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Short communication

Snow leopards or solar parks? Reconciling wildlife conservation and green energy development in the high Himalaya

Jenis Patel [a], Munib Khanyari [a,*], Rumaan Malhotra [a,b], Udayan Rao Pawar [a], Ajay Bijoor [a], Deepshikha Sharma [a], Kulbhushansingh Suryawanshi [a,c]

[a] *Nature Conservation Foundation, Mysore, India*
[b] *National Centre for Biological Sciences, Bangalore, India*
[c] *Snow Leopard Trust, Seattle, United States of America*

A R T I C L E I N F O

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A B S T R A C T

Harnessing green energy from sources like the sun is important to meet increasing global energy demands while reducing dependence on fossil fuel and mitigating climate change. However, the potential negative effects of green energy, especially concerning local biodiversity, are frequently overlooked. We use a case study from Trans-Himalayan India to discuss how green energy development, in our case proposed large-scale solar parks containing 13 solar sites, can be reconciled with wildlife conservation. We use detection-non-detection data for snow leopards with bioclimatic covariates using single-season single-species occupancy model to build a habitat suitability model. We prioritise development scenarios, to ensure the aim of snow leopard conservation, by operationalizing the step-wise (avoid>minimise>remediate>offset) Mitigation Hierarchy (MH). All of the 13 proposed solar plant sites fall within areas of high snow leopard suitability (>0.5). Applying the sequential MH framework, to "avoid" any impact would require either complete halt of all construction of the solar parks, or identifying alternative sites where the suitability for snow leopards is lower. However, collaborative planning is needed to fully implement this framework such that both objectives - solar energy generation and snow leopard conservation - can be optimally decided. We acknowledge that such decisions need integration of local people's perspective, which needs further elucidation. We advocate for a nuanced, data-driven, approach to reconcile conservation aims with development.

1. Introduction

COP 27 urged the need for sustained reduction in greenhouse gas (GHG) emission through promotion of low-emission and renewable energy in order to limit global warming to 1.5 °C (UN Climate Press Release, 2022). The need to prioritise renewable or green energy to meet increasing demand while restricting the pace of climate change is well established but the environmental impacts of green energy infrastructure are often overlooked.

While renewable energy – hydro, solar and wind – generally have low carbon emission, they are often more land-use intensive (Gibson et al., 2017). This need for large geographical space is one of the reasons green energy gets into conflict with biodiversity conservation goals. High mortality of birds at wind turbines are well documented (e.g. Smallwood, 2007) but direct effects of solar plants on wildlife is less documented (Averill-Murray et al., 2012). Much of the published literature on biodiversity impacts of solar energy is focused on south-western desert region of the United States (Gibson et al., 2017). Specifically, solar power plants require more land area and high water-use. Additionally, it is important to note that, beyond the immediate impact on the land where the solar power plants are built, such projects inevitably have broader geographic, environmental and social impacts including increased human use and built-up structures such as roads and energy transportation infrastructure (Cellura et al., 2023).

Across High Asia, the water tower of Asia, home to several local and traditional forms of land-uses and also experiencing heightened uncertainties around climate change, development activities frequently raise polarising opinions (Mishra et al., 2022). The debate around development is critical here, as it is home to some of the most elusive, ecologically important, and culturally-revered species like the snow leopard *Panthera uncia*. Snow leopards are also considered a flagship and indicator species across 12 Central and South Asian countries, including

* Corresponding author.
E-mail address: munib@ncf-india.org (M. Khanyari).

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India (GSLEP, 2017).

India is the third largest emitter of greenhouse gases and has committed to generating 500 GW of its energy from non-fossil fuel sources by 2030 (Ganeshan and Bhattacharjya, 2022). In 2010, India launched the National Solar Mission (NSM) with a target of developing 20GW of solar energy by 2022. This was revised to 100GW in 2014. India's solar power production grew from 0.5GW in 2011 to 55GW in 2021 (MNRE, 2022). To provide a thrust, the Indian government has relaxed due diligence processes like Environmental Impact Assessment (EIAs) for green energy projects, particularly outside protected areas (Ram and Apurva, 2022). However, renewable sources such as wind, solar, and hydropower aren't devoid of environmental and social impacts, some of which are significant. EIA regulations are key to ensure project developers disclose project details and that these projects are legally mandated to mitigate impacts and adhere to legal safeguards (Khera and Kumar, 2010). Therein lies a need to ensure these "green energy" projects are also aligned with biodiversity conservation goals. This is also crucial as biodiversity conservation and climate change goals are interlinked, and climate change goals cannot be achieved at the detriment of biodiversity goals (Díaz et al., 2020).

