Chapter 8.4.2. Sustainable livelihoods: benefits and challenges for communities living near active volcanoes—PART 8: Resources for sustainable development associated with volcanism

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Sustainable Development Goals (SDGs) 1, 2, 3, 8, 10, 11, 12 and 15.

Abstract

Many people settle near active volcanoes and even return to these regions after disasters occur because of benefits provided by the volcanic terrain. This persistence despite the risks is driven by a range of factors, including historical, economic, lifestyle, social, cultural, and livelihood connections to the environment. While challenges posed by volcanic activity can limit development opportunities for local communities, the essential resources provided by volcanoes can also contribute to a community's ability to cope with risks and recover from disasters. Reducing the risk of living and working on volcanoes while supporting sustainable local livelihoods is crucial for communities living within reach of volcanic hazards. This chapter explores how volcanic environments support local communities by offering resources to four major economic sectors: agriculture, mining, geothermal energy, and tourism. It examines the benefits and obstacles faced by people living near active volcanoes and describes the different strategies these communities use to sustain their livelihoods. The two case studies of populations around Ijen and Fuego volcanoes exemplify the trade-offs and synergies between maintaining livelihoods and managing volcanic risks.

Keywords

sustainable livelihood; volcanic resources; agriculture, mining; geothermal; tourism; livelihood strategies.

Introduction

Approximately 800 million people live within 100 km of the world's ~1400 active volcanoes. In developing countries alone, some 722 million people are potentially exposed to volcanic hazards [1], and this figure is projected to increase in the future due to population growth and urbanization, particularly in Southeast Asia and Central America. Historical ties to land , economic opportunities, lifestyle preferences, social structures and cultural connections to the environment explain why people settle in a volcanically active region and return to it after a volcanic crisis (Box 1).

While volcanoes can bring devastation, their activity also creates valuable resources and conditions that benefit those living in volcanic regions. These include fertile soils for agriculture, mineral deposits [E1], geothermal energy [E2], and access to water [E3]. Additionally, volcanoes are associated with unique landscapes and hold spiritual and sociocultural significance. Achieving sustainable livelihoods in these areas requires communities not only to meet their basic needs and safeguard resources for future generations but also to build capacity to withstand and recover from volcanic shocks.

Strengthening livelihood sustainability is a critical pathway to improving the resilience and overall security of populations inhabiting volcanically active areas. Such efforts are closely aligned with SDGs #1, #2, #3, #8, #10, #11, #12, and #15. The sustainability of livelihoods largely depends on the ability of local residents and workers to survive and thrive during periods of volcanic activity, a capacity shaped, to varying degrees, by both internal (community) and external (e.g., government) support systems. Furthermore, the dynamics of community livelihoods in volcanic regions is not determined solely by impacts of eruptions but also by broader environmental, social, economic, cultural and political factors, such as financial crises or political instability.

However, translating the concept of strengthening livelihood sustainability into practice is challenging as volcanic hazards are highly variable in space and time. A single eruption may generate multiple, shifting threats, such as lava flows, ash falls, gas emissions, pyroclastic flows and surges, lahars, landslides and even tsunamis. This variability makes it difficult for communities to prepare for, respond to, and recover from volcanic events. The intensity of a hazard's impact on communities is further influenced by their vulnerability, which is a complex multidimensional variable that operates across different scales, evolves over time, and is specific to both location and context. The interplay between hazard variability, exposure and vulnerability contributes to the dynamic nature of volcanic risk. Barclay et al. [E4] highlighted the close relationship between poverty, livelihood instability and vulnerability to volcanic hazards.

This chapter explores the economic benefits of volcanic resources emphasized in past versions, while also examining the challenges faced by communities living near active volcanoes. Through a sustainable lens, it discusses the various strategies these communities adopt to sustain their livelihoods. We analyze the benefits and challenges of four key volcano-related economic activities, namely agriculture (pgs. 2 - 5), mining (pgs. 5 - 6), geothermal energy (pgs. 6 - 7) and tourism (pg. 8 - 9). Finally, we discuss a holistic movement towards sustainable livelihoods in the last section (pg. 9 - 12).

Exploring the benefits and challenges of economic activities linked to volcanoes

Agriculture

Benefits

Volcanically active regions in East Africa, Central America, South America, Southeast Asia, and Oceania host communities where agriculture plays a vital role in both the local and regional economy. Farmers capitalize on the high agricultural potential of volcanic soils. Although these soils account for less than 1% of the Earth's land, their use in farming supports at least 10% of the world's population [2]. Most volcanic soils form from volcanic ash deposits (tephra <2 mm) and are typically collocated with Pleistocene and Holocene volcanoes in subduction zones. They are renowned for their remarkable fertility, owing to a set of properties rarely found in soils derived from non-volcanic materials [E5]. Volcanic soils exhibit a low bulk density, excellent water-holding capacity, and a reactive clay fraction (solid material <2 µm). Additionally, they accumulate organic matter efficiently, representing a significant contribution to the global soil organic carbon stock. These characteristics make volcanic soils resistant to drought stress and water erosion, and render them excellent plant-rooting media with favorable tilth. The intermittent deposition of volcanic ash helps maintain these properties over time. Depending on their specific characteristics and on the local climate, volcanic soils serve as substrates for growing a variety of crops, including food (cereals, vegetables, and tubers), forage, and industrial crops (coffee, tea, cocoa, and sugar cane). In Japan, Indonesia, and the Philippines, native crops and rice fields have been cultivated in volcanic soils for over ten centuries (Fig. 1a). Vineyards in southern Italy have flourished in volcanic soils, nurturing Mediterranean culture for hundreds of years. In the United States, Chile, Argentina, Iceland, and New Zealand, volcanic soils are primarily used for grassland farming and the rearing of animals such as dairy cows, cattle, sheep, deer, and horses. Rural residents around volcanoes may also rely heavily on subsistence agriculture, raising small livestock like chickens and rabbits, and cultivating family gardens or plots of maize, rice, cassava, taro, or yam to feed their families. Grasses are also advantageous for nearby communities by supplying animal feed, whether it is for personal or business purposes. While crop and livestock production are the main agricultural subsectors in volcanic terrains, forestry and aquaculture also exploit volcanic environments and provide livelihoods. For example, forestry in southern Alaska and along the coastal regions of the Pacific Northwest of the United States benefits from the superior properties of volcanic ash soils. Meanwhile, lakes occupying volcanic craters and calderas are sometimes utilized for fish farming on both small and commercial scales. In several areas, this activity is a primary source of income for local communities, such as at Lake Taal in the Philippines (Fig. 1b) and Lake Batur, Lake Toba, and Lake Maninjau in Indonesia.

