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SUSTAINABLE MOUNTAIN DEVELOPMENT

Shaping the water–energy–food nexus for resilient mountain livelihoods

Many rural mountain communities in developing countries face major difficulties in meeting basic needs for water, clean energy and healthy food, not to mention strengthening economically and socially. Local and global changes – such as population growth, climate change and overuse of natural resources – shape and sometimes constrain these communities' water, energy and food security. Increasing resource demands from nearby urban and lowland areas compound the challenges.

How can rural mountain communities improve their water, energy and food security in contexts of growing resource pressure, competition and uncertainty? Does a water–energy–food (WEF) nexus

approach offer a way to identify forward-looking options and policies to strengthen their livelihoods and resilience? Indeed, a WEF nexus assessment can be beneficial when conducted in a participatory process that effectively engages and empowers mountain communities with a view to fostering equal access to water, energy and food, and enhancing the diversity and depth of mountain communities' livelihood options.

The suggested participatory process aids stakeholders in assessing the status and trends of WEF systems in mountains, in identifying governance and technical options and in negotiating alternative scenarios. It promotes sharing of relevant knowledge and addressing diverging interests and power relations. It helps to build stakeholders' capacity to implement cross-sectoral strategies and policies effectively, thus facilitating transformative change towards increased water, energy and food security in mountains.

Women in Mexico benefit from modern energy. They bake tortillas not only for their own consumption but also as a source of off-farm income. (S. Kummer)

Mountain people are vulnerable to WEF insecurity

The 2030 Agenda for Sustainable Development underscores the importance of equitable, sustainable access to water, energy and food for human well-being and economic development [1]. Many people living in mountains face major challenges in meeting their needs and rights to these resources. The situation often varies widely depending on whether they live in urban or rural areas, at higher altitudes or in lower hill areas, close to roads or in remote areas, etc. In this issue brief, we examine the perspective of communities in rural and remote mountain areas. They often struggle with low agricultural productivity, constrained access to water and sanitation facilities, lack of modern energy services and high exposure to multiple natural hazards. Moreover, their physical remoteness often leads to neglect of their opportunities, needs and concerns in formal policy and decision-making processes [2]. Poverty incidence in these communities is frequently high, making them especially vulnerable to shocks and ongoing stress related to global change – particularly climate change. Their resilience – i.e. their capacity to cope with and buffer against disturbances while maintaining the ability to adapt and transform [3–5] – correlates strongly with the wider conditions of the mountain ecosystems on which they rely for essential services of water, energy and food (WEF) security.

Water security is very context-specific: While in some mountain regions the availability of water resources is comparatively stable and sufficient, in other regions the seasonality of rainfall constrains water availability throughout the year, or water supplies may depend on meltwater from glaciers and snow [6,7]. Sustainable management of mountain ecosystems can enable infiltration of runoff water and help recharge vital springs and groundwater supplies that are essential to ensure stable water availability in mountain communities and lower-lying areas. Mountainous topography can ease the delivery of water from upstream to downstream areas, but it poses natural hazard risks and increases the costs of constructing and maintaining infrastructure for drinking water, agriculture and more. In many places, traditional water management institutions and schemes have been developed to secure water supplies and ensure proper distribution [8,9]. Today, socio-economic conditions, lack or weak enforcement of inclusive regulatory and institutional frameworks, and power relations combine to shape community and household access to safely and sustainably managed water in different ways. For example, in the Ecuadorian Andes, only 52 percent of rural households and 72 percent of urban households have access to safe drinking water; but the access rate differs considerably from one parish to

the other [10]. Factors such as limited human and financial resources, institutional weaknesses of the National Water Secretariat tasked with implementing the National Water Plan, and sociopolitical conflicts over protection of water resources compound each other, hampering sustainable management and just governance of water resources in Ecuador [11].

Energy security still depends on solid biomass: Electrification of mountain villages has improved in recent decades, particularly in Latin America. In Peru, for example, 89 percent of rural households now have access to electricity; in Bolivia, 65 percent have access [12]. Nevertheless, many mountain communities – particularly in very remote mountain areas – continue to face substantial difficulties in accessing clean and modern energy for cooking and heating. Instead, they remain dependent on traditional technologies and solid biomass fuels such as wood and crop residues. In the Hindu Kush Himalayas, households' access to clean fuels and technologies for cooking differs greatly, ranging from 9 percent in Myanmar to 68 percent in Bhutan [13]. Continued use of solid biomass (e.g. fuelwood, crop residues, animal dung) for cooking and heating, especially in combination with inefficient technologies (e.g. rudimentary cookstoves), produces dangerous levels of indoor air pollution and contributes to atmospheric warming [14]. Related high rates of fuelwood extraction can degrade ecosystems, especially forests, eroding ecosystem functions and services essential for WEF security.

