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GUIDING THE FUTURE OF LINEAR INFRASTRUCTURE DEVELOPMENT IN SNOW LEOPARD LANDSCAPES

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SUGGESTED CITATION

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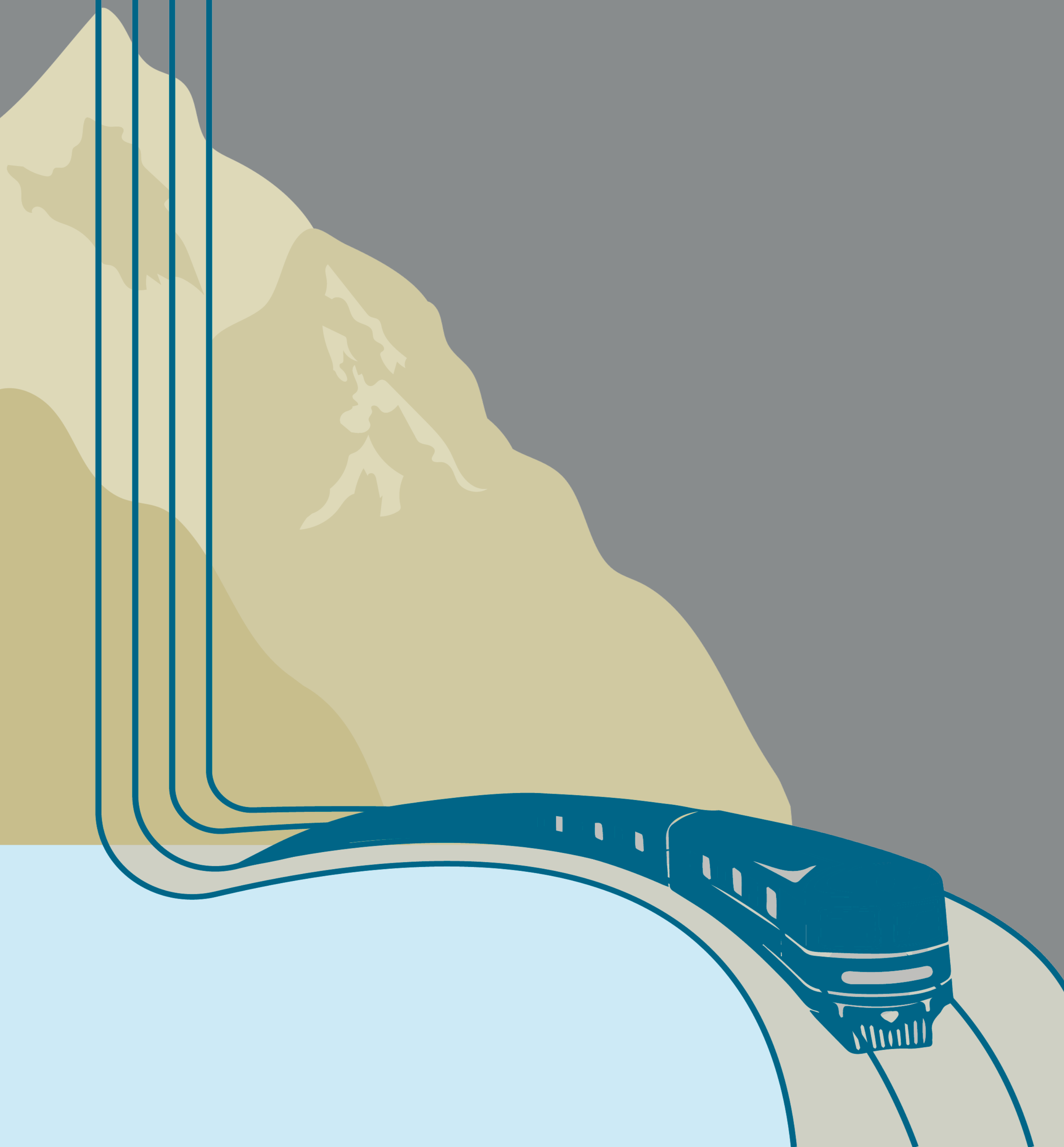
CONTENTS

EXECUTIVE SUMMARY

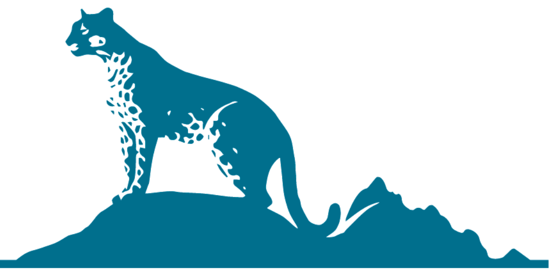
Linear infrastructure (LI)—such as roads, railways, power transmission lines, canals, pipelines, and border security and other forms of fencing—is necessary to connect people and services and support communities. However, it also threatens snow leopards and the high-mountain ecosystems they inhabit. Concerns include habitat fragmentation, illegal hunting and trade, wildlife-vehicle collisions, and other forms of human-wildlife conflict. Feral dogs, invasive species, pathogens, and pollutants further disrupt the environment and drive biodiversity loss. Climate change worsens these threats, while LI itself exacerbates climate change.

This initial guidance recommends how governments in snow leopard range countries, civil society, and local communities can use avoidance and mitigation techniques to address these threats. It covers the infrastructure life cycle and follows the mitigation hierarchy—a framework to avoid, manage, and reduce negative environmental impacts. The guidance offers solutions to protect biodiversity and ecosystem health throughout the infrastructure project's life cycle, but it also revealed gaps in our knowledge that we propose addressing in future work. Implementing the measures defined here and working to address knowledge gaps will reduce risks to snow leopards and their prey, support human communities living in these ranges, preserve the ecosystem services snow leopards depend on, and lower the risk of infrastructure failure.

INTRODUCTION



The purpose of this document is to identify gaps, review existing knowledge, and provide initial guidance in developing linear infrastructure sustainably in the culturally rich and geologically complex ecosystems inhabited by snow leopards.



This guidance was developed for the Global Snow Leopard and Ecosystem Protection Program (GSLEP). This unique platform unites the governments of the 12 snow leopard range countries through an intergovernmental conservation alliance (Sharma et al. 2024). A steering committee comprising environment ministers from these countries oversees GSLEP's operations, with support from various nongovernmental and multilateral organizations. Over the past 10 years, GSLEP has played a pivotal role in mainstreaming snow leopard conservation through high-level political statements, declarations, and resolutions, and supporting their implementation.

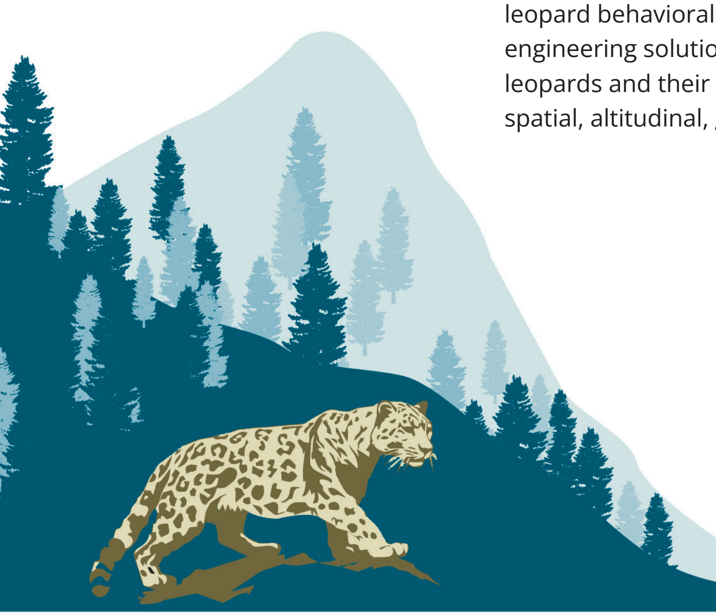
At GSLEP's Seventh Steering Committee Meeting in Bishkek, Kyrgyz Republic, in October 2022, members endorsed the Bishkek Resolution stating that GSLEP and its supporting organizations "[r]ecognize the multipronged threats that LI poses to snow leopard ecosystems and advise the GSLEP Secretariat to set up a dedicated working group to develop policy guidelines and strategy to help mitigate such threats." In July 2023, a working group of GSLEP members and snow leopard and LI experts was formed for this purpose.

As its first action at the Eighth Steering Committee Meeting of GSLEP in Uzbekistan in February 2024, the working group produced a policy advisory titled *Linear Infrastructure in Snow Leopard Landscapes.* This document details the impacts of existing and rapidly expanding LI on snow leopards. During the same meeting, GSLEP member countries endorsed the Samarkand Resolution stating that GSLEP agrees "to develop and adopt best practices and policies in linear and other infrastructure development for safeguarding the fragile snow leopard habitats and corridors."

This guidance is designed to help GSLEP fulfill its pledge by providing policy and management recommendations to mitigate LI's threats to snow leopards and their fragile high-elevation ecosystems. It promotes appropriate planning and the use of avoidance and mitigation measures in infrastructure development to minimize impacts on snow leopards and their habitats.

This guidance also aims to increase awareness and recognition that all development, including LI, impacts wildlife, especially snow leopards because of their long-distance ranging behavior and reliance on prey with specialized habitat needs. In addition, it contributes to the Convention on the Conservation of Migratory Species of Wild Animals (CMS) implementation of Resolution 7.2 Impact Assessment and Migratory Species and Decision 14.202 Infrastructure Development and Migratory Species, adopted by the 14th Meeting of the CMS Conference of the Parties. This includes the new Central Asian Mammals Initiative Work Programme 2026–2031 adopted by the Third Range State Meeting in June 2025, specifically supporting identified activities such as in sections on legislation and ecological connectivity.

This foundational document is the first in a proposed series of publications identifying the challenges and opportunities in the development of linear infrastructure in snow leopard habitat. The purpose of this document is to identify gaps, review existing knowledge, and provide initial guidance in developing linear infrastructure sustainably in the culturally rich and geologically complex ecosystems inhabited by snow leopards. We propose future workshops to develop specific resources to address the following gaps: 1) projections for LI development of all forms in snow leopard habitats, including what is expected to be built and where; 2) identification of the mitigation solutions snow leopards will likely use, based on snow leopard behavioral ecologist experience and expertise; and 3) specific engineering solutions that account for likely use preferences of snow leopards and their prey and include potential adjustments for specific spatial, altitudinal, geological, geopolitical, and cultural contexts.



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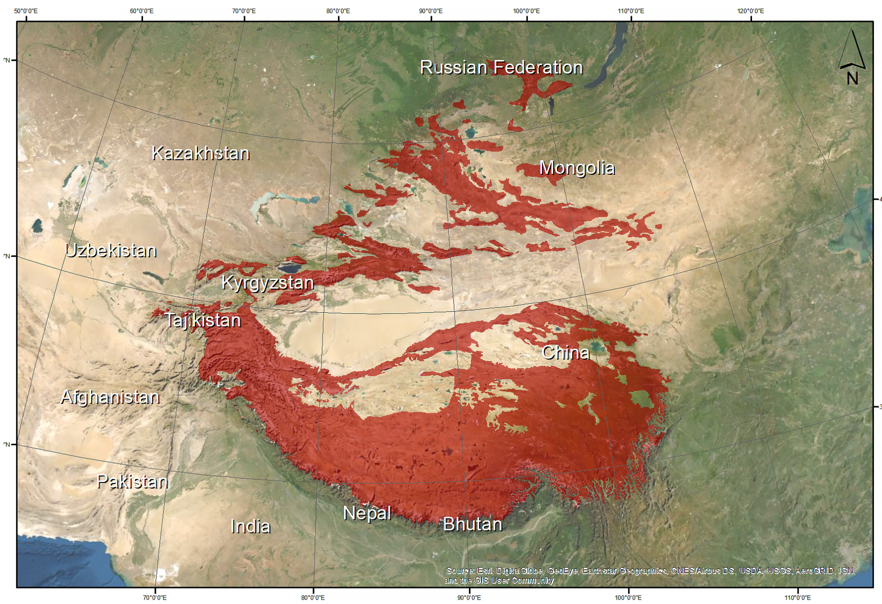


FIGURE 1.
The snow leopard range (red) across 12 countries in Asia.
(Source: Snow Leopard Trust)

Guidance Goals

Although primarily developed for GSLEP and the governments of the 12 snow leopard range countries (Figure 1), this guidance may prove useful to a much wider audience, including conservation practitioners, road and highway development agencies, policymakers, academia, the private sector (including infrastructure designers and builders), financial institutions, planning agencies, civil society organizations, and local community members who are the primary stakeholders in any LI development project in snow leopard habitat. The guidance aims to raise awareness of the impacts of LI development across snow leopard landscapes and guide all stages of the infrastructure life cycle to reduce harm to snow leopards.

The ecology and behavior of snow leopards is not entirely known. Even so, scientists and conservationists are still learning how to apply LI safeguards to snow leopard habitats. This guidance supports that effort by recommending ways to address conservation challenges during LI construction or upgrades and empowering informed decision-making.

Alignment and safeguard measures for snow leopards are undefined and untested. For example, there is no information on overpass or underpass designs that snow leopards and sympatric species will use. Snow leopards live in complex habitats that pose engineering challenges, including avalanches, landslides, freeze-thaw action, earthquakes, and extremely steep slopes in mountainous terrain. These challenges make it essential to involve a range of experts in the design process.

FUTURE RESEARCH:
Overpasses and underpasses have neither been designed nor built for snow leopards, their prey, or associated species. Gathering opinions from infrastructure, transportation, and civil engineering experts, as well as road ecologists, will help to develop appropriate designs to maintain landscape connectivity.

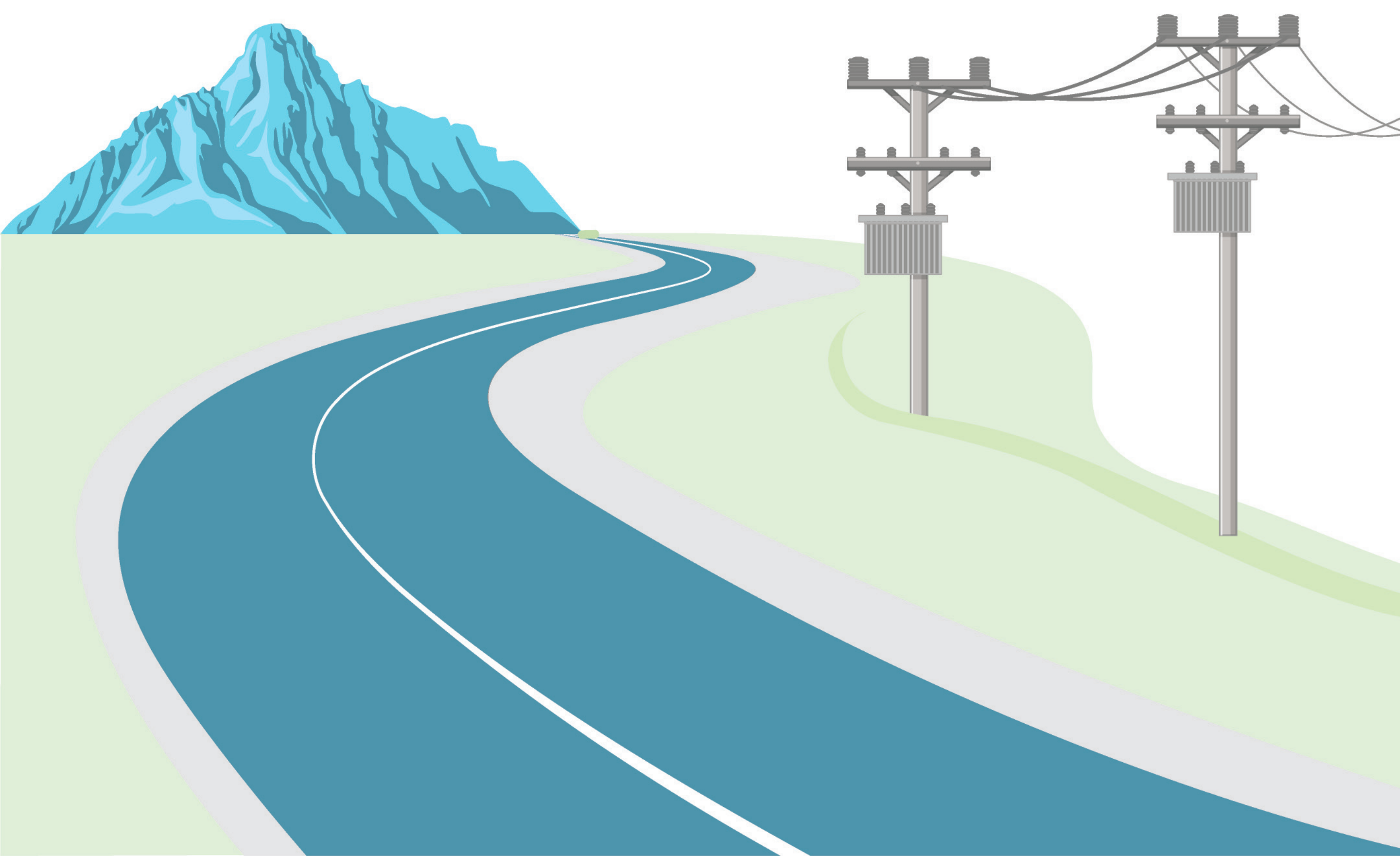
Recommendations included in this guidance reflect the best available knowledge and practices, recognizing that they continuously evolve. Ongoing testing of safeguard measures—along with monitoring, evaluating, and learning from the impacts of construction projects across the region—will improve future recommendations.