Challenges

The multiple benefits that volcanoes provide to agriculture are coupled with their potential to cause corresponding losses. In the worst-case scenario, the magnitude of an eruption is so severe that entire communities must be evacuated rapidly, leaving behind their animals, harvests, and farm equipment as they flee from heavy ash falls or pyroclastic flows [E6]. Crops are destroyed and farm equipment and infrastructure are heavily damaged. Any surviving livestock will likely be weakened, and will soon starve and die if not kept and fed indoors. Such eruptions lead to farmers suddenly losing their livelihoods, with little hope of recovery in the short term. In the case of less explosive volcanic activity or in areas far from the eruption source, the widespread deposition of tephra is responsible for most impacts. While ash-sized tephra enriches soils, tephra of all sizes can also damage or destroy agricultural assets. The impact of tephra on agricultural assets and communities varies depending on the magnitude and duration of the tephra event, the characteristics of the exposed elements (e.g., types of crop, livestock, buildings, etc.), agricultural practices, and other factors such as the time of the year and occurrence of rain or wind during and after the event. Where grazing livestock continues to feed on pastures, chronic exposure to tephra-contaminated forage and water sources poses various health threats to the animals, often translating into significant production losses. For crops, plants can break under the load of the tephra deposits, while tephra on leaves disrupts photosynthesis [3]. This leads to reduced crop yield and harvest quality, which can persist for a single growing season or extend for several years. Overall, the financial situation of farmers, especially smallholders, facing moderate but recurrent tephra fall can become precarious owing to drastic production losses and the costs incurred in keeping livestock healthy, protecting and restoring crops, and keeping farm equipment and infrastructure operational. Tephra fallout impacts are addressed in detail elsewhere in this volume [E7].

There is much value in quantifying spatial and temporal exposure of food crops to volcanic hazards [4,5]. However, despite the long-recognized severe impacts of tephra fallout on agriculture and the communities that depend on it, the associated risk remains poorly understood. This is partly due to shortcomings in how the vulnerability of agriculture to this hazard has been analyzed. Existing impact data are limited, hindering accurate and site-specific assessment of crop and livestock vulnerability to tephra fall. Typically, impact assessment involves coupling the intensity of the tephra hazard (usually represented by accumulated thickness of tephra deposit, or mass of tephra per unit area of surface) to both asset exposure and fragility functions that quantitatively estimate the probability of that asset or resource's damage state being exceeded as a function of hazard intensity and damage/loss [6]. Vulnerability functions, which quantify the relationship between hazard intensity and resulting damage or production loss, are also used. However, the development of crop-specific fragility/vulnerability functions is nascent, partly due to the complexity of accounting for both crop dynamics (e.g., varying susceptibility across different crop-growth stages) and the spatially evolving characteristics of the tephra hazard. Emerging research is addressing this challenge by developing crop-specific vulnerability functions that consider these dual influences [7]. Even less information is currently available regarding the impacts of tephra on livestock. In this encyclopedia, Donovan et al. [E8] illustrates the dynamic vulnerability in a volcanic environment, whereas Wilson et al. [E9] explains the quantification of damage and vulnerability for volcanic hazards. Two chapters address volcanic risk assessment [E10] and multi-hazard risk assessment in volcanic contexts [E11].

Crop- or livestock-specific fragility/vulnerability) functions alone are unlikely to realistically predict agricultural impacts from tephra. A systems-based approach is needed that evaluates tephra effects on crops and livestock as interacting components of a farm system whose organization and management practices vary across space and time. Tephra fall can also produce effects that extend beyond immediate production losses, disrupting value chains, household economies, and food security. Improved understanding of these cascading effects will support the design of locally tailored strategies to reduce volcano-related risk, including context-specific early warning systems, preparedness planning, and pre- and post-event mitigation measures.

Mitigation measures that can reduce agricultural vulnerability in the face of frequent volcanic activity include: 1) diversifying agricultural practices, 2) planting crops and grasses that more easily shed tephra, 3) producing stores of food for livestock should tephra contaminate their forage, 5) building structures to shelter livestock during eruption or evacuation, 6) advancing harvest schedules before an eruption, and 7) installing agricultural infrastructure like overhead irrigation to hasten the clean-up of tephra fall on seedling leaves. When tephra deposits from an eruption are not too thick (<20-30 cm), farmers often incorporate the tephra into the soil by plowing to facilitate replanting. Additionally, farmers may safeguard livelihoods in times of loss through agricultural activity insurance and communal savings for livestock or crops. Governments can encourage evacuation by establishing livestock evacuation plans and emergency management for communities with cattle husbandry in volcanic regions. In Mt.