At the same time, there is substantial potential for generation of hydropower in mountain regions where water supplies are sufficient and reliable. But high upfront costs for infrastructure remain a major hurdle. Because of the poor accessibility of scattered mountain settlements, decentralized off-grid solutions are often promoted such as rivulet-based microhydroelectricity production as well as biogas or household solar. However, even these technologies remain inaccessible and unaffordable for many. The Solu-Khumbu region of Nepal represents an exception that shows how a variety of co-occurring enabling factors can boost local development of hydroelectricity. Here, a ban on firewood collection (following establishment of a national park), liberalization of airfreight commerce (easing transport of heavy equipment) and deregulation of the energy market in 1992 have led to installation of 23 microhydropower plants in the region since 1990, mainly financed by international NGOs and private investors [15].

Vulnerability to food security is increasing: By 2012, almost 45 percent of rural mountain communities in developing countries were assessed as vulnerable to hunger and malnutrition – up from 38 percent in 2000. Hunger and deficits in micronutrients contribute to higher rates of infant and maternal mortality in mountains versus lowlands [16,17]. These findings stem from an assessment of agricultural production, including animal husbandry, in mountain areas. However, some mountain dwellers with access to off-farm income or remittances may be able to meet their dietary needs with purchased goods, mitigating their local production-related food insecurity [18]. Limited food production at higher altitudes – due to soils' low productivity, the harsh climate and the labour intensity of farming on steep terrain – can decrease even further when unsustainable agricultural practices erode the availability of productive land, soils and water resources.

Fuelwood collection in Tajikistan. (R. Fleiner)

BOX 1 Water, energy and food security and the SDGs

Water security is "the capacity of a population to safeguard sustainable access to adequate quantities of acceptable quality water for sustaining livelihoods, human well-being and socio-economic development; for ensuring protection against water-borne pollution and water-related disasters; and for preserving ecosystems in a climate of peace and political stability" [19]. By highlighting the role water plays in socio-economic development, the concept and goal of water security is even broader than that outlined in SDG 6 "Clean water and sanitation".

Food security is a situation in which "all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Based on this definition, four food security dimensions can be identified: food availability, economic and physical access to food, food utilization and stability over time" [20]. Expanding on this, SDG 2 "Zero hunger" also emphasizes the pivotal role of sustainable agricultural practices in increasing productivity and production.

Energy security is defined as "the uninterrupted availability of energy sources at an affordable price" [21]. In addition, SDG 7 "Affordable and clean energy" stresses the need to improve access to clean, modern and renewable energy solutions.

Water from the Tian Shan mountains is an indispensable resource for agriculture in the lower-lying steppes and for hydropower production in the Kyrgyz Republic. (M. Foggin)

WEF security in lowlands depends on mountains

Ecosystem services provided by mountains are essential to agricultural production, water security and clean energy in both highlands and lowlands. Resource management and use in upstream areas also impact the WEF security of downstream and lowland communities.

Globally, more than 3 billion people depend on mountain water whose availability is co-determined by climate, soil conditions and land cover [22]. The contribution of mountain discharge to dry-season waterflow ranges from 30–60 percent in the humid tropics up to 50–90 percent or more in arid and semiarid regions. Water storage and surface/groundwater supplies – aided by natural or constructed infrastructure – are crucial. In the Himalayas, for example, more than 54 000 glaciers comprising 6 100 km^3 of ice reserves form a massive stock of water, serving as the headwater source for ten major river systems in Asia (Figure 1).

The potential for hydropower generation in many mountain regions remains high and not fully realized. In the Himalayas, this potential exceeds 500 GW. It could supply reliable energy to most of the region's population, significantly reducing traditional fuel use and combatting related land degradation, air pollution and health harms. At the same time, larger-scale hydropower projects remain contested, since they pose risks to ecosystems including land degradation in mountain areas [23] and altered downstream water regimes that threaten biodiversity. In addition, the social costs of dam construction and operation are frequently underestimated, with people in mountains often receiving insufficient compensation and fewer benefits [24].