Linear Infrastructure in Snow Leopard Landscapes

As the name suggests, LI refers to infrastructure built in lines across the landscape. It includes roads, railways, fences, pipelines, power and communications lines, canals, irrigation ditches, and even rope-ways, which are all crucial for human economic well-being.

LI development occurs through planned new construction, upgrades, and infrastructure repairs and retrofits. Building new infrastructure creates an original footprint and might require clearing wildlife habitat for construction. Upgrades include paving or widening roads, adding railway tracks, raising speed limits, or boosting power line voltage. Repairs and retrofits involve fixing damage, maintaining road and rail surfaces, realigning segments, modifying drainage systems, and reinforcing foundations.

LI construction is expanding rapidly in Asia and within the snow leopard range. It is a global priority for economic and social development (Meijer et al. 2018; Laurance et al. 2014). The Asian Development Bank (ADB 2017) estimates that US$1.7 trillion of infrastructure investment



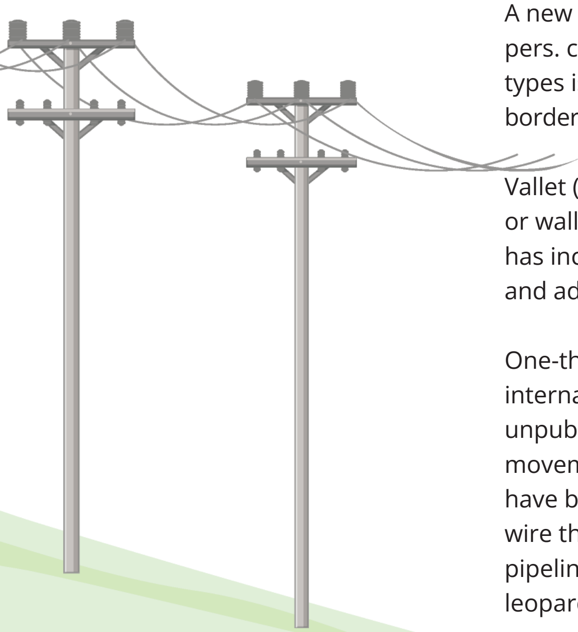
will be required annually until 2030 to support regional growth and address poverty and climate change. Power and transport—the two main types of LI—account for the largest share of this investment, at 56% and 32%, respectively (ADB 2017).

The expanse of roadways worldwide is mind-boggling, with many roads, especially informal ones, remaining unmapped (Engert et al. 2024). In 2018, the Global Roads Inventory Project dataset listed more than 21.6 million km of roads, including highways and primary, secondary, tertiary, and local roads. Of these, about 35% were paved and 50% were accessible year-round (Meijer et al. 2018).

A 2013 study (Dulac) projected that between 2010 and 2050, 25 million km of road lanes would be built worldwide—a 60% increase—mostly in low- and middle-income countries (Alamgir et al. 2017). Over the same time frame, 335,000 km of new rail tracks were projected to be built (Dulac 2013). These numbers will likely increase with expanding global connectivity and trade initiatives such as China's Belt and Road Initiative (BRI).

FUTURE RESEARCH: Mapping all forms of LI, including formally and informally built and proposed future LI, across the snow leopard range will inform spatial planning and habitat connectivity initiatives.

A United Nations Environment Programme (UNEP) World Conservation Monitoring Centre (WCMC) study analyzing the risks and benefits of planned roads and railways worldwide reports that almost half a million kilometers of new roads and railways are planned. While this represents only 1.2% of the existing global roads and railways, it reflects the global extent of coverage of these infrastructure assets (UNEP 2022). At the same time, the global reach of power lines is expected to surge with the transition to renewable energy (Nielsen et al. 2023).



A new initiative is underway to develop a global fencing map (W. Xu, pers. comm.), but estimating the global extent of fences of different types is difficult. Many are installed without being mapped, and data on border fence attributes might not be publicly available (Linnell et al. 2016).

Vallet (2022) estimated that there are 74 international border fences or walls worldwide. The number of border fence construction projects has increased in recent years to delineate jurisdictional boundaries and address national security concerns (Linnell et al. 2016).

One-third of the snow leopard's global range lies within 100 km of international borders shared by the 12 range countries (R. Jackson, unpublished data), making border fences potential barriers to their movement. For example, in Central Asia, many old Soviet border fences have been replaced with impenetrable barbed wire fences and mesh wire that medium to large mammals cannot cross. Similarly, while water pipelines might not significantly impact entire ecosystems in snow leopard habitats, they can still block movement and degrade habitat.

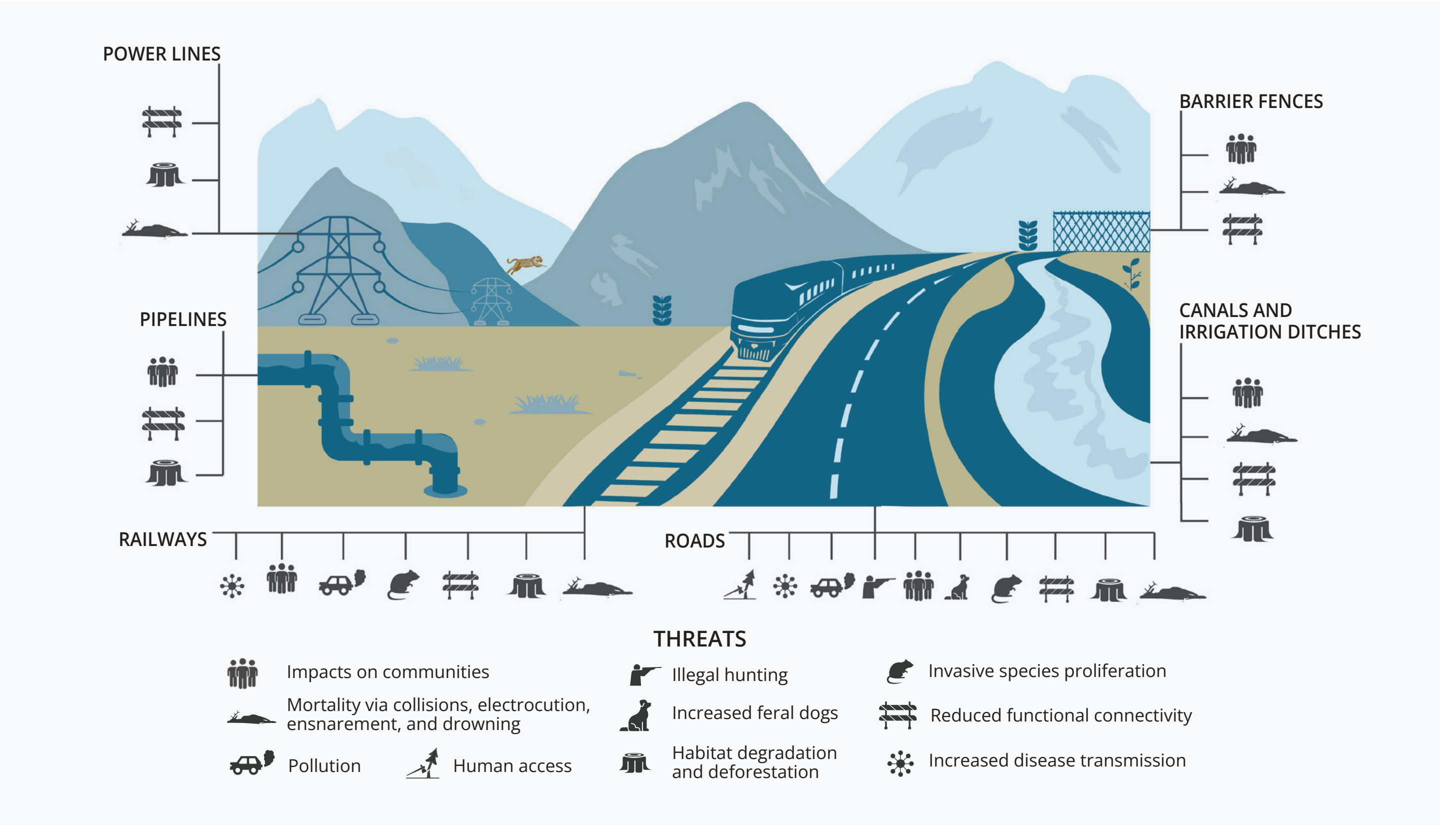


FIGURE 2.
Impacts of the main forms of LI found in snow leopard landscapes.

As detailed in the working group's earlier report, *Linear Infrastructure in Snow Leopard Landscapes* (Snow Leopards and Linear Infrastructure Working Group 2024) and in Appendix I of this document, LI poses many threats to snow leopards and their prey, from direct threats like mortality in vehicle collisions to indirect threats such as pollution (Figure 2).

Natural History Characteristics and Distribution of Snow Leopards

Snow leopards (*Panthera uncia*, Schreber 1775) are the smallest of the great cats of the genus *Panthera* (Kitchener et al. 2024) but the largest cats found in Asia's high-elevation habitats. They primarily hunt ungulates such as blue sheep (*Pseudois* spp.), ibex (*Capra* spp.), argali sheep (*Ovis ammon*), and Himalayan tahr (*Hemitragus jemlahicus*), but also feed on marmots (*Marmota* spp.), lagomorphs, and livestock (McCarthy et al. 2017).

Snow leopards live primarily in the high-mountain ecosystems of South and Central Asia, ranging across 12 countries and about 1.2 million km^2 of potential habitat (Figure 1, McCarthy et al. 2023). They are solitary and territorial animals that travel long distances to meet their ecological needs. Home range sizes vary by region, but one study in the Gobi Desert found the mean home range for males to be 144–270 km^2 and for females to be 83–165 km^2 (Johansson et al. 2016). Like other mountain species, snow leopards can move between mountain ranges by crossing relatively flat terrain (Zahler & Victurine 2024). Because snow leopards and their prey use large areas, they frequently encounter LI and its many threats.

The International Union for Conservation of Nature (IUCN) Red List of Threatened Species lists snow leopards as vulnerable to extinction, with transportation and service corridors being among their primary threats (IUCN 2024; McCarthy et al. 2017). Estimates of the global snow leopard population vary between 3,920 (Snow Leopard Working Secretariat 2013) and 8,745 (McCarthy et al. 2016); this wide range is attributable to sampling bias of this elusive species (Suryawanshi et al. 2019).

Snow leopards also have the lowest genetic diversity of any great cat species (Wang et al. 2025), which makes functional connectivity across the range, including between range countries, especially critical.
LI can disrupt this connectivity and contribute to genetic isolation.

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Why Snow Leopards?

Accounting for snow leopards and their habitat needs while planning LI has many benefits and far-reaching positive impacts. Snow leopards are key members of functioning ecosystems as top-order carnivores and umbrella species. Their presence helps indicate an ecosystem's overall health, as they rely on prey that migrate long distances and use a range of habitats (Sharma et al. 2024).

Snow leopards are also considered a flagship species. Like many wild cats, their charismatic nature rallies support from governments, local communities, the public, developers, financial institutions, and other stakeholders around shared goals—in this case, sustainable infrastructure.

Conserving snow leopards supports multiple global goals under the Convention on Biological Diversity's (CBD) Kunming-Montreal Global Biodiversity Framework (KMGBF) (Table 1), the Sustainable Development Goals (e.g., goals 9, 11, 13, and 15), and the CMS Samarkand Strategic Plan for Migratory Species 2024–2032, especially "Goal 2: The habitats and ranges of migratory species are maintained and restored, supporting their connectivity" and "Goal 3: Threats affecting migratory species are eliminated or significantly reduced." It also aligns with targets set by other multilateral environmental agreements.

This guidance particularly supports CBD Target 14, which calls for integration of biodiversity in decision-making at every level and across sectors, with direct reference to the infrastructure sector added at the 2024 United Nations Biodiversity Conference of the Parties (COP16) in Cali, Colombia.[1]

Sustainable Development Goals Relevant to Snow Leopard Conservation

[1] See footnote 5 in the draft decision for Agenda Item 17 on mainstreaming of biodiversity within and across sectors.

Implementing the recommendations of this guidance document will help governments achieve these and other targets. Additionally, careful infrastructure planning reduces wildlife-vehicle collisions and other conflicts, promoting coexistence between people and wildlife while ensuring minimal damage and injury/loss to both. Developing LI with wildlife in mind benefits biodiversity and the climate, ultimately supporting people and economies. Infrastructure that maintains the flows of nature is more resilient and long-lasting, another benefit to people and governments (Figure 3, Hallegatte et al. 2019).

FIGURE 3.
The overlapping benefits of developing LI with the needs of nature in mind.

TABLE 1.

KMGBF targets relevant to this guidance on sustainable infrastructure in snow leopard landscapes.

KMGBF TARGETS 1, 2, AND 3	
Description of Target(s)	Managing key areas to reduce biodiversity loss, restore degraded habitats, and, most importantly, conserve 30% of globally important biodiversity areas through a participatory approach
Relevance to the Guidance (opportunities)	Less than 25% of the snow leopard's range is protected. Many protected areas (PAs) have adopted participatory conservation approaches that benefit nature and Indigenous peoples and local communities (IPs and LCs).
Challenges (and how to address them)	***Challenge:*** LI fragments and degrades snow leopard habitats, including areas inside and adjacent to PAs, weakening ecosystem connectivity. It also contributes to increased wildlife crime, including illegal hunting and trade. ***Solution:*** Integrate snow leopard corridors, movement zones, and other critical habitat into national and regional spatial planning and PA expansion strategies. *See: Planning and Consultation; Policy Development*

KMGBF TARGETS 4, 5, 6, 7, 8, 9, AND 10	
Description of Target(s)	Species recovery; human wildlife conflict management; sustainable, legal, and safe harvest and use of natural resources that benefit people; preventing and managing invasive species; reducing pollution; enhancing biodiversity and sustainability in agriculture, aquaculture, fisheries, and forestry; and integrating climate resilience for improving community wellbeing
Relevance to the Guidance (opportunities)	Safeguarding snow leopard habitat and its ecosystem functions, including reducing invasive species movement, limiting agricultural encroachment into habitat, reducing human-wildlife conflict, mitigating pollution, and preventing wildlife trade, supports snow leopard recovery, aids global water security, and enhances climate change mitigation.
Challenges (and how to address them)	***Challenge:*** Roads and other infrastructure can introduce human activity, pollution, and invasive species while exacerbating human-wildlife conflict. They also increase rangeland degradation and reduce ecosystems' resilience to climate change. ***Solution:*** Carefully site infrastructure to avoid ecological damage, apply the mitigation hierarchy, and incorporate local ecological knowledge into planning and decision-making. *See: The Mitigation Hierarchy; Avoid and Minimize; Planning and Consultation; Design*

KMGBF TARGET 11	
Description of Target(s)	Restoring, maintaining, and enhancing nature's contributions to people
Relevance to the Guidance (opportunities)	Snow leopards' wide-ranging nature requires integrated landscape management to restore, maintain, and enhance nature's contributions to people.
Challenges (and how to address them)	***Challenge:*** Fragmentation from roads and railways and other forms of LI undermines the ecosystem services snow leopard landscapes provide (e.g., water regulation, grazing). ***Solution:*** Identify essential ecosystem services during the environmental and social impact assessment (ESIA) and strategic environmental assessment (SEA) to enable better ecological connectivity during LI planning and design. *See: Planning and Consultation; Avoid; Design*

KMGBF TARGET 14	
Description of Target(s)	Integrating biodiversity in decision-making at every level
Relevance to the Guidance (opportunities)	Effective landscape management requires engaging all levels of government and sectors, including planners, engineers, and multi-lateral development banks (MDBs), in snow leopard range countries to mainstream biodiversity conservation, including in infrastructure design and implementation.