Merapi, for example, evacuated residents were ready to face individual danger and return to the villages during the 2010 crisis to continue feeding their animals [8].

Mining

Benefits

Volcanic activity has provided useful raw materials for human use for centuries or even millennia; some of the earliest stone tools were shaped from obsidian more than a million years ago. Residents of present-day communities near volcanoes may rely on mining lava rock, ignimbrite, tephra, or mineral deposits for their daily income. For example, elemental sulfur is primarily deposited from high-temperature magmatic gases discharged from fumarolic vents. In the past, sulfur was manually extracted from active volcanoes in countries such as Indonesia, Chile, Japan, Russia, and New Zealand. This artisanal practice still persists at some locations, such as the Ijen (Box 2 and Fig. 1d) and Welirang volcanoes on Java Island, Indonesia. In tectonic arc settings (e.g., Japan, Indonesia and the Philippines), epithermal ore deposits formed near volcanic vents at shallow depth are mined for metals such as gold, silver, copper, lead and zinc [E1, E12]. Volcanic ash, the most widespread eruption product, has properties that make it well suited to construction, including a chemical composition and amorphous atomic structure that make it well suited for use as a binder in cement production. Beginning with the Romans, ash has been used as raw material for manufacturing products like cement, blocks, and bricks. Crushed lava stones are also used to produce these materials in the Democratic Republic of Congo (DRC) and Rwanda. Cinder cones worldwide are also quarried for construction materials and agricultural use. Pumice is utilized as an abrasive cleaner and can be transformed into lightweight construction blocks with outstanding insulation value. Blocks cut from lava flows and ignimbrites are used to construct buildings, walls, and roads. Cities built on and constructed using tuff include Rome, Naples, and Orvieto in Italy, Arequipa in Peru, Morelia in Mexico, as well as Frankfurt and Hamburg in Germany.

Alongside material resources, the mining sector also provides incomes to workers, manufacturers, and sculptors. Around Mt. Merapi, Indonesia (Fig. 1c), mining sites become economic activity centers where street vendors and service providers (taxi bikes) from neighboring villages or regions sell their products to mine workers. Mining activities offer financial benefits to local, regional, and national governments through taxes, fees, and dividends from state-owned mining companies, but informal mining is also conducted in many regions. For example, alongside industrial-scale mining operations in a lahar channel of Fuego volcano in Guatemala, residents collect blocks that they sell to vendors, who in turn sell those blocks for construction in the cities. In addition to providing economic opportunities, mining activities may reduce lahar risk by removing material from channels, therefore increasing their volume.

Challenges

Mining in volcanically active regions comes with several challenges. Volcanic eruption can inflict significant financial costs on the mining sector. Pyroclastic flows and lahars can destroy quarry equipment, while ash fall and gas emissions can damage the mechanical, electrical, and electronic components of machines. Fatalities may occur not only from volcanic activity but also from collapses during excavation. Quarrying and using volcanic materials also pose significant health risks due to occupational or chronic exposure to respirable particles, which sometimes contain crystalline silica which causes silicosis or other lung diseases (prolonged exposure). Sulfur miners in active craters are repeatedly exposed to toxic volcanic fumes (Box

2). Mining activities in volcanic areas contribute to various environmental issues, including changes in local water availability and quality, disruption of river systems, and damage to infrastructure such as dams, bridges, and evacuation routes. Volcanic material extraction, like other forms of mining, can also cause social, economic, and political problems. Conflicts can arise between villages when overloaded trucks damage primary access roads. Additionally, confusion and legal disputes over mining permits across multiple scales and borders are common. A controversy arose in 2017 during a volcanic crisis at Agung volcano on Bali Island, Indonesia, when the local government established an exclusion zone and mandated a stop to all activity within it. Mining operations persisted despite the risks, in response to a demand for gravel and sand for road and building construction for a crucial international economic conference in late 2018. As a compromise, radio communication between the miners and local authorities was improved to make mitigation and evacuation processes easier. Artisanal and small-scale illegal mining can also lead to disputes between nearby communities.

Mining frequently occurs within lahar channels, some of which are active seasonally regardless of eruptive activity. Soon after the 2010 eruption of Mt. Merapi, a community-based system of river condition monitoring emerged in every watershed of the volcano. It involves skilled volunteers (miners or local residents) who had been taught collaboratively by the authorities and scientists to identify the circumstances that can lead to lahars (i.e., pertinent information about conditions in the upper part of the watershed observable from local lookout stations). This self-organized system informs people working within lahar channels when to get to high ground and benefit miners as well as people living in the area and travelling across the channels. During Guatemala's rainy season, heavy equipment at Fuego volcano is stored close to evacuation routes rather than within the lahar channel, work ends by early afternoon when the rains typically start, and workers are similarly attentive to news of rainfall anywhere within the watershed they are working in.

Establishing designated evacuation routes for mining vehicles, setting limits on truck and miner presence in hazard-prone areas when conditions for those hazards are favorable, implementing community-based early warning systems, and supporting use of personal protective equipment are all measures that could reduce risk for people working to mine materials from volcanic areas.