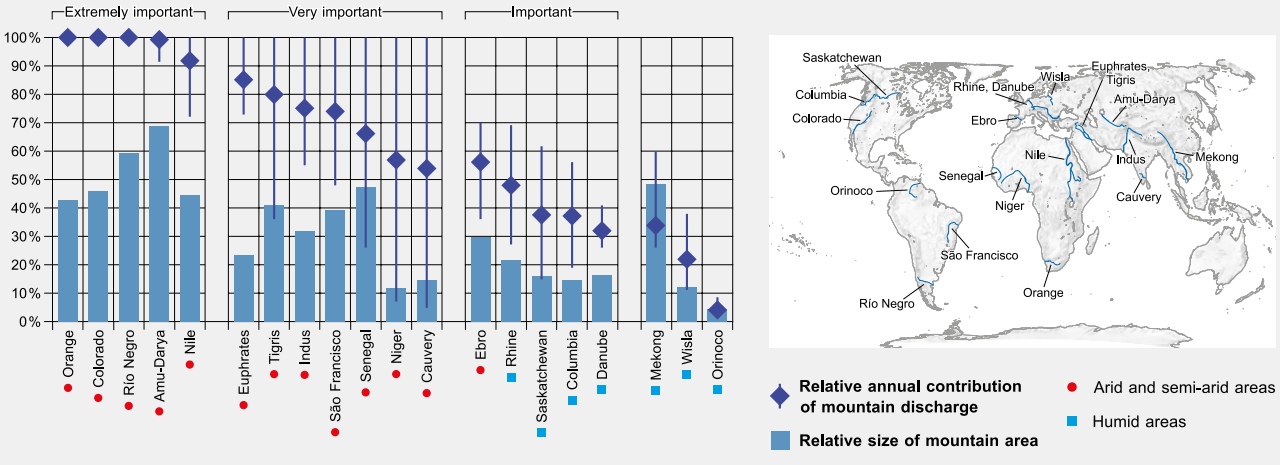

Figure 1: Contribution of mountain discharge to major rivers [2].

Local and global change resulting in competing claims

Rural mountain communities' WEF security and resilience emerge from a combination of local livelihood conditions, development trends and wider global change.

Population growth, urbanization and economic development

Overall, the rate of population growth in mountains remains in step with that of global population growth. On closer inspection, however, it varies considerably depending on the mountain setting: rural–urban migration slows down population growth in rural mountain areas; population growth in urban mountain areas is substantially higher. Between 2000 and 2015, the share of people in mountain areas living in cities of over 50 000 inhabitants rose from 31 to 35 percent. At the same time, the degree of urbanization ranges widely from one mountain region to the other [18]. Moreover, population extents appear to decrease at altitudes over 4 500 m, with above-average mountain-area population increases generally occurring at lower elevations where the potential for agriculture is higher and urban centres are typically located.

Both population growth and urbanization lead to increasing pressure on water, land and energy supplies as a result of rising resource-intensive economic activities and lifestyles [25,26]. Similarly, economic development based on mountain tourism, for example, also fuels increased water demands, changes in energy supplies and food-consumption habits (see Box 2). Finally, mountain systems are under growing pressure from lowland populations who rely on mountain water resources for domestic use, irrigation, hydropower generation and industrial development [27].

Land use change and natural resource management

Traditionally, land and water management practices in mountains have been carefully adapted to local terrain and microclimates; this has led to highly diversified, context-specific agricultural systems of crop growing and livestock rearing, etc. Relatively new land use trends increasingly shape the water, energy and food situation in mountains. Growing intensification of agriculture is providing more food in the short to medium term. However, if not managed properly, it can have negative long-term effects on water regulation services [28] as well as on soil and water quality (e.g. in case of excessive fertilizer use). Similarly, increasing livestock numbers, if not adequately managed, can aggravate ecosystem degradation. Besides harming water quality and quantity, rising demand for irrigation water in high- and low-lying areas can also cause resource conflicts as seen, for example, in semiarid regions of the Andes [25,29], Kenya [30] and the High Himalaya in Nepal [15]. In addition, increasing mining activities can alter water flows, decrease base flows and increase water pollution [31].