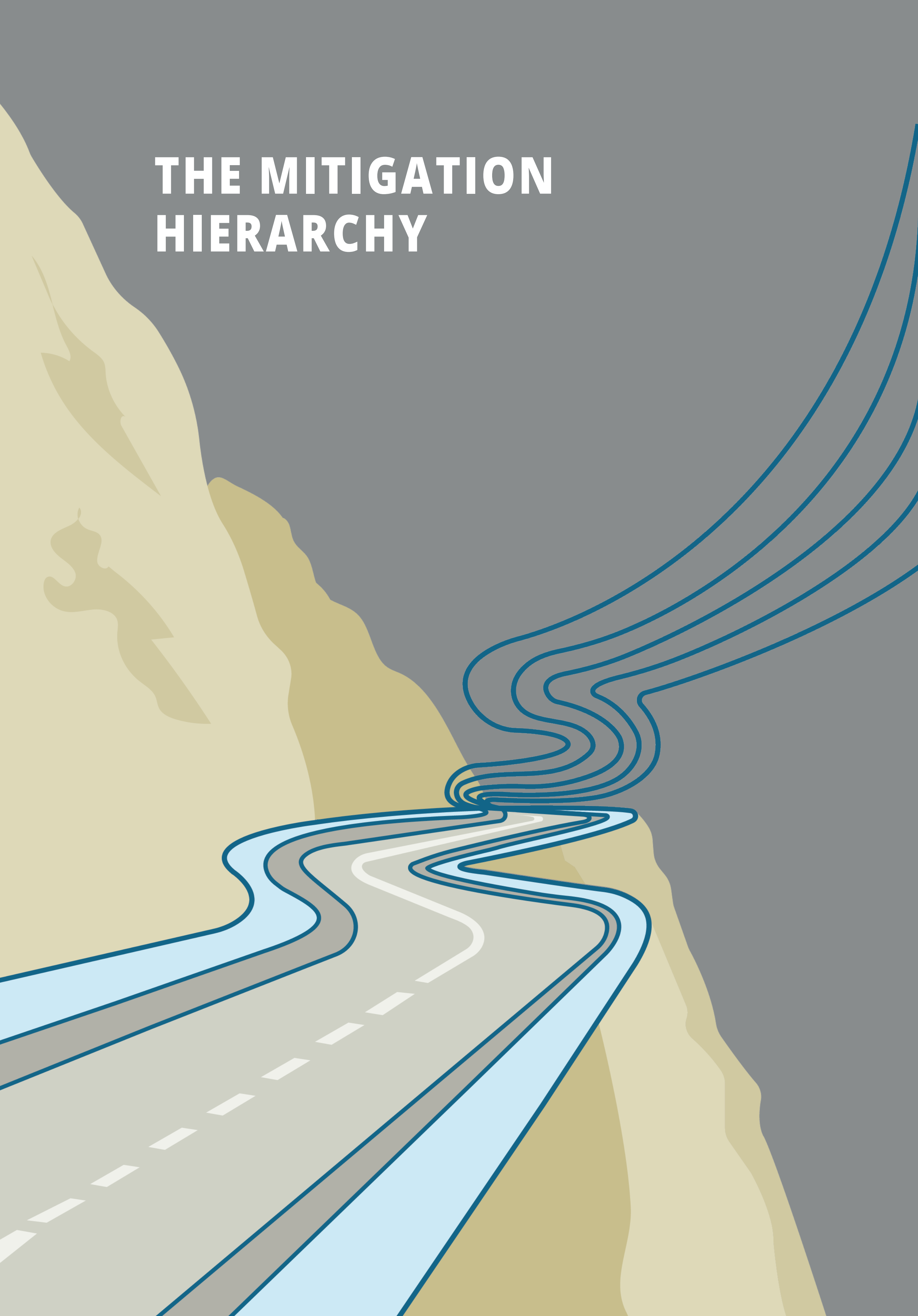
Challenges (and how to address them)	***Challenge:*** Sectoral planning for transport, energy, and urban expansion often fails to consider biodiversity. ***Solution:*** Mandate biodiversity-inclusive ESIAs and SEAs, embed ecologists in project design and approval processes from early design stages, ensure biodiversity considerations are clearly part of spatial and sectoral planning across multiple sectors, and include biodiversity indicators in all impact assessments. *See: Policy Development; Planning and Consultation; Design*

KMGBF TARGET 19	
Description of Target(s)	Mobilizing financial resources for biodiversity
Relevance to the Guidance (opportunities)	In many areas, snow leopards are considered a charismatic species with significant cultural relevance—traits that make them a powerful flagship species for raising awareness about the threats LI poses to high-mountain ecosystems. Partnerships with nonconventional yet influential stakeholders, such as businesses and faith institutions, are vital, and they are easier to mobilize with species like snow leopards as flagships.
Challenges (and how to address them)	***Challenge:*** Conservation efforts often receive far less funding than large infrastructure projects, with limited investment in impact mitigation and long-term monitoring. ***Solution:*** Leverage the snow leopard's flagship appeal to attract public and private investment. Promote biodiversity-inclusive funding mechanisms for infrastructure. *See: Tender and Finance; Offsets; Conclusions*

KMGBF TARGETS 20 AND 21	
Description of Target(s)	Strengthening capacity-building, technology transfer, and scientific and technical cooperation for biodiversity, and ensuring knowledge is available and accessible to guide effective biodiversity action
Relevance to the Guidance (opportunities)	Snow leopards are the least studied of the big cats, and their habitats are among the most extreme and therefore least understood. Globally, there is growing momentum to deepen our understanding of the species and their ecosystems and an opportunity to avoid repeating the mistakes made in other landscapes, especially regarding LI development. Advancing research and monitoring through technology, capacity-building, and citizen science can improve understanding and aid informed decision-making for appropriate biodiversity actions.
Challenges (and how to address them)	***Challenge:*** Lack of baseline data and low technical capacity in remote snow leopard range areas lead to poor decision-making and weak oversight of infrastructure projects. ***Solution:*** Build a shared knowledge base, promote citizen science and local ecological monitoring, and strengthen regional collaboration and data sharing. *See: Planning and Consultation; Operations and Maintenance; Conclusions*

KMGBF TARGETS 22 AND 23	
Description of Target(s)	Promoting inclusive decision-making in conservation and comanagement of biodiversity
Relevance to the Guidance (opportunities)	Many conservation projects and interventions in the snow leopard range integrate the well-being of Indigenous communities, especially women, recognizing this as key to conservation sustainability.
Challenges (and how to address them)	***Challenge:*** Infrastructure projects often lack transparent consultation with IPs and LCs, leading to conflict, displacement, and marginalization. ***Solution:*** Promote inclusive planning processes, ensure Free, Prior, and Informed Consent (FPIC), and build IP and LC capacity to engage meaningfully in infrastructure decision-making. *See: Planning and Consultation; Policy Development; Conclusions*

THE MITIGATION HIERARCHY



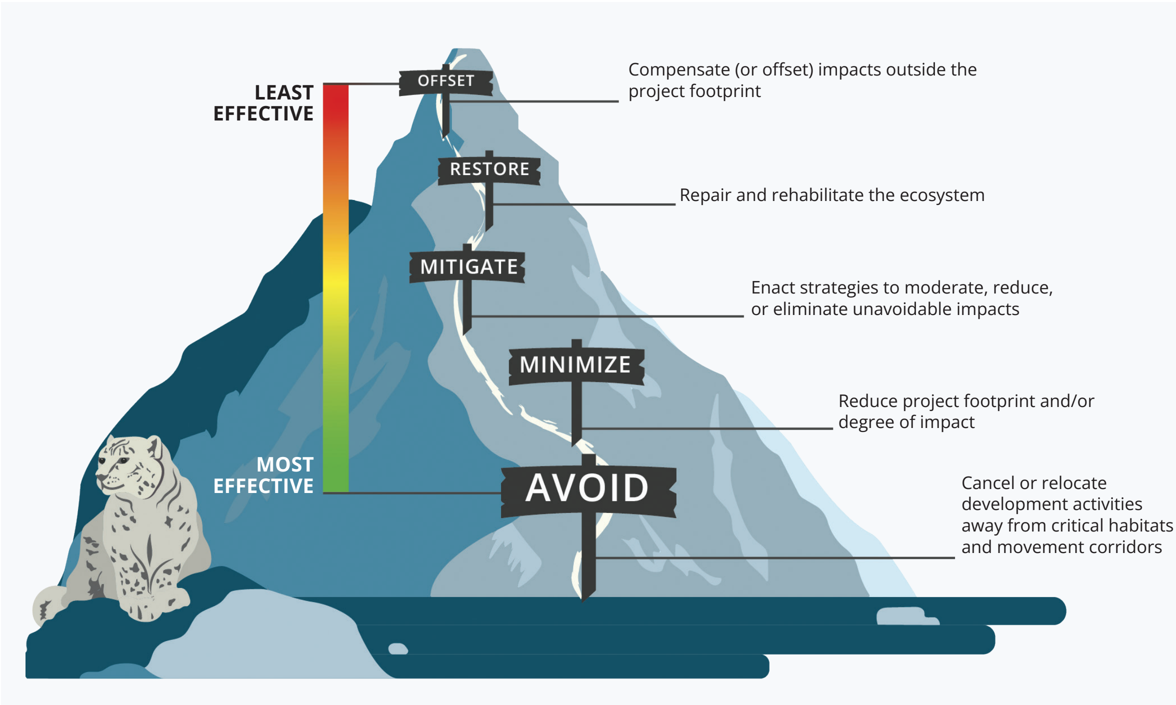


FIGURE 4.
The steps of the mitigation hierarchy. Note that different institutions depict the mitigation hierarchy in different ways, but the underlying premise is the same: fewer negative actions, more positive actions. This version follows the International Union for the Conservation of Nature World Commission on Protected Areas Technical Report Series and the International Finance Corporation's Performance Standard 6.

The mitigation hierarchy (Figure 4) is a framework to address development impacts with an initial focus on *avoidance*. If avoidance is not possible, then impact reduction efforts should proceed in the following order, from most to least effective: *minimization*, *mitigation*, *restoration*, and finally compensating for or *offsetting* residual impacts.

Avoid

Avoidance is the preferred and most effective step in the mitigation hierarchy for reducing project impacts. It requires proper planning and understanding of the ecosystem before infrastructure development begins. Avoidance can be achieved by ensuring development activities are sited away from critical habitats, including ecological corridors. It is important to note that in many areas, snow leopard corridors are not well mapped and require more study. Furthermore, snow leopards use their habitat differently than other cats, such as tigers, and may not use corridors repeatedly. Therefore, avoidance of snow leopard habitat in general is the best option.

Infrastructure project routes that avoid sensitive biodiversity areas might be longer and more expensive than the most direct routes. However, a cost-benefit analysis may show that maintaining ecosystem services and reducing the need for additional actions, such as offsets, can lead to lower overall costs. Even when a project is relocated, the remaining steps in the mitigation hierarchy—minimization, mitigation, restoration, or compensation or offsetting—must still be considered to address residual impacts.

As illustrated in Figure 4, avoidance is the most essential action to implement within the mitigation hierarchy. It is the most effective action in reducing project impacts, while all the other actions are more complex, costly, and time consuming. In snow leopard habitat, avoidance may take the form of ensuring infrastructure projects are designed to avoid movement corridors or other areas important to snow leopards and their prey. For example, a 2019 provision of India's Ministry of Road Transport and Highways requires detour of the alignment of roads away from national parks and sanctuaries.

Minimize

Minimization is second to avoidance in its conservation value and uses proactive measures to limit the project's footprint or degree of impact. This preventive approach could involve, for example, discarding plans for LI expansion, rerouting alignment away from critical habitat areas, or pairing infrastructure such as roads and transmission lines within the same footprint.

Minimization also involves short-term actions during construction to reduce disturbances. Examples include placing construction camps outside of snow leopard habitat and providing strict guidance on waste disposal, preserving habitat adjacent to roads, adjusting the timing of construction to avoid important breeding or migration seasons, or shortening the project duration.

Mitigate

Mitigation is implemented only after genuine efforts have been made to avoid and minimize impacts. These measures—often technological or construction-based—aim to moderate, reduce, or eliminate unavoidable impacts over time. Effective mitigation focuses on mitigating all forms of disturbance; maintaining, enhancing, and restoring ecological connectivity; preventing or reducing wildlife mortality; and addressing other project-related environmental impacts.

Constructing a highway or railway in the mountains, especially in the Himalayas, is a challenging task. It requires complex geoengineering of immense scale, with significant ecological and social impacts, and involves clearing entire hillsides, blasting through mountains for tunnels, and deploying heavy machinery in ecologically and geologically fragile areas. The process unleashes long periods of noise, dust, and vibrations and disruption of the movement of people and animals. High-altitude plateaus are also sources of rivers, and necessary measures should be taken to ensure that water flows are not hampered.

Snow leopard roadkill.
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Wildlife crossing structures, such as overpasses and underpasses, paired with directional fencing to guide animals to the structures, are the most effective approach. These structures are critical for reducing mortality and maintaining, enhancing, and restoring ecological connectivity. Their siting should consider movement data from snow leopards, their prey, and other wildlife to select the best location and design. Engineers must also provide solutions for water runoff, snow loads, earthquakes, unstable slopes, and other environmental factors impacting a crossing structure's efficacy.

Overpasses and underpasses also require directional fencing to channel wildlife to the crossing structure and keep them off the road or railway and jump-outs to avoid wildlife entrapment in the right-of-way, where they risk direct mortality and threaten human safety by potential collisions with vehicles. In areas such as steep mountainous regions where overpasses and underpasses may not be feasible, mitigation for planned and existing infrastructure could also include signage and traffic-calming measures, which can be critical in reducing these impacts. Warning signs can inform motorists about the likelihood of snow leopards or prey and encourage more cautious driving. However, signage without physical interventions that reduce vehicle speed often has a limited effect. Traffic-calming measures, such as rumble strips, speed bumps, chicanes, and reduced-speed zones, can be highly effective, particularly in known crossing hot spots. These interventions not only give drivers more time to react but also reduce the severity of collisions when they occur.

Restore

When project impacts cannot be avoided, minimized, or mitigated, a last resort is to restore areas that construction activities have impacted. Some restoration work will always be necessary because any LI element involves vegetation removal. Restoration strategies could also be part of planning when a project is routed through existing degraded areas.