Geothermal energy

Benefits

Many of the world's geothermal systems are powered by the same magmas that can trigger destructive eruptions. The hottest waters circulating in these systems provide a source of electric power [E2]. Geothermal energy projects are rapidly expanding in volcanic regions such as Indonesia, the Philippines, and Kenya, as companies position themselves to take advantage of the renewable energy shift. Meanwhile, cooler but still warm waters are utilized for diverse purposes, such as aquaculture, growing fruits and vegetables, drying foodstuffs, health and recreation, and heating residential and commercial buildings. In water-scarce environments, geothermal springs and steam vents can serve as a primary water supply, as with nomadic pastoralists living near Dabbahu volcano in the Danakil desert of Ethiopia as well as at Alid volcano in Eritrea. Geothermal systems are also associated with hot springs, geysers, and other hydrothermal features that attract tourists, generating substantial revenues in countries like Japan, Iceland (Fig. 1e and 1f), New Zealand, and the USA.

Local residents may be employed as skilled or unskilled workers in various stages of geothermal projects, from exploration to extraction. The indirect economic impact of the geothermal industry also creates diverse job opportunities for local communities, such as lodging, housing, transportation, goods, and handicraft/souvenir sales. Communities may also benefit through access to geothermal energy and direct-use applications utilizing heat, steam, or hot water. In Iceland and Kenya, for example, communities utilize the heat from hydrothermal sources in greenhouses and in drying crops.

Challenges

Harnessing heat from the Earth's interior poses several environmental and social issues. Drilling wells for geothermal energy can contaminate local water resources, forcing communities to obtain household water from distant springs or private suppliers, thus jeopardizing the economic stability of the poorest residents who cannot afford the additional costs. Depending on the technology used, geothermal plants can emit gaseous pollutants, primarily hydrogen sulfide and carbon dioxide, with methane and ammonia occurring in lesser abundances. Hydrogen sulfide, known for its distinctive "rotten egg" smell, can reduce air quality and cause various health impairments. Although rare, the accidental release of poisonous concentrations of hydrogen sulfide from a geothermal plant can be fatal. Even natural geothermal emissions regularly result in a handful of deaths each year at seeps and vents around the world, such as the USA, Japan, Indonesia, DRC and many others. A chapter on impacts of volcanic gases is presented in this encyclopedia [E13].

Geothermal development requires infrastructure and dedicated use of land; indigenous communities have sometimes been evicted from their ancestral land, pushing them into poverty as they face the loss of their previous livelihoods in the new environment. Relocating communities can also be a consequence of noise and air pollution from the geothermal plant. While the geothermal company may be responsible for ensuring that displaced individuals are not worse off than before, the whole process can be marred by controversy and a lack of transparency. Moreover, ensuring that the community benefits from employment at the geothermal plant is challenging, as the required skills are often not available locally. Additionally, community development from opportunities presented by the plant may be hindered by interclan rivalries. Undoubtedly, the livelihood challenges associated with geothermal operations are deeply intertwined with issues of social approval and community participation. Involving the local communities from the start of the development process is a key strategy for geothermal companies to gain acceptance and implement sustainable business practices

Finally, individuals working at geothermal sites could benefit from targeted safety measures. For instance, carbon dioxide detectors have been installed on the Dieng Plateau, Java, Indonesia to enable early hazard detection and support timely responses that effectively reduce risk. The close involvement of local communities in the planning and decision-making stages of geothermal resource development is beneficial for both the company and local communities in raising awareness of disaster risk mitigation and crucial to ensuring the socioeconomic benefits of the geothermal resource are shared between the private sector and the local communities.

Tourism

Benefits

Volcanoes and the landscapes they create are major tourist attractions and an important source of income [E14]. Even eruptions can be a consumer item, as seen in Iceland, Italy (Fig. 1g), Guatemala, Ecuador, Vanuatu, and Hawai'i. Volcano tourism boosts the regional economy by generating employment opportunities in various sectors such as hospitality, transportation, retail, recreation, and handicrafts. It also promotes the development of infrastructure and public services to accommodate tourists, contributing to the socio-economic development of local communities. Tourist demand encourages the involvement of local communities in tourism management, helping preserve cultural heritage, traditions, and natural landscape. For example, community-based tourism emerged after the 2010 eruption of Mt. Merapi, which left many residents without homes or jobs. Such a community-based approach enhanced democratic processes at the local level and enabled individuals, including women and youth, to benefit economically. Women and young people contributed to participatory actions and planning gatherings to examine potential tourism-related activities, their current resources and constraints, and developing new ways to make a living (e.g., food stall workers, off-road tour crew, etc.). Additionally, tourism benefits communities by enhancing awareness and appreciation of local cultures and history among both tourists and residents. In many cases, residents also learn skills such as speaking an additional language that increase their livelihood opportunities. After the Pinatubo eruption in 1991, organized tours such as hikes to the summit crater developed over time, run by local communities (Fig. 1h). Community-based volcano tourism can also be supported more formally through larger sustainable development frameworks. For example, sustainable, community-centered tourism to Nyiragongo volcano has been promoted through the Virunga Massif Sustainable Tourism Development Plan [9] and subsequently the Greater Virunga Transboundary Project [10]. However, regional political instability has affected these plans and exemplifies some challenges of volcano tourism.