At the same time, young people's outmigration from rural mountain areas is leading to reduced agricultural production, changes in land use and abandonment of land due to labour shortages. Relatedly, workloads are increasing among those who remain behind, especially the elderly, women and children [32–34] – in turn strongly affecting how local natural resources are managed. In addition, poverty and urban expansion can push agriculture higher upslope into fragile terrain, triggering soil loss and shifts in hydrological regimes [35]. Changes in land management practices can also affect the rich (agro-) biodiversity and diets found in mountain areas. In the Himalayas, for example, over 675 edible plants are known – around 1 740 medically relevant species are found in the Indian Himalayas alone [36].

Climate change

Mountain regions are especially sensitive to climate change. It impacts the livelihoods of rural mountain communities and threatens the capacity of mountain ecosystems to provide services needed to ensure water, energy and food supplies [27]. Rising temperatures cause glaciers and permafrost to melt faster, impacting water-storage capacities and runoff regimes particularly in the upper reaches of glaciated watersheds [37] and compromising slope stability in high mountains [38]. Increasing glacial melting may cause more runoff initially, but will decrease it overall in the long term. In watersheds featuring smaller glaciated areas, decreased overall runoff

BOX 2 Reconfiguration of the WEF nexus in the Solu-Khumbu region, Nepal

In the Solu-Khumbu region of Nepal, the number of tourists has doubled in the past 20 years, fuelling increasing demand for water, food and energy. The local WEF nexus is being reconfigured by a combination of booming tourism, changes in natural resource management (especially establishment of natural parks) and new energy and transportation policies. Cultivation of traditional staple foods has been replaced by food imports, greenhouse-based growing of vegetables for tourists and production of fodder for pack animals. Local water supplies are increasingly used for hot showers, greenhouse irrigation, electricity production and bottled water. Liberalization of the energy and transport sectors and a ban on firewood cutting have spurred development of over 20 micro-hydroelectricity plants in the region. Taken together, the WEF nexus has become more dependent on external factors. Water resources are increasingly central to the success of the thriving local tourism industry, giving rise to competing claims and seasonal water scarcity [15]. Recent economic development has certainly improved people's livelihoods in the Solu-Khumbu region. However, it remains unclear how equally the benefits have been shared and whether the livelihood improvements have strengthened people's resilience more broadly.

is already being observed. Further, increasing rainfall variability also affects flow regimes and causes temporal changes in water availability, especially in dry highlands and areas characterized by rain-fed agriculture and pronounced seasonality of rainfall. Increasing weather extremes are likely to raise the risk of natural hazards such as droughts, floods, landslides and mudflows [39]. There are signs that climate change has already decreased agricultural production in the Hindu Kush Himalayas, for example [32]. On the other hand, warming may also push cropping areas upwards in some regions. How climate change will impact WEF security across the world's diverse mountain landscapes is hard to know precisely due to many uncertainties, particularly regarding future amounts and patterns of precipitation, not to mention how high temperatures ultimately rise. However, broad increases in precipitation variability, warming and extreme events will doubtless require adaptive, flexible resource use approaches to ensure long-term WEF security.

→ The marked increase in demand for water, energy and food among urban lowland populations is often prioritized by governments over the needs of people living in rural mountain areas. This is especially the case in places where mountain communities and people are politically marginalized or neglected, lacking the rights and power to shape and equally benefit from development efforts. Unequal development at the expense of such groups, increasing competition over natural resources and degradation of mountain ecosystems result from these dynamics, aggravating mountain communities' vulnerability to WEF insecurity.

Linking nexus thinking and resilience thinking

How can water, energy and food security in mountains be improved while addressing competing claims, trade-offs and risks? A WEF nexus approach combined with sustainable livelihood and resilience thinking can help to identify pathways that benefit mountain people and support them in coping with increasing socioecological pressure, climate change and uncertainties (Figure 2).

Addressing water, energy and food needs of communities in remote areas of Nepal requires holistic approaches and research into context-specific solutions. This research station is testing a combination of greenhouses, water storage and solar infrastructure. (A. Zahnd)

The overall goal of the WEF nexus approach is to accelerate the availability of sufficient safe water, clean energy and adequate nutritious food while sustaining relevant ecosystem services [40–42] (see point 1, Figure 2). It emphasizes the interdependence of the three sectors, and the need to understand and govern them according to a systems perspective [43]. Systematic analysis of interlinkages enables identification of ways to maximize synergies (co-benefits) and helps to uncover trade-offs with possible negative outcomes. Resulting cross-sectoral policies, management strategies and innovations help to advance system-wide efficiency and productivity, promote reuse of waste and reduce pollution. However, the nexus approach alone does not address who wins from synergies or loses from trade-offs.