Restoration can come in many forms, including removing invasive species, planting native species, cleaning up pollutants, and controlling soil erosion. Slope stabilization methods for erosion control, such as bioengineering, block plantations, and terracing, are crucial to restoring an ecosystem after construction. If slopes are not well stabilized, landslides can occur, particularly on the steep slopes that characterize many parts of the snow leopard range. Snow and heavy rain that can occur throughout the year increase pressure on the slopes. Restoring vegetation where LI projects have occurred is also key to reestablishing wildlife movement corridors and providing ecosystem services and must be very context specific to ensure success. Where vegetation does not grow such as on steep slopes, other soil and rock stabilizing techniques will show better results.

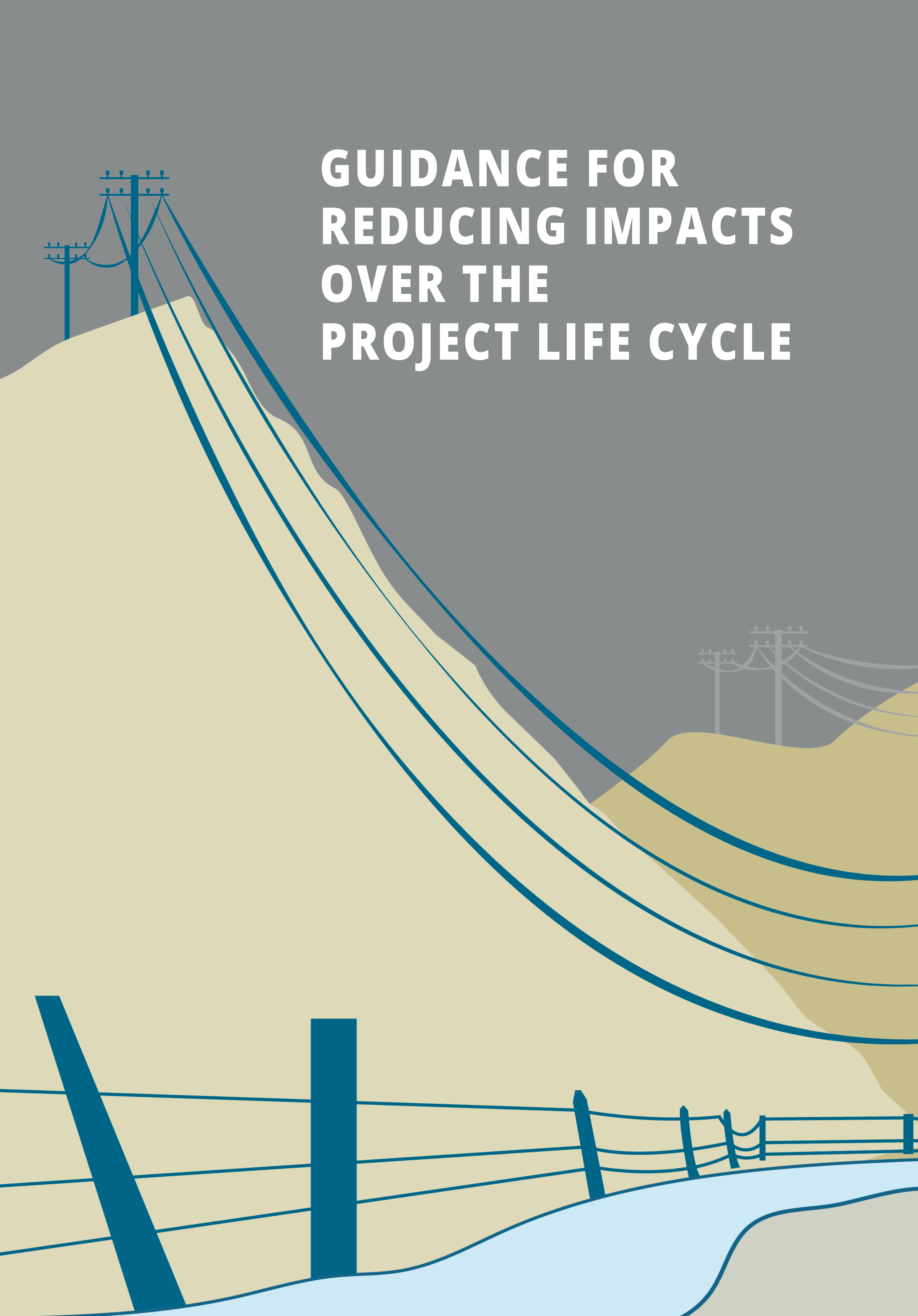
Offset

When impacts remain after completing all other steps of the mitigation hierarchy, offsetting can be considered. Offsetting improves conservation outcomes in areas outside the project footprint to either entirely compensate for the project's impacts (no net loss) or provide benefits that surpass the project's impacts (net positive impact or net gain). There is now a global push for all infrastructure projects to achieve net positive, contributing to the societal nature positive goal (Nature Positive Initiative—A Global Goal for Nature).

Offsetting is the least effective step in the mitigation hierarchy and should be considered only after all other options have been exhausted. The IUCN provides guidance on biodiversity offsets in its *Policy on Biodiversity Offsets* (2016).

The IUCN does not recommend the use of offsets when irreplaceable entities, such as species or ecosystems, are at risk. For example, offsetting impacts in Himalayan ecosystems may be virtually impossible. The IUCN also emphasizes developing offsets in consultation with relevant stakeholders and being transparent about their effectiveness. Any offset must be proportionate to the biodiversity and ecosystem services lost. In snow leopard ranges, offsetting must be done with extreme care because of the vulnerability of snow leopards to extinction and the habitat's fragile nature.

GUIDANCE FOR REDUCING IMPACTS OVER THE PROJECT LIFE CYCLE



Several studies and guidelines document the technical and economic feasibility of mitigation measures and management activities to reduce LI's impact on wildlife. Appendix III lists guidelines that institutions have developed for various geographies and species. The present guidance can be used as a starting point to test, develop, and implement mitigation for snow leopard habitats.

The Sustainable Infrastructure Program in Asia

The Sustainable Infrastructure Program in Asia (SIPA) is a collaborative effort between the Organisation for Economic Co-operation and Development and its consortium partners, including WWF. The program helps countries in Central and Southeast Asia plan infrastructure—like enhanced energy systems, transportation, and industry infrastructure—in a way that is better for the environment and supports long-term economic development.

The program supports national and local governments in transitioning their infrastructure systems to meet the Paris Agreement and Sustainable Development Goals (SDGs). This support includes guidance for the various stages of the infrastructure investment cycle, including strategic planning, project evaluation, policy alignment, and green finance.

Under SIPA, WWF works with the governments of Indonesia and the Philippines to integrate nature-based solutions (NbS)—natural systems or processes used to help achieve societal goals—into transport infrastructure planning. This collaboration involves a nationwide mapping effort to assess priority ecosystem services crucial for climate resilience, which include critical benefits such as water retention and coastal protection that support both road infrastructure and downstream communities. This mapping exercise identifies NbS areas for investment opportunities under habitat conservation and land restoration scenarios for four ecosystem services: 1) sediment retention, 2) flood mitigation, 3) coastal risk reduction, and 4) water recharge.

To inform this decision-making before an LI project is developed, strong baseline data on social risks and biodiversity must be obtained to understand the ecosystem's present status and to identify through various development scenarios how an infrastructure project might impact it. A biodiversity baseline study provides a benchmark of an area's biodiversity and its overall importance in the landscape (Gullison et al. 2015). Monitoring should continue throughout the project implementation process and beyond.

The baseline study involves collecting and interpreting information on the biodiversity values at a site, including species presence, habitats, ecological systems, and ecological corridors, as well as the systems' current condition and trends. Data on species movement, habitat use, and connectivity are also vital for decision-making, particularly for wide-ranging species such as snow leopards. In that vein, the area in the baseline study must accurately account for snow leopard space needs, which might require habitat connectivity far outside the project area, even into transboundary areas.

Biodiversity baseline studies are crucial to assessing the risks and impacts of infrastructure development projects on biodiversity. They allow for the application of the mitigation hierarchy and the design of long-term biodiversity management and monitoring plans. Once the context is well understood, areas of biodiversity importance or cultural heritage areas can be avoided and mitigation policies can be developed, enacted, and enforced to ensure reduced impacts.

To complement the ecological field data, data from online tools such as the Integrated Biodiversity Assessment Tool (IBAT) (which includes the World Database on Protected Areas, the World Database on Key Biodiversity Areas, and the IUCN Red List of Threatened Species) can be used. The International Finance Corporation's Performance Standard 6 also provides valuable guidance on biodiversity protection (IFC 2012). The standard recognizes that protecting and conserving biodiversity, maintaining ecosystem services, and managing living natural resources adequately are fundamental to sustainable development.

The following guidance is rooted in the mitigation hierarchy to address, manage, and reduce project impacts across the life cycle. Measures should be monitored and evaluated across all the recommended actions to assess their efficacy in reducing impacts on snow leopards and their habitat (see Monitoring and Evaluation section).

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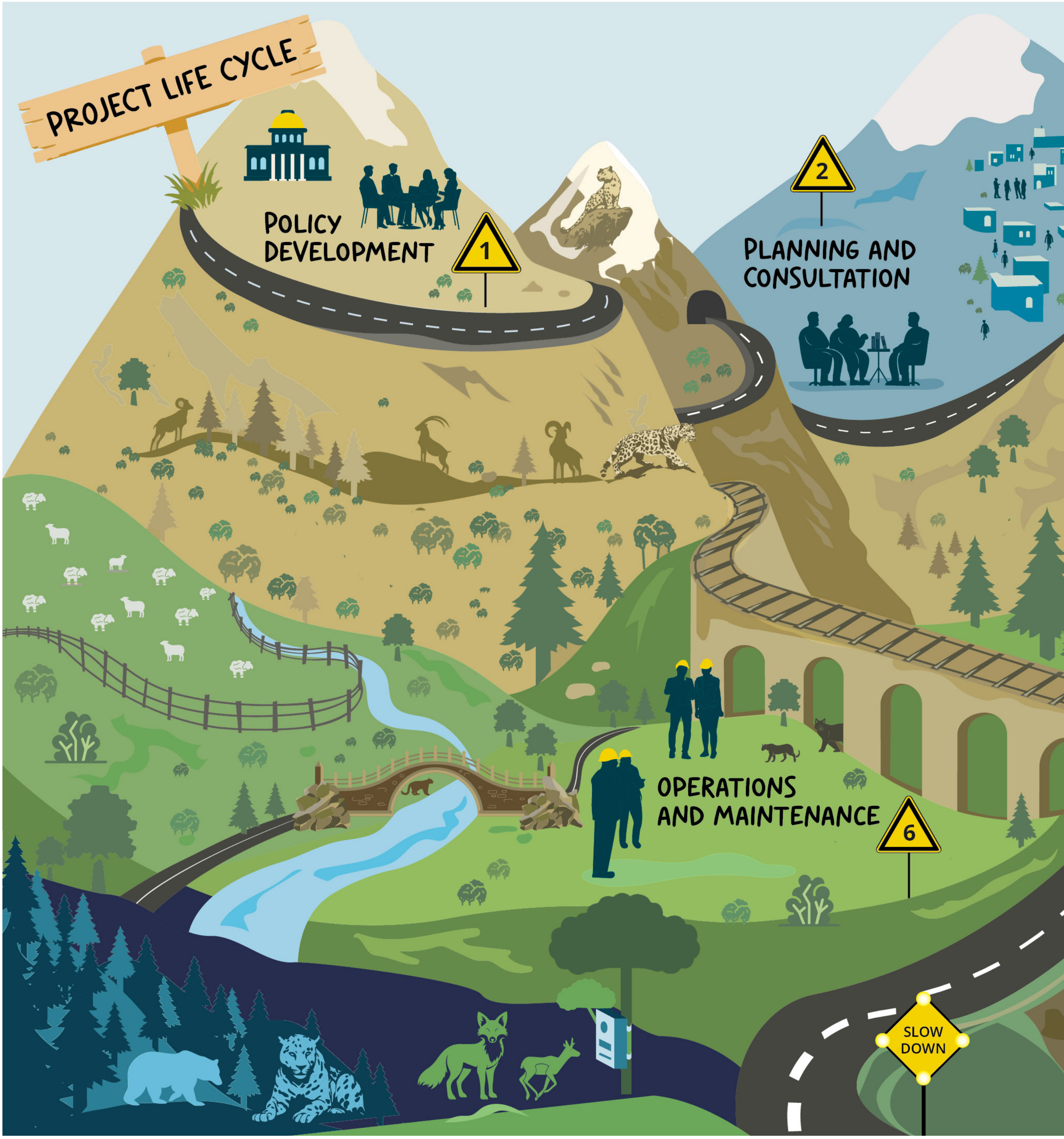


FIGURE 5. *The infrastructure project life cycle with steps that can be taken to reduce project impacts, with earlier steps having more power to avoid and minimize impacts and later steps having more power to mitigate impacts. Note that each bullet is addressed as a separate section within the guidance document.*

1

- Policy Formulation

2

- Spatial Planning (Land Use & Infrastructure)
- Route Analysis
- Natural Resource Area Management Planning
- Protected Area Management Planning
- Pre-Feasibility Study
- Climate Risk Assessment
- Strategic Environmental Assessment
- Multidisciplinary Technical Consultation
- Indigenous Peoples & Local Community Involvement & Consultation
- Natural Capital & Ecosystem Services Valuation

3
- Mitigation to Alter Driver Behavior
- Signs & Warning Systems
- Fencing
- Wildlife Crossing Structures
- Selecting Relevant Mitigation
- Environmental & Social Impact Assessment & Cumulative Impact Assessment
- Project Design

4
- Financing
- Procurement

5
- Restoration
- Mitigation of Construction Impacts
- Slope Stabilization, Erosion & Sediment Control, Vegetation Management
- Water Management

6
- Verge & Vegetation Management
- Monitoring & Evaluation

The Project Life Cycle

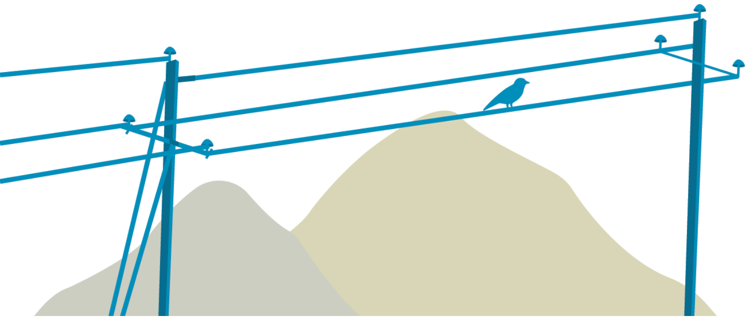
Generally, infrastructure projects involve the following life cycle stages: planning and consultation; design; tender and finance; construction; operations and maintenance; and sometimes decommissioning, all controlled by national and local policy frameworks or national or international standards. At different points in the project life cycle, opportunities arise to address the project's potential or real impacts (Figure 5). For the most part, addressing project impacts in the earlier stages allows avoidance and minimization of impacts, whereas further along in the construction process, impacts must be mitigated.

Policy Development

Strong policy frameworks that include environmental safeguards to prevent LI impacts on snow leopards, their prey, and their ecosystems provide the necessary basis for sustainable LI. Without strong policy, development authorities have little incentive to build in environmental safeguards. For example, green procurement policies that advantage sustainability in contracts encourage better practices. Without green procurement, bids that include sustainability measures, such as overpasses or underpasses, not required in tendering documents can be excluded due to perceived higher costs. When developing policy, environmental considerations should be included in staff hiring guidelines and infrastructure prioritization processes before procurement begins. For example, in the Philippines, the Infrastructure Flagship Programme, led by the National Economic and Development Authority, uses a guidance document with various criteria to prioritize projects for national parliamentary funding.

To build strong and effective policies, ministries need to work together to avoid the pitfalls of siloed policy development. For example, Mongolia's national wildlife-friendly fence standard (Barrier Fences for Railways and Highways: General Requirements, MNS 7042:2024) emerged through a collaboration between the Policy and Planning Department, the Railway and Maritime Transport Policy and Coordination Department of the Ministry of Road and Transport, and the Ministry of Environment and Tourism. In Colombia, the Ministry of Transportation made the *Green Road Infrastructure Guidelines* mandatory after many years of development and piloting. This highly comprehensive set of guidelines is the result of an interministerial environmental agenda between the Ministries of Transportation and Environment and Sustainable Development.

