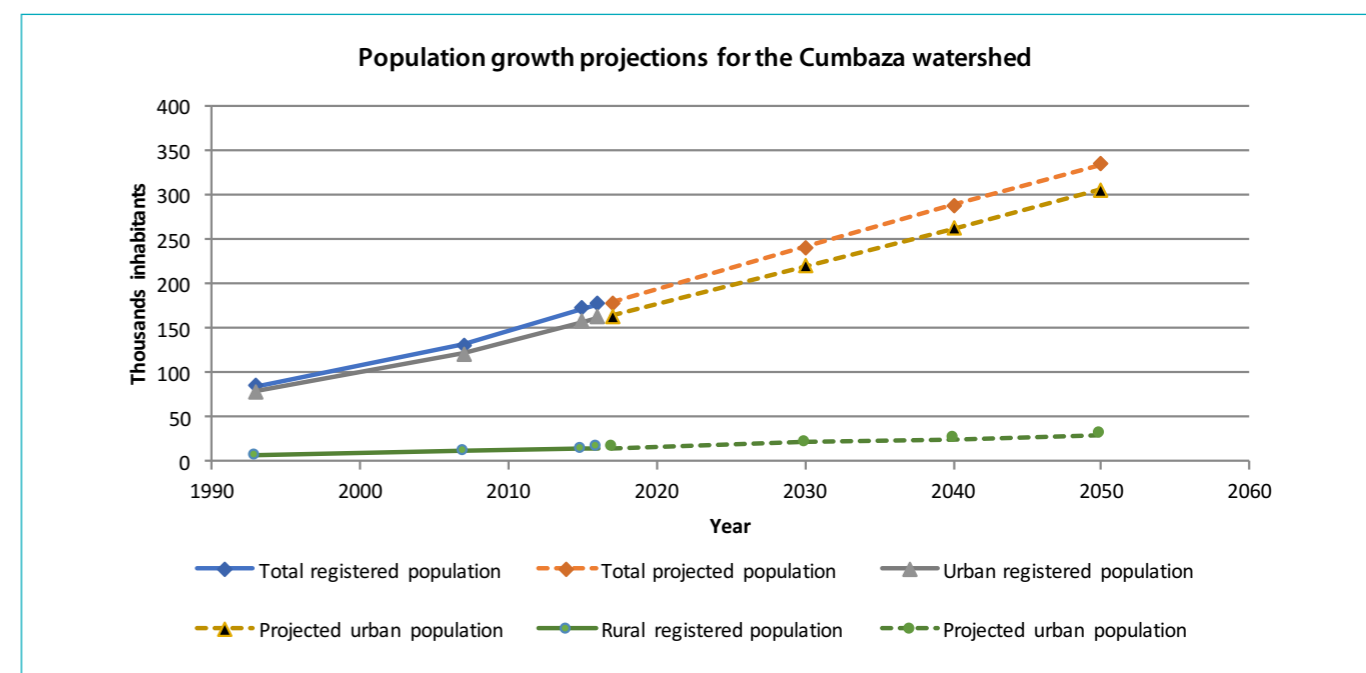
Economic development is based on growth trends between 2007-2015, drawing on specific sectoral GDP growth projections for San Martin region (INEI, 2016). These growth rates were applied respectively to the Nexus interactions prioritised (for example, utilizing sectoral per capita gross domestic product GDP growth rate variations for aquaculture in the water-food interaction). Economic development variables also included food consumption preferences, resource use efficiency and transport costs) projections associated market preferences, resource use efficiency, and operational costs and services linked to transport (freight, fuel price, machinery). economic development (sectoral per capita gross domestic product, food consumption preferences, resource use efficiency and transport costs).
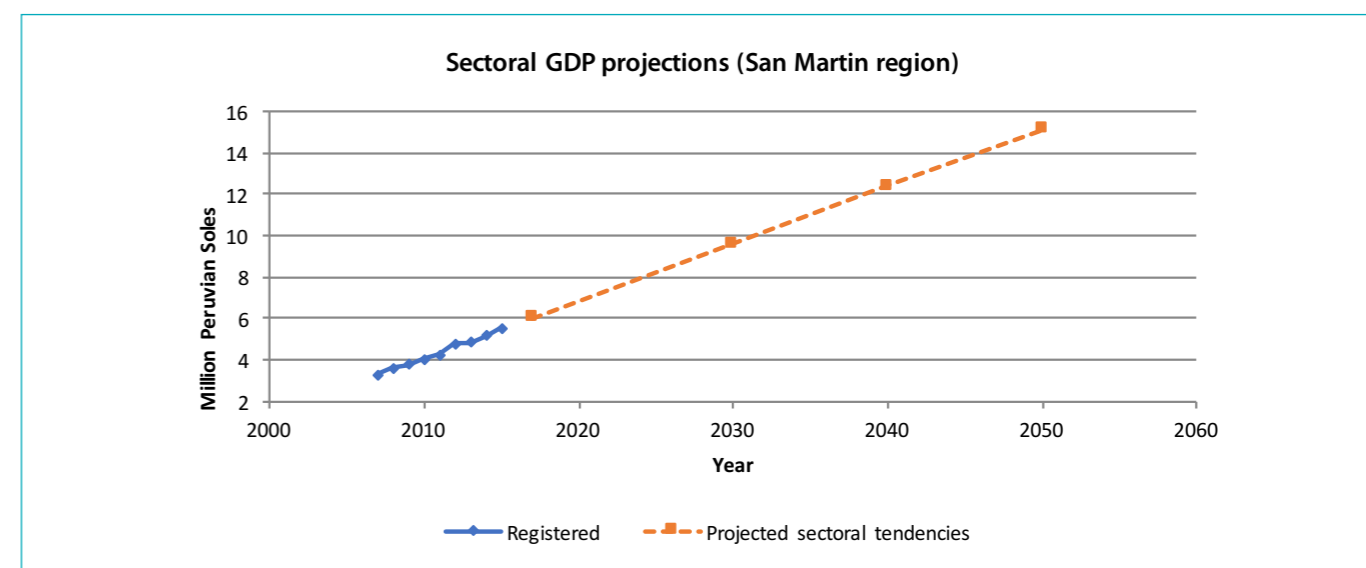
Climate change (average temperature and precipitation variability) projections for 2030, 2040 and 2050 are based on the MarkSim[b] (Jones & Thornton 2013) weather generator of the project area (Lat: -6.418, Long: -76.4117) and based on representative concentration pathways (RCP) of RCP4.5, RCP6.0 and RCP8.5. Table 2 summarizes the main impacts of climate change for the Cumbaza river basin according to different RCP scenarios.