Challenges

Volcano tourism presents several livelihood challenges for local communities despite its economic benefits. One major issue is an overreliance on tourism, making communities vulnerable to economic downturns caused by fluctuations in tourist numbers due to a volcanic eruption, global economic conditions, or political instability [10]. The commercialization of local culture for tourism can diminish its authenticity and value to that community, while the development of tourism infrastructure can displace local populations, disrupting traditional livelihoods. Increased demand for infrastructure and public services can also strain local resources, leading to difficulties in maintaining essential services such as roads, waste management, and water supply. Economic inequality is another issue, as the benefits of tourism are often unevenly distributed, with larger businesses and external investors reaping most rewards, leaving local small businesses and workers with limited gains. Many tourism-related jobs are low-paying and lack job security, leading to economic instability for workers. Adventure tourism on active volcanoes is rapidly expanding but can risk the lives of guides and tourists, many of whom may be unaware of the dangers posed by the volcano. Challenges arise from managing risk with a visiting population with varying levels of risk knowledge, perception, and acceptance. Erfurt [11] explores these challenges across several frequently visited volcanoes, finding barriers such as tourists not proactively informing themselves of volcanic risk (Katla volcano, Iceland), or overestimating their own ability with fatal consequences (Yellowstone National Park). Language barriers can also lead to miscommunication and confusion for foreign tourists, who become linguistic minorities during a volcanic crisis [12]. Moreover, regulating tourist access to active volcanoes can be challenging when multiple stakeholders are involved in volcanic risk management. Ineffective communication between them can result in tragic outcomes, as evidenced by the death of 23 mountaineers during the 2023 Marapi eruption in Sumatra. Volcanoes such as Tangkuban Perahu in Indonesia and San Salvador in El Salvador have lively markets at their summits where numerous individuals work in different shops. If unexpected volcanic activity happens during busy times like weekends and holidays, it would be difficult to handle large-scale evacuations, and long-term evacuations or exclusion zones due to unrest are often opposed by businesses who are reluctant to shut down for an extended duration. Business managers and local leaders may also be reluctant to share educational materials in quiescence or raise alert levels in crisis because of potential economic impacts if visitors become alarmed.

To mitigate volcano-related risks within the tourism sector, collaboration among government entities, scientists, and local communities is essential. Strategies may include developing tourist activities that do not require entering risk zones and creating experiences that remain rewarding regardless of volcanic activity. Following the reawakening of Tungurahua volcano, Ecuador, in 1999, guide-led ascents up the volcano were replaced with other adventure activities such as nighttime volcano-watching tours, bungee jumping, and bike touring. Regulation of access to hazardous areas may also minimize risk (e.g., Mauna Loa and Kīlauea, USA; Yellowstone, USA; Mayon, Philippines). Beyond this, education and outreach campaigns for volcanic hazards and risk awareness, including clear signage, may benefit both the business sector and visitors (e.g., Poás, Costa Rica).

Towards Sustainable Livelihood Outcomes in Volcanic Settings

Community livelihoods in volcanic regions are complex, dynamic, and multidimensional. The diverse spatiotemporal dynamics of volcanic hazards mean that a single eruption can have multiple impacts on people and their livelihoods, on multiple time scales. Immediate impacts may include loss of life and infrastructure. Further economic impacts may result not only from loss of crops, livestock, and arable land, as described above, but also from interruptions to transportation networks, businesses, banks, and utilities such as power, water, sanitation, and communication services. Negative health and wellbeing impacts may result from contaminated air and water, short- and long-term displacement, and disruption of social support networks.

To cope with these challenges, communities near active volcanoes adopt a variety of livelihood strategies. The livelihood strategies of these communities are shaped by factors such as awareness of hazards and risks, perceived consequences, willingness to take risks, ownership of resources and assets, and the degree of vulnerability at the individual, household, and/or community level [13], as well as the level and success of support from higher levels of government and non-governmental organizations. When volcanoes are dormant, some individuals intensify or expand their assets and resources (intensification and extensification strategies). In contrast, during volcanic unrest or eruption, people may sell assets (such as livestock, jewelry, or crops) as a survival strategy, as seen in communities near Tungurahua and Mt. Merapi. Others diversify their income by taking on multiple jobs. Migration, both temporary and permanent (voluntary or through planned resettlement), is another strategy following a major eruption. In some cases, families may choose to live in separate locations, maintaining their former residence near the volcano while establishing a new one in a safer area, and commute on a daily or weekly basis. These livelihood strategies aim to improve economic sustainability (such as increased incomes and savings) and enhance well-being (including better health, security, access to services, self-esteem, and social inclusion). Most importantly, they help reduce vulnerability and increase the capacity to cope with shocks or changes. Measures taken before, during, and after a destructive event can improve a community's ability to absorb and recover from these shocks. Effective strategies enhance resilience of people whose livelihoods are tied to volcanic resources [E15].

Pre-volcanic crisis

While exclusion zones to prevent development in hazard-prone areas may be the most effective risk reduction strategy, this is often not feasible because of already-established populations, lack of political will, economic pressures, and/or populations who prefer to manage the risk in situ. Still, planning the location of key infrastructure can reduce loss of resources to volcanic hazards. Reducing loss of life requires effective warning systems for evacuation and closures [E16]. Warning systems must be established well before an event to socialize the system and ensure it serves the target populations. Planning for and practicing evacuations prepares everyone involved for temporary relocations. Establishing a livestock evacuation plan and emergency management strategies for communities engaged in cattle husbandry can encourage evacuation in addition to safeguarding this livelihood resource. To prepare for further disruptions, governments, communities, and households can safeguard assets, secure backup resources, and diversify income sources to prevent complete reliance on a single economic activity. Adaptability is key to preserving livelihoods; this involves planning for potential disasters, adjusting farming and other place-based practices, and fostering social cohesion within the community. Co-creating plans and establishing resources between officials and communities is essential for ensuring strategies are suited to community needs and capabilities.