In order to meet the needs of mountain people and communities fairly, the WEF nexus approach should be combined with a livelihood and justice lens, i.e. a sustainable livelihood approach. This perspective makes it possible to assess whether interventions in the WEF system support or hinder people's livelihood options and economic opportunities in a balanced way. At the same time, it transparently highlights competing interests, social and power relations between stakeholders. This aids efforts towards equal access to water, energy and food and supports fair benefit sharing between those safeguarding

	Main focus	Mountain-specific challenges: Limited natural resources	Mountain-specific challenges: Marginalized communities, institutional periphery	Mountain-specific challenges: Highland–lowland interactions	Mountain-specific challenges: Hazard-prone and particularly affected by climate change
WEF lens	*(1) How can the **availability** of water, energy and food be accelerated and the functions of mountain ecosystems maintained?*	■		■	
Livelihood lens	*(2) How can mountain communities' capacities and their position be improved to increase their **access to water, energy and food**?*	■	■	■	■
Resilience lens	*(3) How can the diversity, redundancy and adaptive capacity of livelihoods and ecosystems be improved by ensuring **reliable provisioning** of water, energy and food in times of disturbances, shocks and uncertainty?*	■	■		■

Figure 2: Combining the WEF nexus lens with livelihood and resilience lenses enables a more comprehensive approach to improve mountain people's WEF security. The various lenses address different mountain-specific challenges to varying degrees (darker shading equals higher significance).

ecosystem functions and those using ecosystem services (see point 2, Figure 2) [44]. Further, this perspective encourages inclusive participation in planning and decision-making, empowerment of vulnerable and marginalized groups in mountains, and more balanced power relations between rural areas and urban centres as well as highland and lowland communities [42].

The resilience focus supports identification of ways to strengthen the capacity of people and ecosystems to buffer against and cope with disturbances, shocks and uncertainty (see point 3 in Figure 2, Box 3). The aim is to maintain or even enhance diversity and redundancy in both ecosystems and livelihood options, while fostering adaptive management that also accounts for slow changes [45]. Multiple livelihood options – whether combining different income sources, or cultivating a wide variety of crops that react differently to climate change – help mountain people to cope with adverse events and adapt to changes, making socioecological systems more resilient [46].

Improve governance across sectors and levels

Effective governance of mountain-based WEF systems and highland–lowland interactions often requires innovations, such as:

- Cross-sectoral and cross-level platforms that enable open dialogue between stakeholders as well as open sharing of data, information and knowledge: Coordination across sectors and levels can help to harmonize policies and development strategies. Sharing knowledge and nurturing learning and experimentation can help to increase stakeholders' adaptive capacities.
- Institutional actors with the legitimacy and authority to facilitate the process act as knowledge brokers and advance implementation of solutions.
- Increased capacity among mountain communities to participate equally in planning, decision-making and negotiation, thereby reducing unequal outcomes and ensuring equal opportunities for all [47].
- Open exchange that lays the groundwork for negotiating trade-offs and tackling potential conflicts in mountain areas and between highlands and lowlands related to resource scarcity and competing uses [47].

BOX 3 Resilience

Resilience is the capacity of social, economic and environmental systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation [5].

Nexus assessment: steps towards WEF security and resilience

In the following, we outline a participatory WEF nexus assessment process that enables identification of pathways towards optimizing resource use, improving the livelihoods of mountain communities and strengthening their resilience. Transparent setting of normative objectives is important throughout the entire process, but especially regarding negotiation of trade-offs and sharing of benefits. This also reduces the risk of influential actors capturing the process. The proposed four-step process draws on the WEF guidebook for agricultural investments [41].

1. Define the objectives and scope of the assessment

Defining the objectives and scope of the assessment is a demanding, yet critical step given the holistic ambition of the WEF nexus approach. It comprises three interdependent elements: (a) identifying the problem at stake; (b) selecting stakeholders who will participate in the assessment; and (c) defining the spatial boundaries and temporal scale of the assessment. While defining the boundaries is key, external factors influencing the WEF nexus and its outcomes for livelihoods must be considered because they co-define trends and room for manoeuvre.