The Mitigation Hierarchy (MH) is a step-wise, precautionary approach initially developed to reduce the negative impacts of economic development on biodiversity (Arlidge et al., 2018; Gupta et al., 2020). Typically, the MH proceeds in four sequential steps: i) avoid, ii) minimise, iii) remediate and iv) offset, in order to achieve a specified – if possible quantitative – goal for a specific target conservation issue.

With this context, we use a case study from the Indian Trans-Himalayas to discuss how development activities, in our case a proposed large-scale solar park, can be reconciled with aims of wildlife conservation. We demonstrate the potential negative environmental impacts of the solar park. We make use of state-wide data on snow leopard detection to subsequently understand areas of importance for snow leopards. We prioritised potential development scenarios, to ensure the aim of snow leopard conservation by operationalizing the MH framework. We finally discuss the merits and shortcomings of such an approach.

2. Method

2.1. Study area

The Upper Spiti Landscape (USL) is a high elevation (3500–6700 m) region covering *c.* 3944 km^2. The temperature ranges from −40 °C in winter to 30 °C in summer. Precipitation is largely in the form of snowfall and peak winter snow can be up to two to three feet. The vegetation is broadly classified as 'dry alpine steppe' (Mishra et al., 2022). The large mammalian fauna includes Blue Sheep *Pseudois nayaur*, Ibex *Capra sibirica*, and their predators, snow leopards and wolves *Canis lupus*. The human population of Spiti stands at about 15,000 people and is spread across *c.* 95 villages Most people are agro-pastoralists.

A total of 34 solar parks were approved as part of the Ministry of New and Renewable Energy (MNRE) scheme in 2016. One of the sites identified for the development of a solar park is in Spiti. The proposed project is an 880 MW solar park in Spiti with the Satluj Jal Vidyut Nigam Ltd., a public sector utility jointly owned by the Central and Himachal Pradesh governments, as the Solar Power Park Developer (SPPD). The project, supported by the World Bank, is set to come up on 3104 ha of land (Kapoor, 2022). This 880 MW solar park is planned to be a conglomerate of sub-solar station placed across Spiti (Table 1). All of these areas are governed and used by the various villagers within Spiti as pastures for their livestock such as Yak, Dzomo (yak-cow hybrid), sheep/goat, horses and donkeys. These are also lands from which the locals not only collect dried vegetation and yak dung as fuelwood, especially for winters, but also with which they have deep seated connections (Murali et al., 2017). Currently, this solar park is stalled, primarily due to increasing financial costs of the project. Nonetheless, our work highlights potential negative environmental impacts and provides an approach that can be used to reconcile conservation aims with newly proposed, and rapidly increasingly, green energy development in the region.

Table 1
Details of proposed solar plants in Spiti with the village, location, and capacity to generate electricity.

Number	Village	Location	Capacity (MW)
1	Losar	Dindi	130
2	Losar	Latho Thanmo	
3	Losar	Fagdansa	
4	Losar	Soksa	
5	Losar	Tanve	
6	Hull	Paldar	100
7	Hull	Pangmo	
8	Kibber	Dumbachen	100
9	Hikkim	Cho-Cho Kanghilda	200
10	Hikkim	Lungwooh-H	100
11	Demul	Lungwooh-D	
12	Demul	Langwooh	100
13	Poh	Nipti/Gangchhumi	150

Source: Kapoor (2022).

2.2. Data collection

2.2.1. Camera trap data for model building

The snow leopard is the state animal of Himachal Pradesh. Although data from the Himalayas is not available, home range of snow leopards in the Gobi region of Mongolia is known to range from 120 to 200 km^2 (Johansson et al., 2016). Suryawanshi et al. (2021) used 241 camera traps to estimate the snow leopard population size across the state of Himachal Pradesh over an area of 26,000 km^2, across 10 sites. They used a stratified sampling design based on the occupancy distribution estimated by Ghoshal et al. (2019). Their camera traps were primarily placed in high elevation areas (3200-5500 m) in pastures, and along ridgelines and cliffs as that is the primary habitat for snow leopards in this region. We used the 187 snow leopard detections from this dataset as the input to build the species distribution model.

2.2.2. Camera trap data for model validation

While the larger dataset (241 cameras, 13,320 camera trap nights) was used to build the species distribution model, we used a smaller subset dataset from within high quality snow leopard habitat to validate the output (Fig. 1). Suryawanshi et al. (2021) found that Spiti had amongst the highest densities of snow leopards in the state of Himachal Pradesh. Thus, we sampled in Spiti to build our model validation dataset, as the solar parks are proposed in Spiti. Camera trapping in Spiti was done during June–August 2021 to systematically sample 760 km^2. The entire study area was gridded into 4 × 4 km grids and 35 cameras were placed, ensuring one camera per grid (the same as in Suryawanshi et al., 2021, our model training dataset). This is smaller than the estimated home range size of snow leopards, thus allowing for the possibility of capture across multiple traps. Some grids didn't have cameras primarily due to inaccessible terrain. The cameras were installed for 60 days, during which cameras were checked once for battery condition and memory card replacement. Cameras were installed based on prevalence of snow leopard signs like hair, scat, scrape or urine spray marks and suitable microhabitats to maximize detection.