In addition to the example from Mongolia of a fencing standard, several policies of snow leopard range countries are good examples of policies that govern sustainable infrastructure development in snow leopard landscapes (Appendix II).



To build strong and effective policies, ministries need to work together to avoid the pitfalls of siloed policy development.

Planning and Consultation

During the planning and consultation stage of infrastructure development, projects are evaluated for technical, financial, environmental, and operational feasibility. This stage involves engaging with stakeholders—including local communities, statutory bodies, and experts—to gather feedback and ensure project viability. Key outputs of this phase include feasibility studies, environmental studies and impact assessments, development plans, and contracts.

Spatial Planning (Land Use and Infrastructure)

One of the most effective ways to avoid or minimize an LI project's impacts is to incorporate spatial planning and scenario-based analysis of alternative routes. Although a route away from a key conservation area for snow leopards might be longer, the benefits of avoiding fragmentation of large tracts of habitat outweigh the costs by enhancing habitat integrity and connectivity, ultimately improving habitat quality for snow leopards and their prey.

GSLEP's *Population Assessment of the World's Snow Leopards* (PAWS) and other survey initiatives provide estimates of snow leopard distribution and abundance across much of their range (e.g., see Sharma et al. 2023). These survey results should be considered at the design and tender stages of LI planning to ensure infrastructure routes avoid as many known snow leopard ranges and higher-density regions as possible. Additionally, planners should avoid what may be corridors of movement for snow leopards between areas of high occupancy or density, as well as habitats providing key ecosystem services for the survival of the leopards and nearby communities.

Because all snow leopard range country governments and national-level teams are engaged in the PAWS process, they constitute an invaluable source of information on snow leopard distribution and abundance. They should be consulted during the design and tender stages to ensure LI projects minimize their impact on snow leopard populations and the ecosystems they rely on.

Route Analysis

Route analysis evaluates and compares potential infrastructure routes by considering geographic, environmental, economic, social, and technical constraints and priorities to identify the optimal, safest, lowest-impact, most efficient, cost-effective route. Early engagement with environmental experts, local communities, and land-use authorities helps identify critical habitats, significant sites, and existing land uses that should be avoided or carefully navigated. Planners should incorporate all available resources to assess multiple alignment options, selecting routes that reduce fragmentation, minimize earthworks, and avoid areas prone to erosion, flooding, or slope instability. This process presents a crucial opportunity to integrate climate resilience and natural infrastructure for long-term functionality. By iteratively refining route selection through environmental assessments and stakeholder consultations, planners can ensure that the final alignment balances development goals with conservation priorities.

Natural Resource Area Management Planning

A natural resource management plan delineates strategies to manage and protect natural resources within a project's area of influence, such as flora, fauna, water bodies, and other landscape features. The plan first establishes baseline information on existing natural resources, then defines goals and objectives for the resources, and then defines strategies for resource management. Regular monitoring and evaluation help determine whether goals are being met and identify necessary adjustments.

A well-structured natural resource management plan helps prevent secondary environmental impacts throughout an infrastructure project, such as water contamination, illicit hunting, and deforestation. Anticipating these impacts and developing a plan to avoid them are part of the management plan.

Protected Area Management Planning

Much of the snow leopard range lies within PAs that have varying legal and management requirements. As infrastructure development expands into high-mountain regions, it increasingly threatens the ecological integrity of these areas and the connectivity between them. PA management plans must explicitly assess and address existing and anticipated infrastructure development to protect biodiversity and preserve snow leopard ecosystems.

Management plans should include spatial mapping of existing and proposed LI within or near the PA boundaries, assessing their potential ecological impacts and proposing mitigation strategies that consider wildlife corridors, buffer zones, seasonal movement patterns of key species, and climate risks to snow leopards.

Coordinating with relevant infrastructure planning agencies must be institutionalized to ensure the integration of PA management priorities into ESIAs and consideration of alternative routes or designs where impacts are significant in critical wildlife habitats. PA governance frameworks should also be updated to require all infrastructure projects within or near PAs to undergo conservation-sensitive review processes aligned with national and international biodiversity safeguards.

Finally, building the PA staff's capacity to monitor and respond to infrastructure threats is also essential. Proactively integrating infrastructure considerations into PA management planning strengthens conservation outcomes and ensures the long-term sustainability of snow leopard landscapes.

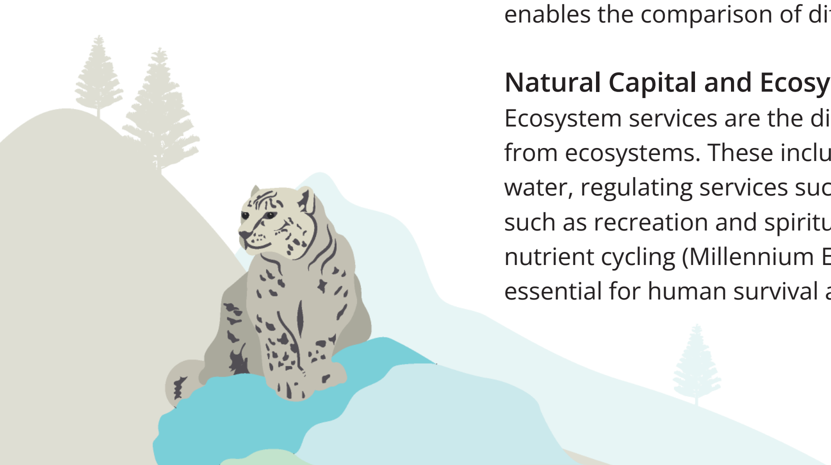
Pre-Feasibility Study

A pre-feasibility study must be conducted before a project's design can go forward. It initially analyzes a project's viability and potential benefits and is an important evaluation to ensure project success or determine whether a project should be discarded or modified. Pre-feasibility studies can also assist in evaluating project options, including routing alternatives, to determine which is the most environmentally and economically suitable.

Pre-feasibility studies evaluate projects' technical, environmental, social, economic, legal, and operational feasibility. In snow leopard landscapes, pre-feasibility studies help reveal and assess potential impacts to snow leopards and how to avoid and minimize them. Online tools such as Exploring Natural Capital Opportunities, Risks and Exposure (ENCORE) facilitate understanding of the proposed projects' risks and dependencies and help map out the relevant mitigation measures early in the infrastructure project. Similarly, pre-feasibility studies can integrate environmental and social sensitivity analyses, which is now straightforward if done through tools such as the Monitoring and Evaluation Systems Analysis (MESA) if spatial data are available, which enables the comparison of different scenarios and outcomes.

Natural Capital and Ecosystem Services Valuation

Ecosystem services are the direct and indirect benefits people obtain from ecosystems. These include provisioning services such as food and water, regulating services such as climate regulation, cultural services such as recreation and spiritual value, and supporting services such as nutrient cycling (Millennium Ecosystem Assessment 2005), which are essential for human survival and well-being. Similarly, natural capital



refers to the global stock of natural assets, such as soil, air, water, and biodiversity. An effort to measure the value of global ecosystems in monetary terms estimated their services were worth at least US$125 trillion per year (Costanza et al. 2014) in 2011, when global GDP was approximately US$74 trillion. A World Economic Forum study indicates that more than half the world's GDP moderately or highly depends on nature, further substantiating the value of natural capital and ecosystem services (Herweijer et al. 2020).

Snow leopard habitats within the 12 range countries contain large tracts of intact natural spaces. Their ecosystem services provide socioeconomic security for local communities reliant on agropastoralism, non-timber forest products, and tourism, among other activities (Ud Din et al. 2020). They also contribute to the well-being of human populations by aiding carbon sequestration and serving as global water towers. The USAID-funded Asia's High Mountains Program found the region to be the home of headwaters that supply water to one-third of the global human population.

This region is seeing an increasing growth of LI, which could cause irreparable harm without measuring and mapping ecosystem services. For instance, roads built to improve the economy of local communities often increase human disturbance, leading to a decline in rangeland productivity and impacting local herder community livelihoods. The pollution generated from increased traffic might impact revenue sources such as tourism and non-timber forest products trade.

Embedding the true economic value of ecosystem services into decision-making is challenging. The United Nations (UN) contends that sustainable development is "about recognizing, understanding, and acting on interconnections—above all those between the economy, society, and the natural environment" (UN 2012). Therefore, while the economic assessment of ecosystem services improves over time, acknowledging the short- and long-term impacts of land-use changes, such as LI development, is essential. Working with experts to incorporate measures that enhance positive impacts and minimize negative ones can support more sustainable infrastructure development in these important ecosystems.

Valuing ecosystem services and natural capital is important in sustainable development planning. It recognizes the value of the continued provision of such services in the face of barriers such as infrastructure. Placing monetary value on ecosystem services helps recognize their contribution and the consequences of their absence. For example, if a construction project reroutes a stream or causes siltation that degrades a watershed, a community might lose access to clean water, requiring an alternative and likely more expensive solution.

Several methods exist for valuing ecosystem services and natural capital that involve a variety of experts, from economists to biophysical and social scientists. These efforts should include consultation with local communities about their needs and dependencies.

The System of Environmental Economic Accounting Central Framework must be used to map and measure the ecosystem services, particularly environmental flows, environment stocks, and economic activity related to the environment.

Indigenous Peoples and Local Community Involvement and Consultation

Policymakers, planners, and implementers of large infrastructure projects must ensure long-term benefits and co-benefits to IPs and LCs and nature. Where infrastructure impacts IPs and LCs, governments have a duty and other actors a responsibility to uphold the rights of these communities (see *UN Declaration on the Rights of Indigenous Peoples*). Planning, design, and construction processes must include obligatory practices that ensure all potentially affected stakeholders and rights holders have adequate opportunities to participate in and provide input on the decision-making process. Thus, it is necessary to properly inform and consult with local communities at all LI development stages and to build understanding of how LI may impact their livelihoods and social circumstances (Figure 6). It is important to understand stakeholders' perceptions of snow leopards in order to meet both human and snow leopard needs.

FIGURE 6.
WWF community consultations with local elders in the village of Passu, Northern Pakistan, through which the Karakoram Highway passes.
(Credit: Hamza Butt)

FIGURE 7.
Animals such as sheep and yaks are kept as livestock in snow leopard habitats. They are often left to roam freely, increasing their vulnerability to predatory attacks.
(Credit: Hamza Butt)

While LI development contributes to global, national, and regional economies, it can significantly impact communities near project alignments. While these impacts can be positive, they can also cause cultural shifts and changes in resource availability. This is particularly true in snow leopard landscapes where communities rely on natural resources, such as clean water and land for agriculture and livestock, for their livelihoods (Figure 7, Din et al. 2020).

Consulting and engaging IPs and LCs in LI project planning, design, and construction stages should be mandatory in identifying, minimizing, and mitigating negative impacts. Understanding the local context, including community values, political economy, conflict dynamics, and formal and informal power structures, will guide the design of the consultation process—considering the where, when, who, how, and what—and ensure it aligns with the grassroots circumstances. Because LI projects can stretch vast distances, identifying all stakeholders and ensuring their participation can be more difficult than for localized, small-scale projects. Stakeholders can include IPs and LCs far from proposed developments and even across borders into neighboring countries, presenting numerous challenges.

Human settlements in snow leopard landscapes are often very far apart. Ensuring community members can easily access consultations and planning multiple consultations in several sites are essential to enabling effective community involvement, both in letter and spirit.

It is vital to involve representatives from all interest groups while considering their unique circumstances to ensure that infrastructure development benefits as many households as possible. For example, nomadic and rotational grazing communities follow sustainable resource use models that require mobility. In contrast, high-mountain communities can spend long hours farming during certain seasons to produce often insufficient harvests. Gender roles might also vary, with men and women potentially available for engagement at different times of the day, week, or year. It is therefore important to be thoughtful about the timing and seasonality of consultations to ensure inclusive and equitable participation and socioeconomic safeguarding.

Early communication about the time and place of consultations allows communities to prepare and maximize attendance. In multilingual regions, translators might be necessary to overcome language barriers, which is essential for effective communication. Formal or informal consultation settings must ensure participants feel safe and comfortable sharing their views. Cultural context should also be considered; for example, some communities might prioritize avoiding conflict over voicing opinions, to maintain cohesion.

Facilitators should be selected based on their knowledge of the potential impacts of LI development on communities and local community language, contexts, and cultural dynamics. Moreover, facilitators must be able to accurately understand and document community views and suggestions during reporting. Getting Free, Prior, and Informed Consent (FPIC) is an extremely important part of the consultation process, and numerous toolkits and guidelines for FPIC are available to support this process. For example, the Food and Agriculture Organization's *Free, Prior, and Informed Consent (FPIC) – An indigenous peoples' right and a good practice for local communities* provides a valuable set of good practices (FAO 2016).

Snow leopard landscapes with increasing infrastructure development present an opportunity for ethical engagement with communities. As the pace of development can be rapid, everyone benefits from having processes ready and agreed on ahead of project plans. To ensure effective consultation, governments and the entities that carry out the consultation process should do the following:

- Ensure that public participation and consultation practices are outlined in legislation or legal frameworks, including providing sufficient time for thorough consultation.
- Aim to facilitate the broadest participation across the landscape affected by planned infrastructure; governments and project proponents should identify and use all available means to effectively reach affected communities and different groups within them and engage in thorough FPIC.
- Include local perspectives in decision-making concerning site selection, infrastructure design, avoidance, mitigation, and offset/compensation measures, as well as implementation and ongoing monitoring and evaluation.

FIGURE 8.
WWF data collection exercise with a park ranger from Khunjerab National Park. (Credit: Hamza Butt)

Multidisciplinary Technical Consultation

Similar to how interministerial collaborations reduce siloed thinking in policy development, multidisciplinary technical consultation on environmental components during all planning, design, and construction phases allows for more comprehensive and sound project development. This includes consulting with various engineering and planning experts, wildlife biologists, botanists, soil scientists, and people such as park rangers, foresters, local government authorities, and community-based institutions (Figure 8). Solutions developed by planners or engineers alone, without input from ecologists or environmental managers, are bound to be ineffective. For example, a project in India's Lumding Corridor included an underpass for elephants that was only slightly larger than the animals themselves and had to be upgraded at a later stage. Like most animals, elephants require a clear line of sight through a dark tunnel and adequate height and width to move through (Dodd et al. 2024). Elephants are now using the upgraded structure, and this successful upgrading was a result of collaborative efforts between forest department and highway development authorities.

Strategic Environmental Assessment, Environmental and Social Impact Assessment, and Cumulative Impact Assessment

Strategic environmental assessments (SEAs), environmental and social impact assessments (ESIAs) or environmental impact assessments (EIAs), and cumulative impact assessments (CIAs) play vital roles in fostering sustainable development by identifying and preventing environmental impacts. These are complementary assessment methods to ensure that environmental and social considerations are incorporated into decision-making processes at different levels and scales of infrastructure projects (Alshuwaikhat 2005). SEAs and ESIAs/EIAs focus on examining potential impacts caused by proposed actions, while CIAs also take into account combined impacts of a proposed project and other projects occurring in the past and in the surrounding area. They all provide data and analysis to support sound decision-making. However, they focus on different parts of the decision-making process; SEAs require the review of "strategic" processes such as policies, plans, and programs and are performed during the planning and consultation phase, while EIAs are for individual projects and occur during the design phase. At the national level, ESIAs or EIAs are the most common legally mandated tool for assessing project impacts and identifying mitigation measures. CIAs are less common but provide a much more holistic overview of landscape-level impacts.