A small group of committed stakeholders can begin the process by drafting objectives and tentative boundaries for the WEF nexus assessment based on an initial evaluation of the problem and its context. This preliminary appraisal can serve as a basis for identifying and motivating a more comprehensive, diverse group of stakeholders and experts to contribute to the assessment and identify options for transformation pathways. Experience shows that a thorough stakeholder analysis – including assessment of stakeholders' likely interests, values, incentives and influence – helps to identify and foster participation of a balanced group of legitimate, committed representatives from different social groups in mountain (and lowland) communities as well as from different private and administrative sectors at different levels (community, district, national) [48,49].

Careful selection of participants maximizes knowledge contributions, fosters joint learning, builds trust in the process, ensures stakeholder ownership of outcomes and aids implementation of identified solutions. At the same time, the selection should also consider the timeliness and effectiveness of the process, and the ability of chosen stakeholders to participate in key consultative moments of the process. This is particularly important for women and socio-economically disadvantaged groups who may face time constraints and lack power, experience or confidence [50,51]. Equally important for a constructive process is a committed facilitator who is accepted by the participants, has the authority to advance the process and can call for implementation of the results.

Selected participants are tasked with re-evaluating and developing a joint understanding of the problem. A more generic overview of the components and interlinkages of the WEF nexus (as outlined in Figure 3) can help to identify areas of concern, which in turn helps to define appropriate boundaries of the system for assessment. In mountain contexts, the boundaries may correspond to a watershed, a transboundary basin or an administrative unit such as a community, a district, a state or some combination of these. Boundary definition depends on whether only local mountain areas are considered, or whether their linkages to downstream or lowland areas or even the wider region are also considered. Delineation of the system for assessment may also be done according to particular themes

Mountain communities are benefiting from the Basochhu hydropower plant in Bhutan through improved medical, school and telecommunication facilities. (R. Zeiner, ADA)

BOX 4 A sectoral and highland–lowland perspective: hydropower generation in Vietnam

The Vu Gia Thu Bon River Basin, the fifth-largest river basin in Vietnam, reaching 2 000 m above sea level, bears major hydropower potential to meet Vietnam's increasing energy demand. A total of 44 hydropower projects are being constructed or slated to be built in the basin, projected to generate about 5 000 × 106 kWh per year. A nexus assessment revealed that the plant water diversion of the Dak Mi 4 project would likely lead to more droughts, impacting the irrigation of 20 000 hectares of paddy rice and the water supply of 850 000 inhabitants of Danang city downstream [52].