During volcanic crisis

During a volcanic crisis, evacuation separates people from their place-based livelihood resources and communities, often on short notice and for an indeterminate length of time. Maintaining livelihoods throughout the evacuation period is as crucial as the evacuation itself. Loss of income and also purpose can motivate evacuees to return to homes and land despite risks. For example, many of the nearly 400,000 people who evacuated from Mt. Merapi area during unrest and eruption in 2010 demonstrated a willingness to face personal risks and return to their villages in order to care for their crops and livestock [8]. In the Mayon Volcano eruption in 2014, some evacuees returned to evacuated zones during the day to tend or harvest their crops, or to salvage what remained [14]. Fear of property loss motivates household or community representatives to stay behind during an evacuation to protect assets, as documented at, for example, Nyiragongo, DRC [15], and Fuego, Guatemala [16].

In evacuation camps, a sense of purpose and livelihoods can be supported by providing a range of activities and work programs, such as training in food preparation, brick making, and other income-generating activities. Ensuring that people can maintain their daily income and sense of purpose in the midst of a crisis is vital, regardless of personal or community savings and external support. Residents who have lost their homes and livelihoods may switch jobs within their home region, such as farmers temporarily becoming sand miners after the 2010 Mt. Merapi eruption, or may migrate to other regions with different livelihood opportunities.

Post volcanic crisis

Rebuilding and improving livelihoods is crucial in the post-volcanic crisis phase. This phase includes two main components: restoration, in which people receive and use various aids and resources to rebuild their livelihoods, and adaptation, in which they explore alternative living options and new income-generating activities, or alter previous livelihood approaches to fit their new circumstances (e.g., change crops or the focus of tourism). Individuals may either return to their villages or relocate to safer areas outside the hazardous zone, depending on factors such as environmental conditions and regional political decisions. Despite potential hazards, individuals may return to their previous homes and livelihoods due to unfavorable relocation conditions, a lack of relocation options, or significant investments in the land, even if the area had been directly impacted by deadly hazards [17]. To encourage relocation, planning processes must include local communities to ensure community needs are met. For example, the active participation of local residents in the Community-Based Settlement Rehabilitation and Reconstruction Project (REKOMPAK) after the 2010 eruption of Mt. Merapi not only enhanced their awareness of hazards and risks but also improved their living conditions over what they experienced before the eruption [18]. A comprehensive chapter on engaging communities at risk, describing challenges and solutions, is presented in Part 7 Chapter 3.2 of this encyclopedia [E17].

Prioritizing livelihood support in development and risk reduction efforts

Living near active volcanoes often reflects a willingness to accept the associated risks. However, people with the assets and capacity to handle environmental shocks are less vulnerable, leading to more sustainable livelihoods [19]. Maintaining a sustainable livelihood enables individuals, households, and communities to meet their basic needs, survive shocks, and preserve assets for future generations. Integrating disaster risk reduction and management into all development pathways is essential. Enhancing community capacity for disaster risk reduction needs not only a bottom-up approach but also support from the government officials (top-down) [20]. Investing in disaster-risk-resilient economic activities safeguards community livelihoods, reduces disaster response costs, and preserves critical infrastructure. Understanding the complexity of disasters and incorporating livelihood perspectives into risk reduction measures further enable communities to manage risks effectively.

Conclusions

Many people live near active volcanoes due to the resources these environments provide, which underpin livelihoods through physical, financial, natural, and social capital. These resources contribute to the enrichment and preservation of cultural practices and allow for livelihood diversification. However, living close to a volcano brings many challenges—whether the volcano is active or dormant. These challenges can arise in both the short and long term and are exacerbated by the complex hazards linked to volcanic activity. The socio-economic and political contexts of the volcano's situation add layers of complexity to these issues. When eruptions occur, they can severely disrupt both lives and livelihoods, making the protection of these livelihoods a critical component of crisis management, often overshadowed by immediate actions like mass evacuations.

People's responses to volcanic eruptions, including their strategies to restore livelihoods and create new ones, are varied and context-dependent - much like the eruptions themselves. To ensure sustainable livelihoods in areas with active volcanoes, strategies should promote collaboration among various stakeholders and enhance both well-being and economic advantages. The impacts of an eruption unfold over a variety of timescales; thus, a comprehensive approach to sustainable livelihoods must encompass the entire eruptive cycle.

This chapter provides a snapshot of several sustainable livelihoods pursued around active volcanoes. Future areas of work are, among others, analyzing the effects of volcanic eruptions on human activities and livelihoods, how societies respond to eruptions, and the utilization of volcanic resources to address challenges and find solutions. Since livelihoods and their vulnerabilities are so context-specific, we need more focused studies of volcanic livelihoods in specific physical (various eruption types and the magnitude, frequency, intensity, and duration of hazards) and social (cultural, economic, political, environmental, and geographical settings) contexts. The findings from these studies have the potential to contribute to existing knowledge and offer solutions to challenges faced by communities on volcanoes. The growing global population, coupled with swift socioeconomic change, is intensifying the demands and challenges faced by the livelihoods outlined in this context. To strengthen communities' ability to withstand shocks of volcanic eruptions and to promote improved well-being and health in alignment with the SDGs in regions adjacent to active volcanoes, it is essential to engage in collaborative initiatives aimed at deepening our understanding of the various dimensions of sustainable livelihoods. Furthermore, it is crucial to foster cooperation that integrates these diverse aspects effectively. Achieving these objectives necessitates the involvement of a wide range of persons and perspectives.