TABLE 2. TEMPERATURE AND PRECIPITATION VARIATIONS UNDER DIFFERENT RCP SCENARIOS FOR THE CUMBAZA WATERSHED

YEARS	TEMPERATURE			PRECIPITATION		
	RCP 4.5	RCP 6.0	RCP 8.5	RCP 4.5	RCP 6.0	RCP 8.5
2030	26.3	26.1	26.4	1486	1480	1457
2040	26.6	26.4	26.7	1482	1474	1480
2050	27.0	26.8	27.6	1482	1471	1502

Land use change, considers variations in forest area (hectare), urban area, transitional crops (rice), secondary forest, mixed agro systems and pasture (see Figure 2 in main text).

Linear regression and multiple regression models were used to elaborate four scenarios (see Table 3 below) with the following characteristics:

TABLE 3. KEY CHARACTERISTICS OF THE SCENARIOS DEVELOPED FOR THE WEF NEXUS ANALYSIS

SCENARIO	WEF NEXUS DRIVERS						
	Population growth	Climate variation (RCP 4.5, RCP 6, RCP 8.5)[g]	Regional economic growth (sectoral GDP)[h]	Product consumption preferences (+/- 5%)[i]	Resource use efficiency +/- 10%[j]	Transportation costs +/-10%[k]	Land use change (forest cover)
BAU (B-SCN1)	+3.55%	RCP 4.5	0	-5% Local	+5% Imported	0	-2.5%
Negative change (N- SCN2)	+3.55%	RCP 8.5	-	-5% Local	-5% Imported	+10%	-5%
Moderate change (M-SCN3)	+3.55%	RCP 6	-/+	+5% Local	-5% Imported	-/+	-1%
Positive change (P-CN4)	+3.55%	6	+	+5% Local	+5% Imported	-10%	+5%

(+) Positive changes (-) Negative changes, (+/-) Moderate changes (0) No change

The variables applied across the 11 nexus interactions are as follows:

Water
- Water for human consumption: populations growth (number of users), per capita consumption changes and temperature fluctuations (RCP 4.5, 6, 8.5), deforestation/reforestation
- Water for local industrial food processing: uses manufacturing GDP growth and average consumption by users and number of users, deforestation/reforestation
- Water for local agricultural production (irrigation): considers rice area variations (in hectares), temperature variations and rice demand projections, deforestation/reforestation
- Water for local aquaculture production: uses sectoral GDP growth projections, temperature variations, deforestation/reforestation
- Water supply determined by precipitation variability (RCP) and forest cover change.