In snow leopard landscapes, procedures such as ESIAs and SEAs are often compromised and not based on data and knowledge, due to growing economic development needs, limited capacity of environmental protection agencies and consultants, lack of political will, outdated regulations, and weak legislative procedures (Khan et al. 2020). Furthermore, the assessments are often completed too late in the decision-making process. By the time a project is proposed, various decisions have usually been made, making it sometimes impossible or too costly to design alternatives or build in appropriate avoidance and mitigation measures (Wingard et al. 2014). The lack of both knowledge of the infrastructure impacts on nature and society and approaches to mitigate those impacts exacerbate the problem.

LI is important to local and regional economies. Governance by multiple local, national, and even international agencies can complicate the implementation of environmental standards. Several resources provide guidance on conducting SEAs, ESIAs/EIAs, and CIAs, including the International Association of Impact Assessment's *SEA Performance Criteria* (IAIA 2002), the Development Corridors Partnership's *Impact Assessment for Corridors: From Infrastructure to Development Corridors* (DCP 2022), the United States Environmental Protection Agency's *Interim Framework for Advancing Consideration of Cumulative Impacts* (EPA 2025, in draft form), and the UNEP's *International Good Practice Principles for Sustainable Infrastructure* (UNEP 2022), which provides guidance on ensuring sustainability across the infrastructure project life cycle.

Climate Risk Assessment

As climate change accelerates, extreme events such as landslides, floods, avalanches, fires, windstorms, and droughts are expected to increase, greatly threatening linear infrastructure in snow leopard landscapes. Protection of these critical ecosystems requires thorough climate risk assessment during project planning and development as part of the SEA, using a watershed-wide approach for comprehensive evaluation.

Climate risk assessments involve defining present and future climate scenarios and identifying potential hazards, such as floodplains and river channels, areas prone to landslides, avalanche-prone zones, and areas susceptible to wildfires and windstorms. After identifying hazards, evaluating areas of vulnerability in the infrastructure project is crucial. This includes determining the infrastructure's direct exposure to potential hazards and assessing the susceptibility of infrastructure components to damage from specific hazards.

Along with identifying areas of vulnerability, potential damage costs should be estimated. Economic losses can be calculated by assessing the direct and indirect costs of infrastructure damage, including repair, replacement, and operational disruptions. The environmental and ecological consequences of infrastructure damage, such as habitat fragmentation, erosion, and pollution, should also be determined.

With climate change causing more powerful, unpredictable, and extreme weather patterns, considering ways to prevent infrastructure from being damaged in the first place is most cost-effective. Infrastructure construction should be avoided in areas with high hazard potential, such as steep mountain slopes, gorges, and floodplains. Climate-resilient design features—including reinforced structures, drainage systems, erosion control measures, and NbS such as maintaining wetlands and mangroves to absorb water—should be considered during the design and construction phases. Future water flow scenarios should be used to design bridges and culverts to avoid loss. Early warning systems should be established to detect and monitor potential hazards and provide timely alerts to local communities and infrastructure operators. Emergency response plans should also be developed.

By conducting comprehensive climate risk assessments and implementing effective mitigation strategies, stakeholders can significantly reduce the negative impacts of linear infrastructure on snow leopard landscapes and minimize financial losses.

FUTURE RESEARCH:
Designing LI to avoid, minimize, and mitigate impacts on snow leopards and their prey requires strong baseline data on the distribution of habitat features the animals require and their movement corridors. It is important for researchers to gather and map this information and for decision-makers to use it to make project mitigation measures effective and reduce long-term financial risks.

Design

Designing LI relies on multidisciplinary planning. It is an iterative process of decision-making and trade-offs. Designers choose the infrastructure vertical and horizontal alignments, plan for drainage and water conveyance systems, select materials and methods, and make detailed design choices such as foundation and surface types and structural elements. Approaching infrastructure design with nature-positive approaches allows designers to plan for additionalities by using NbS and hybrid solutions, understand how to promote ecological connectivity and ecosystem services, and evaluate the infrastructure's and nearby ecosystems' resilience to critical climate and natural events.

ESIAs determine the potential negative or positive effects of preliminary designs. Then the design is revised to incorporate safeguards and avoid/minimize impacts, and mitigations are designed to address unavoidable impacts. The design process also includes life cycle assessments of the planned materials to understand their environmental effects throughout the project's life cycle, including construction and material transport, operations and maintenance, and decommissioning. Life cycle assessments can be useful to understand a project's carbon output or footprint and the impacts of material sources such as extraction and production techniques, energy usage, and disposal.

Selecting Relevant Mitigation

Effective mitigation measures are critical to reducing project impacts and preventing further habitat degradation. A growing body of experience and research helps enhance understanding of the technical and economic feasibility of various mitigation measures and management activities designed to reduce LI's impact on wildlife (Andrews et al. 2015; Barrueto et al. 2014; van der Ree et al. 2015). Mitigation measures have proved increasingly important to help address LI's impacts on other species such as the Asian elephant (Alamgir et al. 2017; Ament & Bell 2021; Dodd et al. 2024).

FUTURE RESEARCH:
Along with understanding what types of crossing structures snow leopards and their prey might use, engineers must design solutions that meet the behavioral needs of animals and are viable in the diverse and often geologically complex landscapes they inhabit.

Conservation practitioners and development officials working in snow leopard ranges can use lessons from other species and studies as learning material and guidance. Knowing how, when, how far, and why snow leopards move is essential to developing appropriate avoidance and mitigation strategies. The design of mitigation measures should carefully consider the abundance of target species, their behavior, geographical features of the target area, and the availability of water sources and food for the target species. A site-specific understanding of habitat use, presence, and movement should inform mitigation, and implementation depends on site-specific contexts and goals.

Mitigation can be structural or nonstructural. Structural components are the on-site physical construction activities to facilitate wildlife use, including guiding fences, noise barriers, overpasses, and underpasses. Nonstructural components consider human behavior alteration through awareness, sensitization activities, and traffic-calming measures such as speed meters, signage, speed bumps, and crash barriers.

No specific infrastructure crossings have been designed for snow leopards, but existing mitigation measures designed for species such as tigers and leopards can be a starting point for mitigation design. To effectively design and test mitigation measures, further research is essential and will require collaboration among biologists, ecologists, animal behaviorists, planners, and engineers. This collaboration is especially critical due to the limited understanding of snow leopard movements and habitat use. Moreover, appropriate mitigation strategies are likely to differ based on location, terrain, and other site-specific factors, emphasizing the need for tailored and well-informed approaches.

FIGURE 9.
Camera trap image of a common leopard (Panthera pardus) *passing beneath a flyover at the Lal Tappar crossing in the Rajaji Tiger Reserve. This image is for illustration; over- and underpasses in snow leopard habitats, especially in mountain ecosystems, will have a different design.*
(Credit: © WWF-India/Uttarakhand Forest Department)

FUTURE RESEARCH:
For preexisting LI, collision and other mortality data combined with hot spot analyses can help to identify priority locations where fencing, crossing structures, warning systems, and other forms of mitigation should be installed.

Wildlife Crossing Structures

Overpasses and underpasses are passages constructed either above or beneath LI, predominantly roads and railways, that are designed to allow wildlife to move from one side to the other. Crossing structures can take many forms, from culverts to viaducts and flyovers (Figure 9; see Dodd et al. 2024, pp. 21–22). Not only do overpasses and underpasses provide crossing locations to reconnect habitat, but when paired with appropriate fencing, they can decrease the potential for collisions with wildlife (Donaldson & Elliott 2021).

While overpasses and underpasses can functionally connect habitat for wildlife and maintain ecosystem services, they can involve a significant additional cost. Fortunately, financial institutions increasingly are funding these forms of impact mitigation (see Finance section). Furthermore, various options carry different costs, and underpasses, which are much less costly than overpasses, may be the best option. For a road upgrading project, an even lower-cost option than creating new underpasses is to modify existing culverts to increase their attractiveness to snow leopards for crossing (Smith et al. 2015). For example, dry ledges in culverts are known to increase use by some species (Soanes et al. 2024). A project in the Atlantic Forest in Argentina is modifying existing culverts under a road by adding dry ledges made of concrete to one side of the underpass above the water level. Since the installation of the sidewalks, ocelots (*Leopardus pardalis*), a species known to avoid water, have begun to use them frequently (L. Lazzari, pers. comm.).

Identifying the locations for overpasses and underpasses, their dimensions, and their spacing is crucial to ensure their effectiveness. Underpasses should be placed at locations of natural depressions in the landscape that wildlife may already use for travel. Natural depressions contribute to maintaining a line of sight—if animals cannot see through the underpass to detect a destination on the other side, they are less likely to use it. On the other hand, overpasses should be constructed to strategically match the vicinity's geographic context by maintaining gentle slopes on the approaches (see further detail in Dodd et al. 2024, p. 25). The dimensions of the mitigation measures should be carefully evaluated to accommodate the species in the area.

Underpass designs should consider the body size of the species expected to use it (Figure 10) and accommodate their space and behavioral needs using the openness index (see below), which measures the height and width of and visibility through the structure. Other underpass characteristics, such as the acoustics, the substrate (including whether there is water and sand), and the presence of additional features such as brush for cover, should also be considered.

As noted above, to our knowledge, crossing structures have not been built for snow leopards, and data regarding what snow leopards will

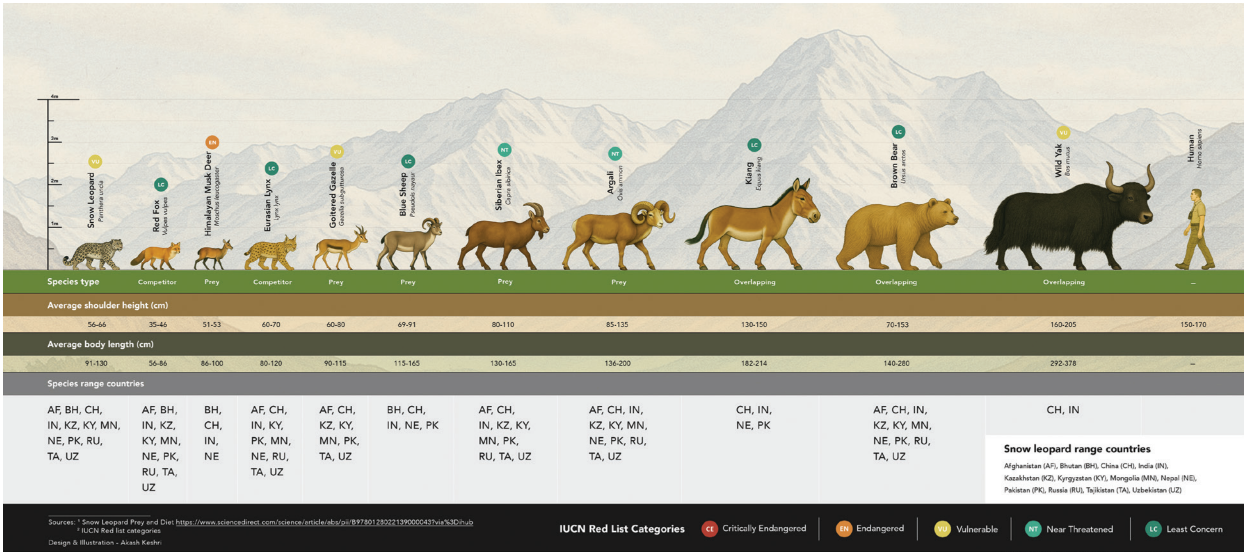


FIGURE 10.
Comparative body sizes of species, including prey and the largest species, in snow leopard habitats. To accommodate all local species, underpasses might be designed to accommodate the largest species.
(Designer: © Akash Keshri)

use are lacking. Snow leopard behavior experts need to work with engineers to design mitigation solutions that snow leopards are likely to use and to follow up by monitoring the mitigation structures with, for example, camera traps to verify their use. Because this is a new area of study, developing designs animals will use might take several iterations, so it is valuable for teams to disseminate their results.

Openness Index

The openness index (OI) is the relationship between the dimensions of an underpass—that is, the area of the opening—divided by the distance through the structure.

$$OI = \frac{\textit{width x height}}{\textit{length}}$$

The OI provides a metric to address a species' likelihood of using an underpass based on its visibility and comfort. The greater the OI, the higher the chances of wildlife using the underpass. Longer underpasses require a larger opening than shorter ones. *The Handbook to Mitigate the Impacts of Roads and Railways on Asian Elephants* (Dodd et al. 2024) provides an excellent guide to calculate the OI and to design appropriate structures for a target species. As data from snow leopard regions are limited, existing guidelines will be highly valuable in informing the design and testing of underpasses and other mitigation measures.

> **FUTURE RESEARCH:**
> Overpasses and underpasses and other forms of mitigation can be designed not only for snow leopards and their prey but also for other species of conservation concern, including small mammals.

Fencing

Funnel Fencing

Fencing can be used for various purposes to mitigate LI's impacts on wildlife. To successfully have wildlife use crossing structures, fencing is combined with the structure to funnel wildlife toward the crossing and prevent them from attempting to cross elsewhere. This combination

FIGURE 11.
Fencing leading to a wildlife jump-out, designed for wildlife (e.g., ungulate) escape upon accidental entrapment inside of the roadway, along Interstate 25 in Colorado, United States.
(Credit: Tremaine Gregory)

helps reduce unsafe crossings and the potential for collisions with vehicles. However, if animals find their way past the fencing because of a fencing failure, for example, the fences can trap the animal inside the roadway, making a collision very likely. For this reason, fencing along LI often includes a jump-out—a ramp to allow animals to escape should they be trapped in the roadway (Figure 11). Snow leopards might be able to climb over many types of fences, but their ungulate prey are highly likely to be impacted by fences.

Mitigating Barrier Fencing

International border fences can cause substantial impacts because of their extensive length and challenges in reconciling the needs of wildlife populations with the national security goals of the fences (Linnell et al. 2016). However, attempts have been made to address those competing needs. In 2016, Kazakhstan adopted measures to mitigate the impact of the fence on its border with Uzbekistan on saiga antelope migration. Following the recommendations made by Olson (2013), the bottom barbed wire was removed at 125 locations along a 150-km stretch of border fence. The measures were ultimately unsuccessful because of the failure to mitigate the impacts of the adjoining new railroad infrastructure, preventing the saiga from accessing the crossing points along the border.

A different project, following the same approach, aimed at restoring the ecological connectivity of Kazakhstan with Uzbekistan and Turkmenistan for Persian leopards and their wild prey, is seeing some success (Pestov et al. 2024). In Tajikistan, deploying "virtual fence" technology has allowed the border to be remotely monitored while detecting, in real time, attempts to cross. Another option includes creating openings in the border fence that are monitored through video cameras, "virtual fence" technology, or camera traps that can send information in real time through LoRa networks or satellite connection.

FUTURE RESEARCH:
Fencing can be designed to keep some species out and others in. It is important to develop solutions tailored to the local context, keeping both wildlife and livestock safe.

Mitigating the Impacts of Fencing: A Case Study in Mongolia

The fencing along various railroads and roads in Mongolia, designed to keep livestock away from railway tracks, has become a significant environmental concern. These fences act as barriers, hindering wildlife movement and fragmenting their habitats. Additionally, climate change is altering the migration patterns of nomadic species, causing them to deviate from their traditional routes, and increased habitat fragmentation due to fencing inhibits this adaptation. These issues highlight the need for new fencing regulations that address these challenges.

In response, WWF-Mongolia, through the USAID-funded Asia's Linear Infrastructure safeGuarding Nature (ALIGN) Project, collaborated with the Ministry of Road and Transport and the Ministry of Environment and Tourism of Mongolia to create a national standard for wildlife-friendly fences. In May 2024, after extensive collaboration among stakeholders, the Mongolian Agency for Standard Metrology approved the national standard called "Barrier fences for railways and highways, General requirements MNS 7042:2024" (MNS 7042 2024). This standard is part of a broader effort to balance infrastructure development with environmental conservation, protecting species and their habitats while supporting Mongolia's economic growth.