Box 1: Land and livelihoods at Fuego volcano

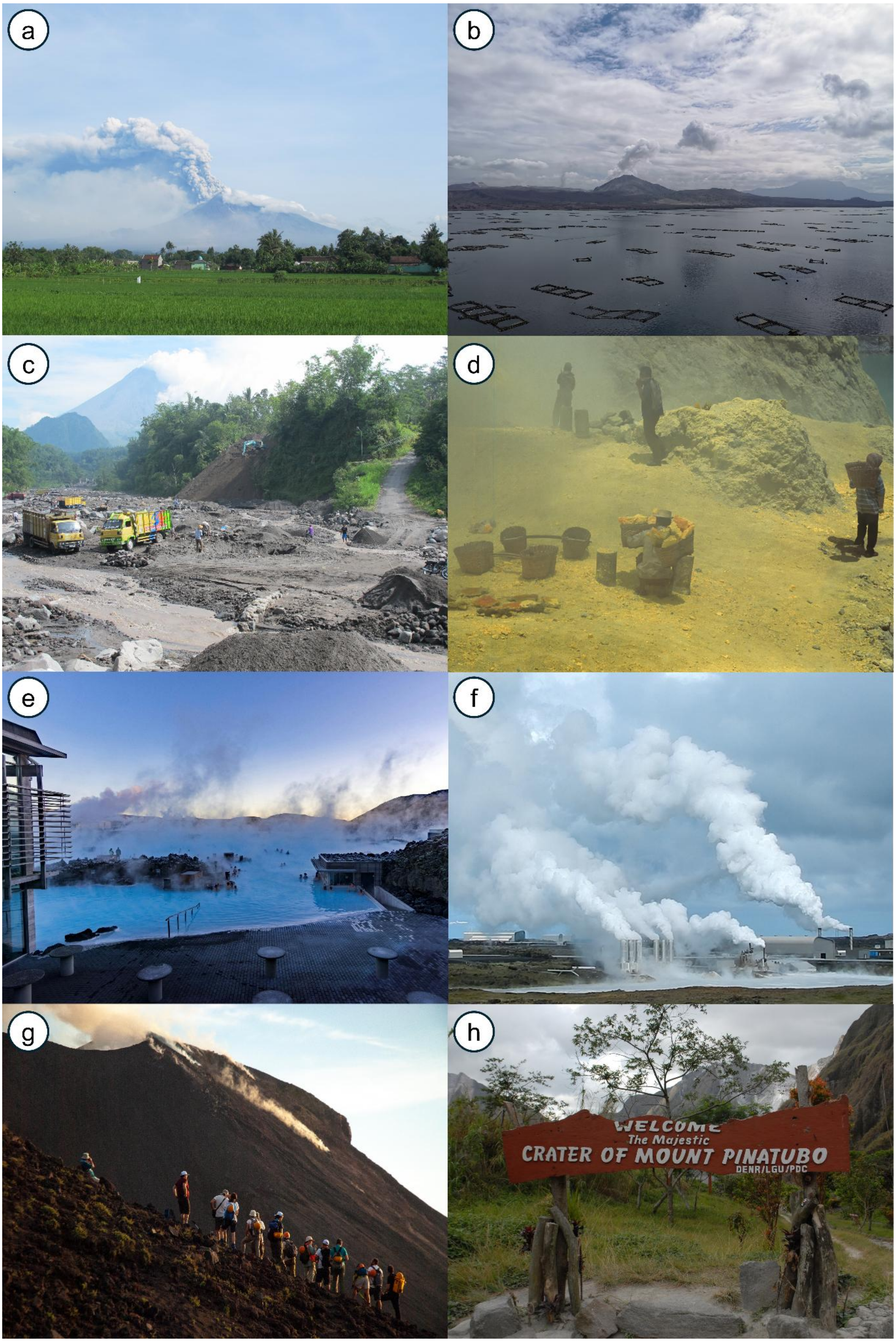
People come to live on volcanoes for diverse reasons. Like many stratovolcanoes, Fuego volcano (Guatemala) provides rich livelihood and lifestyle opportunities owing to its fertile soils, ample water resources, temperate climate, abundant and accessible sand and rock, and awe-inspiring views. Current settlements around the volcano are tied to these local resources but have been driven in large part by national-level political decisions. Changes in land ownership laws in the mid-1800s to allow substantial land purchases attracted large-scale investors, many from overseas, who established plantations of labor-intensive crops like coffee and sugar cane on Fuego and other volcanoes. Workers migrated to these new plantation towns, many of which became independent communities in the 20th century. Residents owned small land plots that they then bequeathed to their children, sustaining and even growing these communities. In the late 1990s, as a decades-long civil war came to a close, communities of indigenous refugees who had fled came to own larger estates communally as part of peace negotiations. Still others move to the flanks of Fuego because their spouses are from there, because land is more affordable than other places, or even because they are moving into a development of low-density luxury homes.