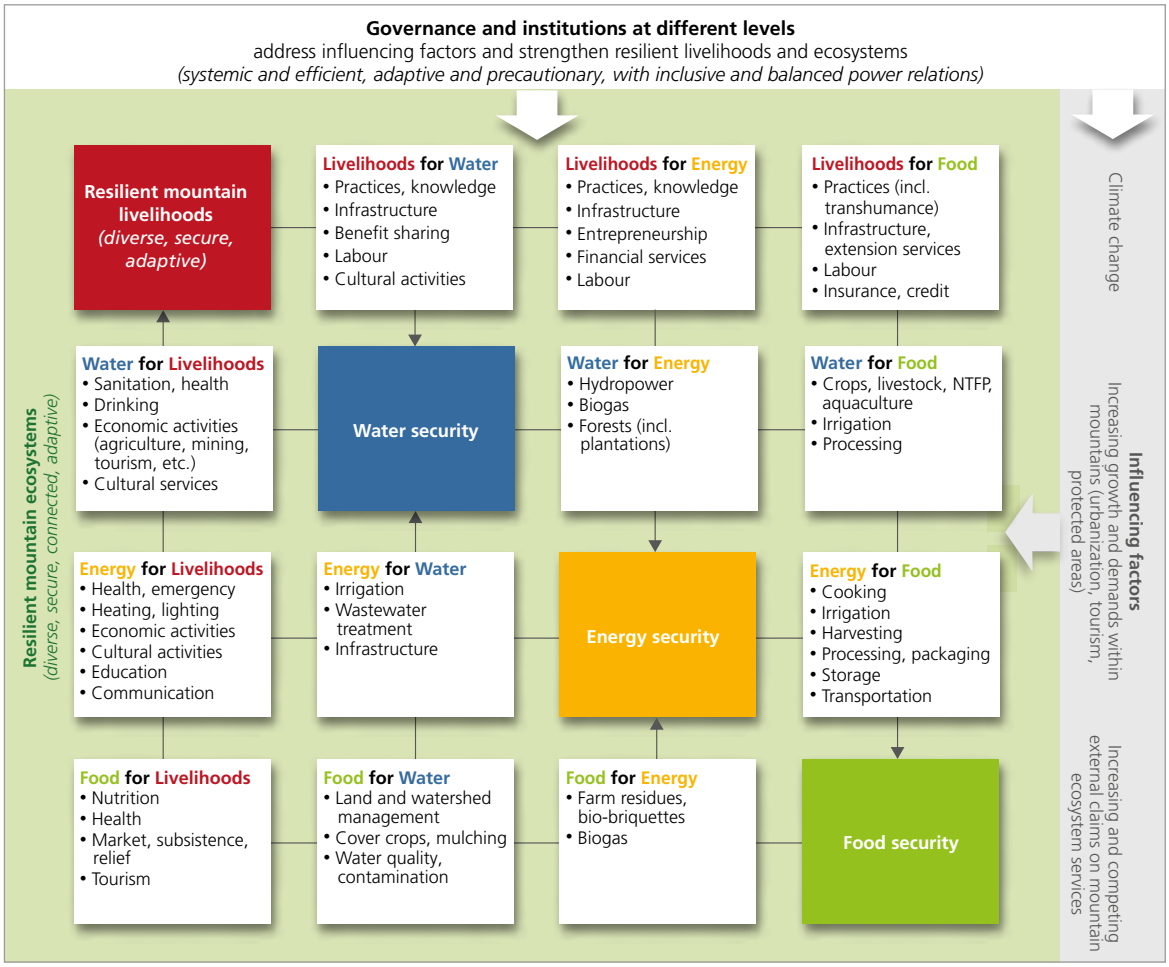

Figure 3: Generic overview of the WEF nexus in a mountain context. It depicts key components, interlinkages, influencing factors (grey area) and the institutional framework (modified based on [47]).

or issues, such as hydropower development in mountain areas that may pose risks to the quality and quantity of local water resources needed for food production (Box 4).

2. Assess the WEF system and its challenges

In the second step, the selected stakeholders work together with experts to identify and assess in more depth: (a) the relevant components including actors, their assets/investments and their interests; (b) the interactions between them; and (c) the context of the WEF nexus including relevant natural resources, infrastructure, social resources of the communities and institutions (policies, laws, formal or informal arrangements). The mapping of key actors should also include evaluation of their assets/investments (not only in terms of finances), capacities, interests, values and norms, as well as their level of influence or power. Expanded historical-contextual analysis can help to identify drivers of change, resulting stresses and required adaptations, as well as future risks. In the context of mountains, drivers may include climate change, natural hazards, regional imbalances, migration and competing claims in a transboundary or highland–lowland context (Box 5). Special attention should be given to disparities of availability or access between affected social groups with regard to water, energy and food. Assessment of interactions as well as historical, contextual and institutional analysis enable identification of entry points and levers for change, as well as the room for manoeuvre allowed by existing regulatory frameworks [53,54]. Finally, they can reveal potential conflicts and need for negotiations.

BOX 5 Transboundary assessment in Central Asia

Assessing and improving WEF security in a large transboundary basin is complex. UNECE [55] has developed a six-step methodology combining expert preparation and analysis with stakeholder consultation processes, concluding with a nexus dialogue that prepares the ground for identification of synergies across sectors and countries. In the Syr Darya Basin (Kazakhstan, Kyrgyzstan, Tajikistan and Uzbekistan), the assessment methodology was applied to examine different sectors (water, energy, food) separately and in terms of resources, socio-economic key indicators, pressures, drivers and governance resources. The assessment considered linkages between sectors and projected future trends. Subsequently, possible nexus-based solutions and benefits for managing the basin were identified. The resources of the basin – particularly water – are key to the economies and development of all the riparian countries in question. Core challenges include environmental degradation, increasing pressure on common resources and lack of trust and transboundary cooperation among the countries. These challenges must be addressed to implement a nexus approach across the sectors and countries capable of generating significant shared economic benefits, reducing poverty and improving the natural environment [55].