Key features of the standard include

- using non-barbed fences: preventing wildlife from getting caught and injured (e.g., Figure 12)
- permitting wildlife movement: ensuring that fences allow free movement of wild animals, which is crucial for migratory species, including the wild ass, goitered gazelle, Mongolian gazelle, argali, ibex, and Mongolian saiga
- keeping livestock contained: designing fences to allow wild animals to move freely while preventing livestock from crossing the fence

The standard, effective since June 4, 2024, is being implemented by two railroad companies for their planned fences in Southern Mongolia, home to endangered ungulate species. This standard aims to mitigate or reduce the negative impact of problematic fences along LI. Consequently, it will facilitate the movement of migratory species and those with isolated populations, such as the snow leopard, ensuring their long-term survival through well-positioned, wildlife-friendly passages.

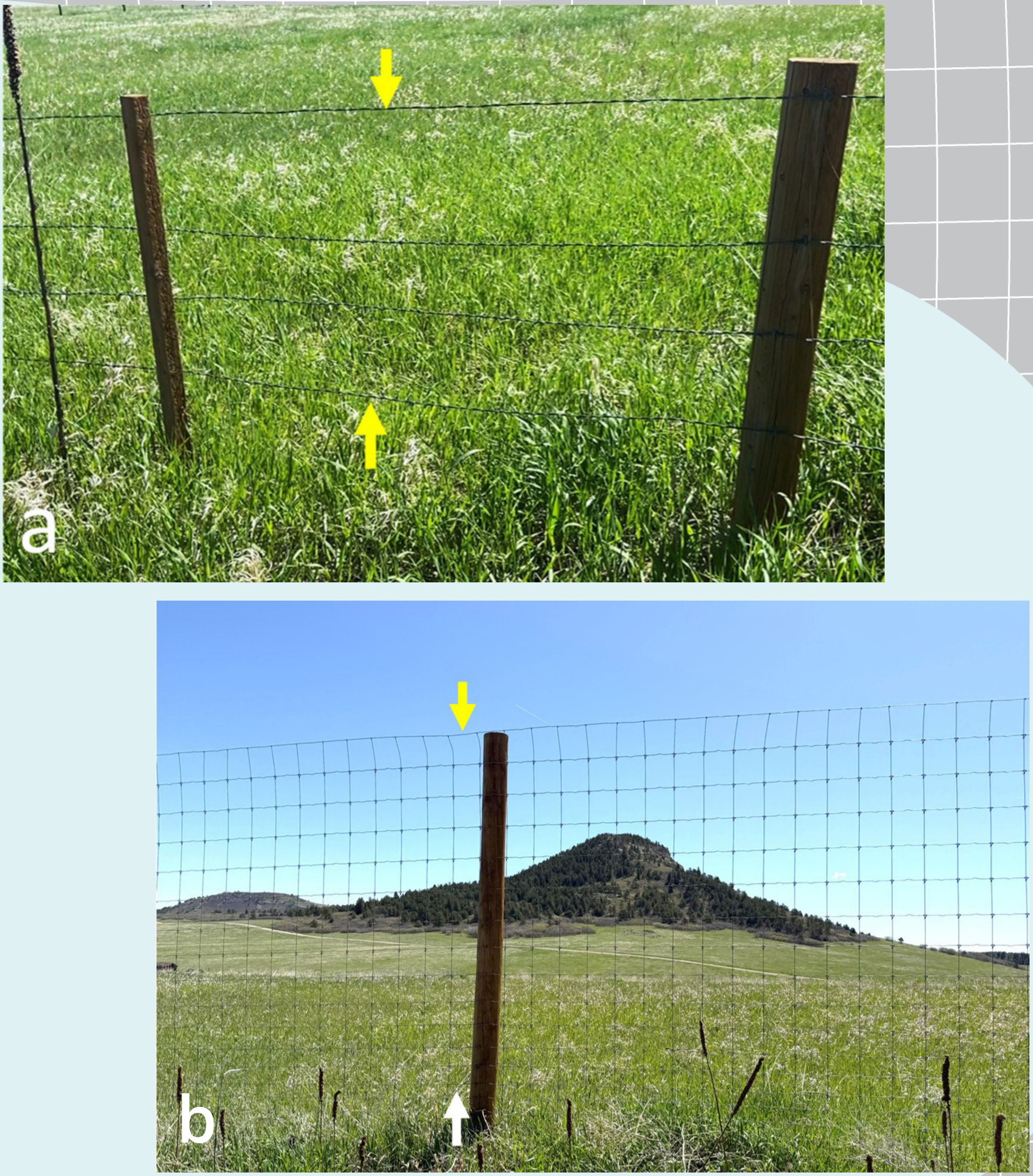


FIGURE 12.
Types of wildlife-friendly fencing along Interstate 25 in Colorado, United States, ***a)*** *to allow wildlife passage [no barbs on the top and bottom wires (yellow arrows)] into highway underpasses but prevent livestock escape and* ***b)*** *to keep wildlife out of the roadway with mesh with wires further apart at the top to prevent large mammal passage (yellow arrow) and closer together at the bottom (white arrow) to prevent small mammal passage.*

FUTURE RESEARCH:
A variety of warning systems should be evaluated, adapted, and tested in different contexts to compare their effectiveness in reducing wildlife mortality and augmenting driver safety.

Signs and Warning Systems

Various signage and wildlife warning systems exist, with variable results, to alert drivers of crossing wildlife and prevent collisions. Stationary signs do not tend to have much effect on driver behavior because reinforcement of sign messaging is rare—rarely do animals appear when drivers see signs (Huijser et al. 2015). Various types of warning systems—called animal detection systems (ADS)—can be more effective in detecting wildlife and preventing collisions. ADS use different types of sensors, including thermal, infrared, and motion, to detect wildlife approaching a road and warn drivers via signs that light up. ADS have predominantly been used in North America and Europe, where they are substantially more effective than stationary signs (Huijser et al. 2015). They have never been used for snow leopards and require heavy testing and maintenance. However, they remain a mitigation option to consider at points where collisions are likely and construction of overpasses or underpasses not possible due to cost or landscape constraints, such as prohibitively steep mountain slopes.

Mitigation to Alter Driver Behavior

Along with warning signs, other mitigation methods can be used to reduce vehicle speed, which is the main reason collisions with vehicles occur. Speed detection systems can alert drivers to speeding and, when paired with enforcement, can encourage drivers to slow down. Time card systems, which record the time of entry and exit of vehicles, can be used on stretches of road that pass through PAs or other critical habitat areas to help maintain vehicular speed. Because drivers can be tempted to drive as rapidly as the design of a road permits, increasing a road's sinuosity (the degree to which the road meanders around curves), adjusting the grade, or adding speed control bumps or humps can help slow down vehicles. Visibility along sinuous roads can be improved with vegetation management, convex safety mirrors, and other reflective devices, and choosing appropriate design criteria such as increased stopping sight distance. In national parks and other controlled natural areas, roads can be closed or patrolled more heavily at night or when drivers and wildlife are most at risk.

FUTURE RESEARCH:
Roadway engineers can test different driver speed reduction options to select those that are most effective in different regions and contexts.

Tender and Finance

The tender and finance stage of infrastructure development involves soliciting bids from contractors and securing funding for the project. The first step is developing a comprehensive plan for the project, including technical details—often named the "detailed project report"—and then using that plan to attract contractors and financial institutions.

Financing

While thorough environmental and social due diligence is generally a pre-requisite to financial approval of LI projects, the standards for and quality of the due diligence processes can vary significantly. Environmental and social due diligence assists a lender in deciding whether to support the proposed project and, if so, how environmental and social risks and impacts will be addressed in the project's assessment, development, and implementation.

LI projects, particularly in emerging economies, are often financed with public resources (e.g., tax revenues and government borrowing), although private financing options are on the rise. When projects are financed by multilateral development banks (MDBs), for example, due diligence should focus on all facets of the development finance institution's operations manuals and, in particular, relevant environmental and social safeguard policies. Even though financial institutions have their own sets of environmental and social standards, the policies across most MDBs are similar and typically are based on the policies of the World Bank (Ament et al. 2023, Chapter 6). The World Bank's 2018 Environmental and Social Framework for public clients and the International Finance Corporation's 2012 Performance Standards (IFC 2012, Chapter 3) for private clients are considered good industry international practice for multilateral, bilateral, and commercial loans (Losos et al. 2019). Additional consideration should be given to the approach and methodology for developing a project's cost-benefit analysis. When possible, a scenario-based cost-benefit comparison between different levels of safeguarding measures should be used, which enables financiers to better understand and compare project life cycle costs, including appropriate safeguard measures.

China's Belt and Road Initiative (BRI), launched in 2016, and the emergence of associated financial institutions such as the Asian Infrastructure Investment Bank (AIIB) and the New Development Bank (NDB) have changed the landscape of LI development globally. The People's Republic of China is cognizant of the potential detrimental impacts on nature and biodiversity of BRI investments absent mitigation measures.

To streamline and coordinate sustainable LI investments, the BRI International Green Development Coalition (IGDC) was established soon after the conclusion of the second Belt and Road Forum in April 2019. The main goal of the IGDC is "to promote international consensus, understanding, cooperation and concerted actions to realize green development on the Belt and Road, to integrate sustainable development into the BRI through joint efforts and to facilitate BRI participating countries to realize SDGs related to environment and development." The IDGC, supervised by the Chinese Ministry of Ecology and Environment, publishes many policy documents and guidelines to enable host countries and companies to integrate environmental considerations throughout a project's life, from planning to construction, management, and deconstruction, as well as information disclosure. AIIB published its Environmental and Social Framework in 2016 (last updated in 2024, AIIB 2024), which lists "Conserving Biodiversity" as Objective 17, with further elaboration in its Environment and Social Standard 1. In contrast, the NDB uses the national systems of the member countries, which typically have lower standards, instead of commonly agreed-upon safeguards to address environmental, social, and procurement risks.

Procurement

Public procurement processes are often perceived as cumbersome, bureaucratic, and generally motivated by a "least cost" approach to selection. This can undermine opportunities to introduce less conventional or difficult-to-quantify green or sustainability objectives. However, as governments have changed procurement policies to reflect technological advances (such as e-procurement practices aimed at improving transparency and efficiency) and data accessibility, they have introduced more sustainability criteria into the procurement processes for goods, services, and works. Green or sustainable procurement policies advantage project bids that include sustainability provisions in the project design, such as low or negative carbon costs, biodiversity considerations, and mitigation measures (e.g., wildlife crossings); sustainable verge development and management; and the use of sustainably sourced and lower-impact construction materials.

Various procurement models are used for sustainable infrastructure projects, each with unique implications for integrating sustainability measures. Common models include design-bid-build, design-build, construction manager at risk, and public-private partnerships. While this guidance does not consider the merits and opportunities associated with embedding sustainability approaches within these models, an important common thread is that all stakeholders in the procurement process are strongly committed to and understand how to deliver sustainability in LI projects. Without green procurement policies, government agencies responsible for selecting the winning bid have no basis for selecting more sustainable bids if, for example, they involve a higher cost.

In 2023, the Heads of Procurement network of the MDBs issued a joint statement that reflects the collective intent for sustainable procurement. The statement recognizes the role of procurement in supporting the SDGs and the long-term development plans of the banks' client countries. The banks collectively identified the need for a common approach to procurement and underscored the importance of better integrating environmental, social, economic, and institutional considerations into procurement policy and practices.

Case Study From Kaligandaki Corridor, Nepal

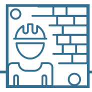
Nepal recently estimated it has 397 snow leopards. The Kaligandaki corridor is a 435-km north-south national highway from Triveni, on the border with India, to Korala, on the border with China. Almost 250 km of this highway is within the snow leopard habitat in the Annapurna Conservation Area, which crosses through the fragile Himalayan desert ecosystem. Development progress varies between sections of the highway, with some sections still under construction and others fully operational. One section in Charang includes provisions for an Initial Environmental Examination, which requires that the highway plan address the related environmental and social needs to minimize adverse impacts.

Since Nepal's shift to federalism in 2015, development of local roads has surged countrywide because of the local government's ability to access novel revenue streams. However, the local roads connecting to the Kaligandaki corridor highway lack sustainability planning and implementation because of limited technical human resources and capacity. This has led to redundancy and overlap between road corridors and a lack of proper environmental assessments, contributing to biodiversity loss. For example, improper disposal of materials leads to increased sedimentation load in the downstream rivers. These roads also directly and indirectly impact snow leopards and their prey during the operation phases, including through the loss of vegetation, unstable slopes, and pollution.

The environmental mitigation plan for the highway requires soil stabilization, and methods are still being tested for this fragile desert ecosystem (Figure 13). It also requires upgrading the existing water transmission structures to widen them, allowing debris to flow and wildlife to use them as underpasses. Unfortunately, the local roads rarely undergo any environmental scrutiny.

FIGURE 13.
The Kaligandaki corridor highway with gabion walls in the Charang region.
(Credit: Pramod Neupane)

Construction



FUTURE RESEARCH: Construction mitigation measures should be adapted to local ecosystems and wildlife populations, especially as ecosystems and behaviors change over time.

Following design, the physical work of implementing an infrastructure project plan occurs during the construction stage. This process involves site preparation, excavation, foundation work, the construction of the infrastructure, and associated activities like slope stabilization. The main contractor is responsible for implementing the design plans, documenting progress and compliance, achieving the desired system performance (in performance-based contracting), and obtaining approvals from technical experts and inspectors. Construction activities may have long-term and short-term impacts on the environment, especially where they deviate from the plans. The means and methods used in each project, which might differ depending on the landscape, should be considered, as well as the completed project.

Water Management

Careful planning of road drainage is essential for stabilizing slopes and controlling erosion during construction and use. The site's original topography and hydrology should be considered, and understanding vegetation associations with slope and drainage is vital for successful restoration (Gullison et al. 2015). Implementing construction-based stormwater controls, stream restoration, and permanent sustainable stormwater management practices can prevent water degradation and its cascading effects (Montgomery et al. 2015).

Mismanagement of water can present a major threat to infrastructure; proper management benefits the infrastructure and the species that depend on the water. Water management systems, including subdrains, culverts, bridges, and drainage ditches, should consider current and projected future water flows (see Climate Risk Assessment section). If possible, they should also permit wildlife movement, including that of aquatic and terrestrial species.

FUTURE RESEARCH: Culverts can be valuable for wildlife movement. Including design features such as a natural substrate may encourage crossing by wildlife. It is important to monitor to evaluate wildlife use.

Drainage structures such as culverts and bridges can include a dry area or a bench/platform along the side to allow terrestrial species movement, making them more wildlife-friendly (Keller 2023). Culverts should also be bottomless, as concrete bottoms can cause the formation of a waterfall at the outlet, which can become a barrier for species (Keller 2023). In addition, roadside ditches should be carefully designed to avoid trapping small mammals and other species and incorporate design elements to capture trash and treat pollutant runoff.

In general, drainage designs should avoid concentrating water in areas where it was not concentrated previously. If the concentration of hillside runoff is unavoidable, for example, via collection in a curb and gutter and transmission across the infrastructure through a culvert, the water should be dissipated to reduce flow velocity and returned to sheet flow or subsurface flow with level spreaders, T-spreaders, infiltration basins, and so on. Drainage outfalls should be downhill of any improvements, including any constructed slopes, to avoid saturating the subsurface interface or causing surface erosion.

Slope Stabilization, Erosion and Sediment Control, and Vegetation Management

During LI planning and construction, special attention must be given to soil types, gradients, slope shape and length, and water diversion and dissipation to minimize erosion risk and the loss of natural vegetation (Hamilton & McMillan 2004). When vegetation is removed or soil is moved in building infrastructure, the potential for erosion, sediment transfer, and landslides increases. The result can be higher levels of silt and other pollutants in nearby water bodies, pavement cracking and failure, and additional and even uncontrollable soil movement, particularly in the mountainous regions where snow leopards live. For this reason, slopes must be well managed and stabilized.