Living on this volcano can be complicated. Fuego has been active since long before current communities settled on its slopes. Its frequent activity threatens the over 100,000 residents living and working in areas potentially exposed to its hazards, which range from widespread tephra fall to more localized but deadly pyroclastic flows and lahars. These hazards have repeatedly damaged agricultural land, homes, and roads over the past century. Most tragically, a series of particularly large pyroclastic flows in 2018 destroyed a resort, a major bridge, and the community of San Miguel Los Lotes in minutes, resulting in hundreds of fatalities. Escalation from its persistent background unrest to larger eruptions can occur over hours, forcing crucial decisions about evacuations on short timescales. Many residents around Fuego live on rough, rural dirt roads that cross multiple lahar-prone channels without bridges, a consistent challenge during the rainy season. Many also lack their own transportation and require help during evacuations. Can Fuego's population live and work safely and sustainably with this level of volcanic activity?

While some residents would like to relocate to safer ground, moving is complicated. Globally, government programs that provide housing outside high-hazard zones often fail to consider social, cultural, and economic contexts, particularly when people's livelihoods depend on the land and land is not provided with the housing relocation. Some Fuego residents provided with houses in a nearby city after the 2018 eruption have moved back to their communities on the volcano's flanks; they feel the city is unsafe because of crime, and their rural communities provide what cities cannot when work is scarce. Families with larger plots on the volcano cultivate coffee, tilapia, or maxán, the leaf used regionally for wrapping tamales, to sell at urban markets. Residents use smaller landholdings to grow maize for tortillas, raise small livestock like chickens, and maintain gardens that feed their families. Some residents say "Lo único es el volcán" - the only thing about living here is the volcano. Everything else is good. Others say they miss the sound of Fuego's explosions when it's quiet.

Box 2: Resources and livelihoods near Ijen Volcano

Ijen (2,386 m above sea level) is an active stratovolcano located within the Ijen caldera in eastern Java, Indonesia. It hosts the largest hyper-acidic crater lake on Earth and is the center of vigorous gas emissions and a non-mechanical sulfur mine (case study box of Shinohara et al. describes the magmatic-hydrothermal system and its acid alteration formation [E5]). Sulfur, a valuable commodity, is used in matches and to bleach sugar, among other applications. Sulfur extraction at Ijen has been operated by a local company since the late 1960s. The workforce includes miners, porters, and factory workers. Miners work within the crater, managing a pipe network connected to the volcano's high-temperature fumarole vents to enhance sulfur production (Fig. 1d). Porters, who make up most of the labor, carry raw sulfur chunks up the crater and down to the base camp. They transport loads of up to 90–100 kg for the strongest individuals. Porters are independent workers, paid based on the amount of sulfur they deliver. Working for the sulfur mine requires no formal education and is one of the highest-paid jobs in the region; sulfur workers are well-respected in their communities. However, it involves significant risks. The work in the summit crater is extremely arduous, and daily exposure to toxic volcanic fumes poses a serious health risk. Many porters cannot afford protective equipment, such as gas masks, or choose to forgo them because it hinders their work. The hyper-acidic crater lake is also a threat, capable of suddenly bursting meter-sized bubbles of noxious gases. Over the past two decades, tourism in the Ijen area has expanded significantly, sparked by media reports showcasing the dramatic and photogenic nature of the Ijen crater and its sulfur workers. This growth intensified when a rare feature appeared: a significant temperature increase in the fumarolic field caused molten sulfur discharging from the gas pipes to combust, creating blue, lava-like rivers of light. This stunning phenomenon quickly made the news, attracting more visitors to the site. Today, Ijen Crater is a must-see destination, with more than a thousand national and international tourists climbing the volcano daily during the high season. The tourism sector has capitalized on this situation, developing additional activities in the area, such as agrotourism (civet coffee plantations on the Ijen plateau and honey production), as well as sporting and cultural events. This has fostered the development of the service (tour guides, porters, and guesthouses) and commercial sectors (sales of food, drink, and souvenirs), creating economic opportunities for the locals. The sulfur workers themselves, especially the younger ones, are now diversifying their revenue by becoming tour guides and homestay providers. In doing so, they face new challenges as they must develop their communication (for example, learning English) and management skills. The additional income improves their families' economic well-being, allowing their children to have access to quality education, a key component of sustainable development. In 2023, UNESCO designated Ijen volcano and its surroundings as a Global Geopark, recognizing the spectacular volcanic scenery, diversity of geological structures, and cultural heritage offered by this region.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CRATER OF MOUNT PINATUBO
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Figure 1. Various livelihoods in volcanic environments. (a) Rice-growing area on the fertile lower flanks of Mt. Merapi (Credit: E.T.W. Mei); (b) Aquaculture in Taal Lake (Credit: PHIVOLCS photo archive); (c) Sand and block mining in the Boyong River filled by pyroclastic flow deposits from Mt. Merapi (Credit: E.T.W. Mei); (d) Artisanal sulfur mining in Ijen volcano's crater (Credit: P. Delmelle); (e) The Blue Lagoon is a highly popular man-made geothermal spa in Iceland (Credit: R. Benjamin on unsplash.com). Its operation has been repeatedly threatened by the recent volcanic activity on the Reyjkanes Peninsula; (f) The Reykjanes power station in Iceland (Credit: P. Delmelle); (g) A trekking expedition on the active volcano of Stromboli (Credit: B.A. Bartel); (h) The crater of Mt. Pinatubo, which formed after the 1991 eruption, is now a popular tourist destination (Credit: P. Delmelle).

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