Energy demands
- Energy for importing processed and agricultural products: product volumes, unit costs, fuel costs variations, fuel expenditure (-10, 0, +10%)
- Energy for food preparation (electricity): population by zone, per capita electricity consumption by type of household appliance (-10, +10%)
- Energy for food preparation (biomass): population by zone, % use of biomass (-5%, 0, 5%), consumption per capita (-10%, 0, +10%)
- Energy for food preparation (butane): (-10, 0, +10%) demand tendencies; changes in urban/rural demands,
- Use of electricity for processing of food: Volume of processed goods (-10, 0, 5, 10% variations; Number households, per capital consumption
- Energy for local food transport: product volumes, unit costs, fuel expenditure, fuel costs variations (-10, 0, +10%)
- Energy for agriculture production: surface area, fuel consumption by type of machinery (-10, 0, +10%)
- Use of electricity for the process of obtaining and/or distribution of drinking water: population growth variation in energy efficiency (-10%, 0, +10%)

Food demands:
- Population growth, food consumption preferences (local, imported) variations by (-10, 0, 5, 10%)

ANNEX ENDNOTES

a   For example, we found that many of the databases, or information registered by the governmental entities in charge, were generated in different periods of time, some for example as it happens with the Censuses in Peru have a periodicity approximately of 10 years, while other records such as drinking water consumption are monthly. It was necessary to estimate or project data for the purpose of standardizing the evaluation period.

b   MarkSimGCM, employs 17 types of General Circulation Models models (GCM) from which we chose the HadGem2-ES model, since it is one of the models that best represent the synoptic systems that modulate the South American climate and was employed by SENAMHI in 2013 for the generation of scenarios in nearby regions, as well as being one of the recommended models for countries like Peru. Source: http://gisweb.ciat.cgiar.org/MarkSimGCM/#)

c   Total human consumption accounts for urban domestic, commercial and public consumption categories provided by the public water services company EMAPA San Martin which registers water withdrawals in three main tributaries: Ahuashiyacu, Shilcayo, Cachiyacu. Rural consumption averages were calculated through additional data collection methodologies with four indigenous communities. We obtained an average consumption of 88.35 ltr/inhabitant/day which was then multiplied by the total number of inhabitants in the rural area.

d   For the estimation of the electricity consumption used by household appliances in the food preparation, a guide by Organismo Supervisor de la Inversión en Energía Osinerg was used to calculate household electrical consumption (eg refrigerator, blender, blender, microwave, etc.) and estimated the number of dwellings in the micro-basin categorized according to poverty levels. Biomass consumption was estimated through by the percentage of households that use fuelwood and charcoal (0.29% ad 0.0047% respectively.

e   Based on average fuel consumption by type of agricultural machinery (tractor, dredge) used per hectare of productive agricultural land.

f   The use of hydrocarbons for local food production was calculated based on the average fuel consumption per hectare according to the type of machinery used (dredge, mechanical mule).

g   Indifference to climatic variations (0), in this case none of the RCP projections are used. Positive variations (+), uses the projections generated by the scenario RCP 4.5, which proposes slight modifications on the parameters. Negative variations (-), uses the projections generated by the RCP 8.5 scenario, which poses severe modifications to the parameters. Conservative variations (+/-), uses the projections generated by the RCP 6.0 scenario, which proposes moderate modifications on the parameters.

h   B-SCN 1, only the trend of the sectoral GDP is projected. N-SCN2, uses the minimum growth rate presented by the historical series of the sectoral GDP. M-SCN3 (+/-), uses an average rate of growth of sectoral GDP. P-SCN4 uses the average annual growth rate based on the historical series of the sectoral GDP.

i   Variations of 5% of average consumption per capita are proposed for each local or imported product: B-SCN1, reflects a decrease of local products (-5%) and increase of imported products (+ 5%) is used. N-SCN2, involves reduction (-) of consumption of local products (-5%) and imports (-5%). M-SCN3, raises (+) consumption of local products (+ 5%) and reduction of consumption of imported products (-5%). P-SCN4, raises (+) consumption of local products (+ 5%) and imported (+ 5%).

j   In this case, average consumption per capita (+/- 10%) are considered, in particular for water and energy. B-SCN1, current growth trends are used, in which resource savings practices are not introduced, maintenance of facilities is not conducted and / or there is a presence of leaks/resource loss. N-SCN2, with negative efficiency (-), occurs when average per-capita consumption increases by 10%, due to inadequate practices, savings and similar practices. In M-SCN3, with regular efficiency (+/-), occurs as an average of P-SCN4 and N-SCN2, with the aim of capturing some good use practices and saving resources. P-SCN4, with positive (+) efficiency, occurs when average per-capita consumption is reduced by 10%, due to adequate use, saving practices.

k   These scenarios show positive or negative variations depending on: the unit cost per transport of products, the price of fuel and the performance of machinery. The variations are between +/- 10% according to each scenario: B-SCN1, reflects the unit cost of transport remains the same as the current one, the fuel price increases, and the performance of the machinery is reduced by 10%. N-SCN2 (+), occurs when the unit transport cost, fuel price and machinery performance increases by 10%. M-SCN3 (+/-), is an average situation between scenarios B-SCN1 and N-SCN2, so it is mainly used the current values of unit cost, fuel price and machinery performance. P-SCN4 (-), occurs when the unit transport cost, fuel price and machinery performance is reduced by 10%.