FIGURE 14.
Building resilient infrastructure through tunnel slope stabilization on the Karakoram Highway, Hunza, Pakistan.
(Credit: Hamza Butt)

Slope stabilization solutions are temporary during construction and might include rolled erosion control products or temporary ground cover with vegetation or other organic materials like straw or mulch. Fiber- or wool-based erosion-control blankets, which are organic alternatives to synthetic, nonbiodegradable geotextile materials, have proved effective in reducing soil erosion and water runoff and improving the environment for revegetation, as they can act as slow-release nitrogen fertilizers due to their gradual decomposition (Ament & Bell 2021).

Once the project is complete, the slopes should be permanently stabilized (Figure 14). Several methods can be used to permanently stabilize slopes; among them are the construction of engineered fill slopes and retaining walls, and the use of soil terracing and riprap (loose stone used to maintain slopes) or native vegetation to hold the soil in place. Some products that

FUTURE RESEARCH:
It is important to evaluate local vegetation to select species that are appropriate to the geography/terrain, seasonality, and soil type and to evaluate how long they take to become established and their ability to hold soil in place in relation to the length of time erosion control is needed.

can be sprayed onto hillsides contain seeds and a tackifier to stabilize the soil surface and establish ground cover. However, applying sprayed products must be carefully planned around precipitation to avoid washouts or germination failures. Slope stabilization planning should always include drainage plans, with extreme rain and water flows in mind. For more information on restoration and using native plant species to combat erosion, see the Restoration section.

Mitigation of Construction Impacts

To mitigate the environmental impacts of construction, a comprehensive suite of best practices should be implemented to minimize disturbances and protect the surrounding ecosystems. Soil disturbance should be minimized by confining activities to delineated work zones and staging areas. High-visibility fencing/signage should mark sensitive habitats and species, water bodies, and wildlife corridors to prevent encroachment.

Construction crews should receive thorough training in identifying and avoiding sensitive species and habitats and general construction best management practices for dust and erosion control, proper waste disposal, and safe operations near waterways and slopes. Materials should be stored and managed to prevent runoff. Equipment should be inspected regularly to avoid fluid leaks, and idling should be limited to reduce emissions and noise. Work should be scheduled to avoid critical periods for wildlife, such as migration seasons for snow leopard prey, and noisy activities should be restricted during early morning, evening, and other sensitive periods. Ongoing environmental monitoring during construction enables adaptive management if unanticipated impacts arise.

Building LI requires extensive human labor, encampments for construction teams, and additional supporting infrastructure. LI construction sites and crews can have major, although often site-specific, short-term effects on wildlife populations and habitats. The potential impacts of these crews must be recognized and minimized. In the Himalayan countries, relatively large crews of workers, instead of heavy construction equipment, typically perform LI construction. These workers usually migrate from other parts of the country for the project's duration and live with basic amenities in camps within these harsh environments. Workforces often depend on local biomass for shelter, and fuel for warmth and preparing food. In addition, waste disposal and residual items might unnaturally attract wildlife in the area, resulting in negative interactions between humans and wildlife. Incidents of illegal wildlife hunting and removal of medicinal plants can increase as a consequence of construction camps in snow leopard landscapes. The construction is often slow, and the workforce remains in the snow leopard areas for a prolonged period, causing continuing disturbance. Such disturbance and pressures may be long term for areas that need continuous maintenance even after the infrastructure is completed.

Because agencies such as forestry departments have difficulty monitoring and enforcing laws in remote construction camps, they must be informed of the work schedule and the labor force in the area. Construction crew camp impacts should be considered in ESIAs and include conditions to minimize harm to snow leopards, their habitat, and their prey due to the camp and work crew presence. Under these conditions, the construction agency or contractor must be obligated by the authority to provide sufficient fuel and food for the work crews. Campsite selection should ensure they are not in or near sensitive areas such as snow leopard movement corridors, prey fawning sites, or wetlands.

Furthermore, there should be adequate methods to dispose of debris and waste. Work in such areas should efficiently minimize the crew's stay. Continuing awareness programs with clear messages targeted at the contractors and labor force can be crucial in minimizing harm. Importantly, the welfare of the workforce must always be kept in mind. Food and shelter in LI construction camps often attract feral dogs. Workers at these camps may inadvertently provide food scraps, which can draw feral dogs from surrounding areas (Figure 15). The temporary

FIGURE 15.
A feral dog pack along the road in North Sikkim, India.
(Credit: Rohan Pandit)

structures and waste the camps generate offer shelter and scavenging opportunities. Effective waste management and community awareness programs are essential to mitigate these impacts and ensure the safety of the construction workers and the local ecosystem. When the workers leave construction sites, these dogs remain feral in the landscape. They can become a major threat to wildlife, including snow leopards, wild ungulates, and domestic livestock (Home et al. 2017). Authorities must require LI contractors to manage feral dog populations after construction to prevent their further impact. Mitigating the impacts of feral dogs might include removal or sterilization and vaccination programs, as was done in Uttarakhand, India (Kotnala 2023).

Restoration

Ecosystem restoration encompasses a wide range of activities, including removing contaminants and pollutants near transportation corridors, reconstructing or mimicking natural terrain, rehabilitating ecosystem functions and services in areas degraded by infrastructure construction or operation, restoring existing degraded areas where infrastructure is planned, and assisting in recovering ecosystems to their original trajectories had degradation not occurred, or, better yet, to a healthier and more biodiverse state contributing to a nature-positive outcome (FAO et al. 2021). Any restoration effort should begin with understanding baseline conditions, based on assessments conducted before LI construction, to determine the type of ecosystem to be restored. Identification of the direct and indirect causes and the magnitude of ecosystem degradation due to road operation is imperative so that appropriate actions can be taken to control, minimize, or eliminate the drivers of degradation (FAO & UNEP 2023).

Restoring and promoting vegetation on slopes is fundamental to controlling erosion and mitigating the residual impacts of road construction. Mountains are particularly susceptible to species invasion, especially when disturbed, so eroded areas should be stabilized and restored with native species, and invasive species should be eradicated (Wingard et al. 2014). Restoration projects in high-altitude regions should consider how climate change exacerbates the situation, for example, by creating more favorable conditions for invasive species. Restoration efforts should include a diversity of native species reflective of the original vegetation cover, which might require a stock of germplasm (seeds, cuttings, seedlings) collected from the site before road construction or from nearby areas. Additionally, organic soil material from the site should be collected and stored for later use during restoration (Gullison et al. 2015).

FUTURE RESEARCH: Experimentation may be required to identify restoration techniques that work for particularly harsh climates or steeply sloped areas. This might include methods with native vegetation or, where vegetation will not grow, use of other materials.

Operations and Maintenance

During the operations and maintenance (O&M) stage of infrastructure development, the focus shifts to ensuring the infrastructure's long-term functionality and sustainability. This involves various activities, including routine inspections, preventive maintenance, repairs, upgrades, and ensuring ongoing compliance with relevant regulations. Essentially, O&M keeps the infrastructure running efficiently and effectively while extending its useful life.

FUTURE RESEARCH: Verge management strategies should be tailored to local conditions, and experimentation and adaptive management may be necessary to determine the best methods for each context.

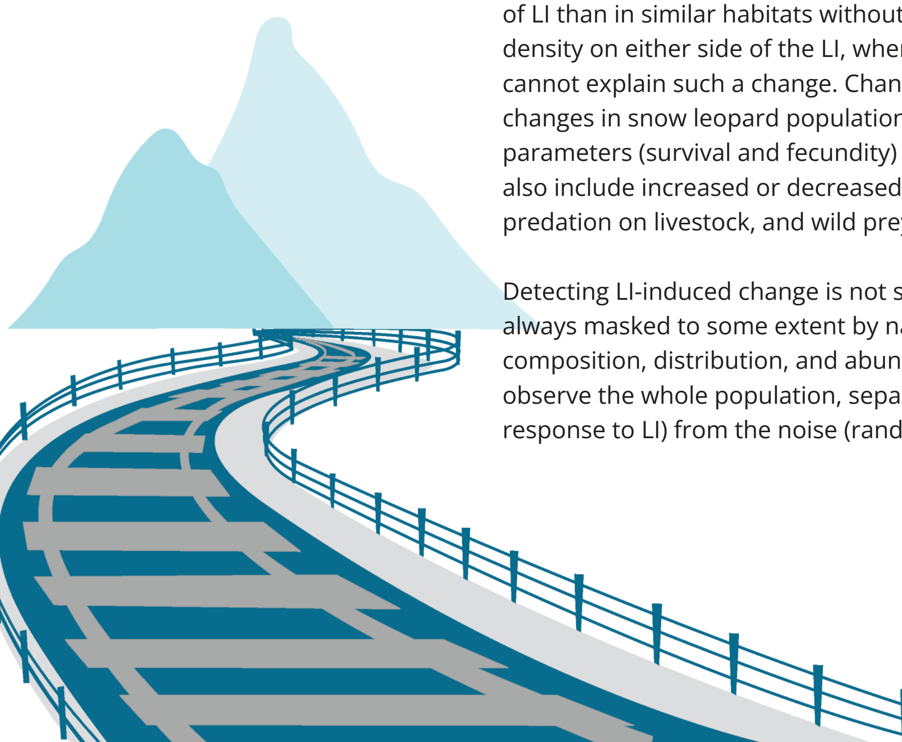
Verge and Vegetation Management

Road verges are the strips of land adjacent to roads and railways. Estimated to cover 270,000 km^2 worldwide, they provide many ecosystem services, including air and water filtration and the storage of approximately 0.015 Gt of carbon per year (Phillips et al. 2020). Verges without high, woody vegetation provide better visibility for drivers on roads that wildlife regularly approach, enabling them to slow down to avoid collisions (Hegland & Hamre 2018). However, verges can also be used as travel corridors for non-native plant species (Turner et al. 2021). Herbaceous vegetation and roadkill attract ungulate grazers and scavengers to verges, increasing the potential for collisions (Dean & Milton 2003; Seiler et al. 2016). Verge management plans should consider potential impacts and benefits to snow leopards and their prey.

Monitoring and Evaluation

Monitoring and evaluation represent key components of project implementation, especially given the long time frame of the impacts caused by most LI projects. In this context, the main purpose of monitoring is to assess LI impacts on snow leopard populations, including changes over space, over time, or both. Changes over space might appear as a lower or higher density of key species in the vicinity of LI than in similar habitats without the LI. Or it could be a difference in density on either side of the LI, where habitat or other spatial variables cannot explain such a change. Changes over time might appear as changes in snow leopard population abundance or demographic parameters (survival and fecundity) over time, or both. Changes can also include increased or decreased human-wildlife interactions, predation on livestock, and wild prey switching.

Detecting LI-induced change is not straightforward because it is always masked to some extent by natural randomness in population composition, distribution, and abundance, so that even if one could observe the whole population, separating the signal (change in response to LI) from the noise (randomness in population composition,



distribution, and abundance) might not be easy. To make the task more difficult, snow leopards are particularly cryptic, and observing an entire population is impossible, which adds to the noise and reduces the power to detect change—hence the need for robust sampling methods and adaptive management.

To maximize the ability to detect change, a monitoring design like Before-After-Control-Impact (e.g., see Christie et al. 2019) is ideal, as it controls for variables that might be confounded with the spatial and temporal effects of LI on snow leopard populations. Although the size of snow leopard landscapes and logistical and practical constraints might make the use of this methodology infeasible, considering how this or a similar design can be implemented when planning a monitoring program is important. Failing to do so risks deploying monitoring efforts in ways that reduce the ability to draw inferences about the effects of LI.

Camera traps are generally the best tool for monitoring snow leopards and are widely used, and statistical methods for drawing inferences about snow leopard populations from camera traps are well established. However, all methods of detection add valuable information. Other data sources, including data from GPS-collared animals, scat surveys, and acoustic monitoring, should be considered in addition to camera trap data. These provide information unavailable in camera trap images (namely, individual animal movements over time at high spatial and temporal resolution from GPS collars, and eDNA, diet, disease, and population structure from scat surveys). Questionnaires for local community members on snow leopard occupancy and interactions with livestock might also provide useful data on changes in snow leopard populations.

Besides monitoring snow leopard populations, any LI impact mitigation measures that are implemented should include proper monitoring of their effectiveness. As monitoring continues, the effectiveness of mitigation measures should be evaluated to determine whether the installations and modifications meet defined objectives, whether they are sufficient, or whether adjustments are necessary, following an adaptive management framework (Williams 2011). Success can be measured at different levels; for example, an animal's acceptance of a wildlife crossing structure demonstrates the structure's effectiveness at the individual level (Denneboom et al. 2021), while measuring whether species' movement rates are mitigated compared to no-road or unmitigated conditions can define effectiveness at the population level (Soanes et al. 2024). Similarly, measuring restoration outcomes regarding the recovery of species populations can indicate whether impacts were mitigated at the community or ecosystem levels. Monitoring plans should be developed to assess the success of all mitigation measures and designed to enable adaptive management as conditions at the site change.

To help determine the success of mitigation measures, developers and regulators need to follow the following steps:

- **Establish goals and objectives:** Typically, these focus on reducing habitat fragmentation and barriers to movement, maintaining genetic exchange, and reducing the potential for wildlife-vehicle collisions on roads and rail lines.
- **Develop specific monitoring questions and relevant indicators to answer questions such as the following:** Is animal movement across the road increasing or decreasing? Is road-related mortality increasing or decreasing because of the mitigation measures? Are animals able to disperse, and can populations carry out migratory movements?
- **Establish baseline conditions:** This involves collecting data on the current state of the ecosystem and wildlife populations, ideally before any construction begins or, in the case of existing LI, before any mitigation measures are implemented. Baseline data provides a reference point against which future changes can be measured. Baseline data can be collected using a baseline biodiversity assessment.
- **Develop indicators and metrics:** Identify specific, measurable indicators that will be used to assess progress toward the goals and objectives. These indicators should be relevant, reliable, and easy to monitor. Develop one or two targets per indicator, with the expectation that the indicators will measure progress toward the target.
- **Identify control and treatment areas:** If pre-mitigation data are available, indicator responses in adjacent “control” areas might be compared with responses in treatment areas (road sections where wildlife crossings have been added). Control and treatment areas should comprise similar habitats, and some means of obtaining population abundance indices should be used to check for confounding effects.
- **Implement monitoring activities:** Collect data regularly using the established indicators. This might involve field surveys, remote sensing, or other data collection methods such as camera trapping.
- **Analyze and interpret data:** Evaluate the collected data to determine whether the mitigation measures achieve the desired outcomes. This step involves comparing the current data with the baseline conditions and assessing trends over time.
- **Employ adaptive management:** The results from the monitoring should be used to make changes to project management as necessary to ensure the success of the mitigation measures over time. The monitoring plan should be designed to link the monitoring data collected to management decisions and approaches.

CONCLUSIONS

This guidance document is the first of its kind for LI across the snow leopard range. It offers policy and management recommendations for developing and constructing LI in unique ecosystems inhabited by snow leopards. Given the limited knowledge and testing of measures designed to accommodate snow leopards, this document also lays the foundation for developing appropriate strategies and assessing their effectiveness.

The following are recommendations to enhance governance and oversight of infrastructure projects in snow leopard landscapes:

- **Legal context and policy review:** Assess gaps and overlaps in current laws and regulations regarding environmental safeguards in infrastructure development at the federal, state, and local levels. Recommend legal and policy reforms to align national and provincial frameworks with the tools and concepts described in this guidance.
- **Planning and design**: Ensure snow leopard and broader biodiversity considerations are included in infrastructure planning and design at the earliest stages of conceptualization.
- **Monitoring framework**: Develop and operationalize a standardized monitoring framework based on GSLEP guidelines and other tools and guidelines to evaluate the ecological and social impacts of ongoing and planned infrastructure projects in snow leopard habitats.
- **Implementation oversight**: Facilitate regular project design and implementation monitoring, ensuring that approved mitigation measures and safeguards are followed in practice.
- **Evaluation and review**: Conduct regular meetings or discussions with all key stakeholders to assess progress, share lessons, and update the status of LI projects within snow leopard ranges. This review should inform adaptive management and cross-sector planning.

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