3. Develop scenarios of future WEF systems
In the third step, experts collaborate with the stakeholders to develop plausible scenarios of WEF security in the region, accounting for the situation of different social groups in the mountains and their resilience. The scenarios are based on identified trends, expected investments and consider future demands for water, energy and food based on population growth, socio-economic changes and urbanization as well as climate change impacts and demands for ecosystem services from lowlands. Ideally, the scenarios will provide enough information about possible future challenges in the WEF nexus such that the stakeholders can develop a set of coherent solutions including adapted or new policies, adequate collaboration, incentive mechanisms, technical innovations, infrastructure and more (see Box 6).

BOX 6 Scenarios to assess future impacts of changes in the Alpine water sector

The MontanAqua project assessed water resources and their management in the touristic area of Crans-Montana, Switzerland, in order to develop future strategies for sustainably managing local mountain water resources. In close collaboration with regional stakeholders, the project developed four scenarios, based on different governance directions and expected climate and socio-economic changes, with the potential to sustain water availability for its multiple use by households, the tourism sector, hydropower plants and agriculture in the valley below. Results showed that the current water management system is only partly sustainable, and that socio-economic changes will likely impact water availability more than climate change. Sound water management, including equal access to water and infrastructure, must be combined with institutional reforms, improved data management and transparency to ensure long-term water supplies in the area [56].

These options can be broken down according to different scenarios, and their viability in future pathways can be assessed based on the following guiding questions:

How and to what extent do the proposed solutions …

- increase the efficiency of resource use, maximize synergies (co-benefits) and reduce waste, pollution and ecosystem degradation?
- improve mountain people's access and rights to water, energy and food by enhancing their position and capacities? And are co-benefits fairly distributed in favour of mountain communities?
- maintain or even increase the diversity and depth/redundancy of livelihood assets and ecosystems, strengthening mountain people's and ecosystems' resilience and adaptive capacities?
- help to balance trade-offs and their burdens?

A matrix analysis can be used to evaluate desired future scenarios and relevant solutions according to these criteria. The matrix can facilitate stakeholder negotiation and decisions regarding alternative desirable scenarios based on people's specific needs and contexts. However, the process is not always straightforward – and it may reveal conflicting interests [48].

4. Create an enabling environment to facilitate transformative change
How can we move from a shared vision of a more integrated, resilient and just WEF system to actual transformative change?

Implementing jointly identified solutions requires widespread support and buy-in from other relevant stakeholders – e.g. in the region or the lowlands – and a pragmatic approach enabling stepwise processes as well as a combination of practical interventions, dialogue and advocacy capable of fostering policy-level change. Establishment of a coherent story, based on desired future WEF security and sustainable management of mountain ecosystems, can help to develop an implementation and investment strategy. Next, the story and implementation strategy should be shared in a targeted manner with institutional actors, the public and investors (public and private) who were not involved in the original assessment and visioning process. The aim is to familiarize them and discuss how they can contribute to achieving the envisaged changes and overcoming any obstacles or resistance that may emerge. In this step, it is important to address concerns proactively, particularly in view of likely trade-offs. Targeted sharing of principles that should guide future action can help to integrate them in project cycles [42].

At the policy level, actors who participated in the assessment can play a key role in developing cross-sectoral strategies to guide adaptation and creation of new measures towards the envisioned future in the water, energy and food sectors. These policies and strategies may need to include appropriate financial and incentive mechanisms capable of accelerating transformation of the WEF system. Besides the targeted sharing of the strategy, a stepwise approach to implementation may require capacity-building, with adaptations as necessary based on new insights [57]. Careful monitoring of interventions towards the envisioned future can help to highlight and share achievements, as well as identify barriers and unexpected consequences that must be addressed. Insights from monitoring can also support scaling up of effective approaches [41]. Overall, the development, implementation and monitoring of WEF strategies requires a strong, committed group of institutional actors that works together to enhance WEF security and strengthen people's resilience in rural mountain regions.

→ More efficient WEF systems in mountains and fair distribution of benefits will enable progress towards SDG 2 "Zero hunger", SDG 6 "Clean water and sanitation", SDG 7 "Affordable and clean energy", SDG 13 "Climate action", SDG 15 "Life on land", SDG 12 "Responsible consumption and production" and many more interlinked targets [58].

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