2.3. Analysis

2.3.1. Species distribution model (single-species occupancy)

Detection-non-detection data for snow leopards from the state-wide camera trapping effort (2.3.1) were modelled with bioclimatic covariates (www.worldclim.org) using an occupancy modelling framework (Kellner et al., 2023). We explored the relationship with snow leopard detection-non-detection through graphs and decided to use linear term

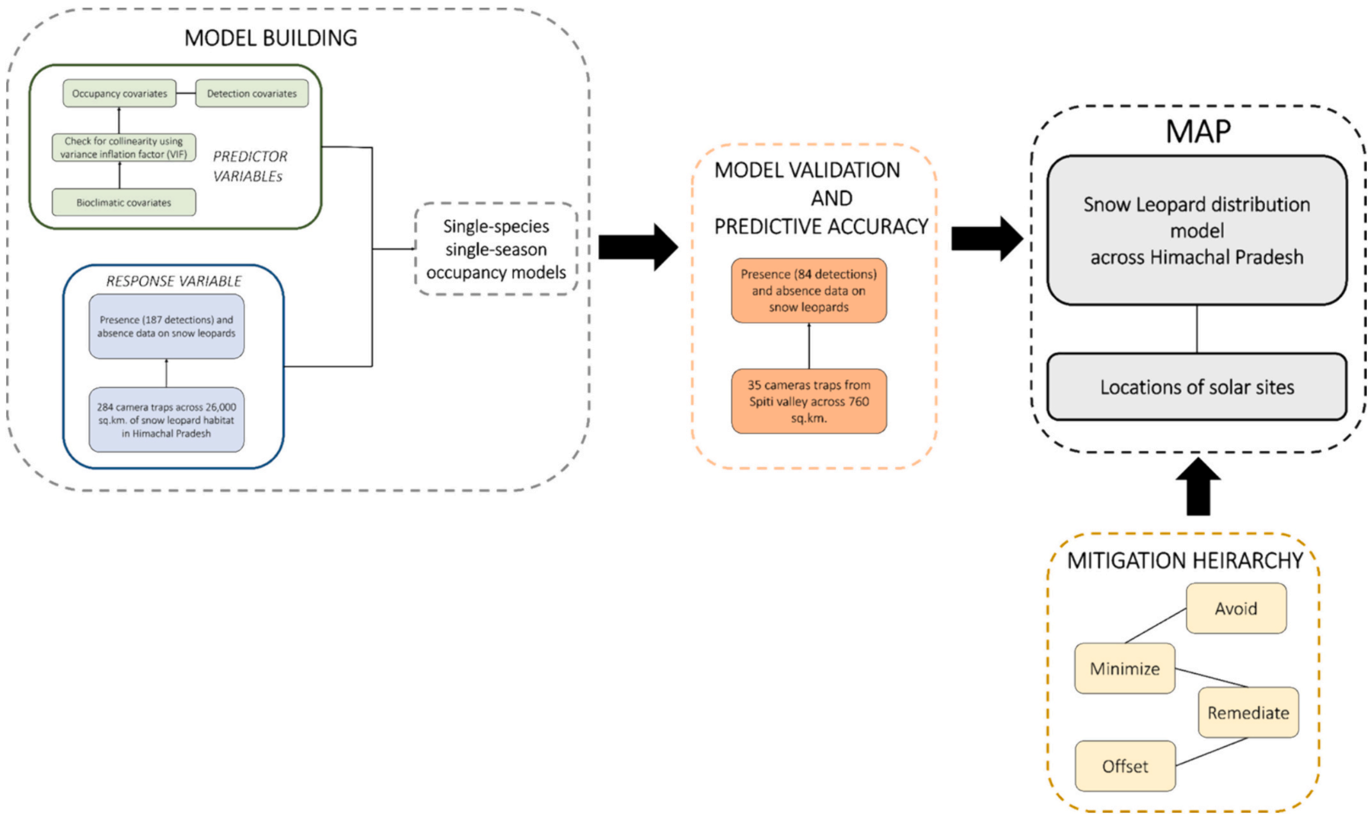

Fig. 1. A schematic displaying how various pieces of knowledge were used together to obtain the snow leopard distribution model and subsequently used to reconcile solar energy generation and snow leopard conservation.

or square term based on the known biology of snow leopards. The covariates were checked for collinearity and reduced using variance inflation factors (VIF) (Senaviratna and Cooray, 2019), and the final occupancy covariates used in the global model were isothermality (how much temperature varies over a year compared to the daily temperature variation), mean temperature of the wettest quarter, mean diurnal range, with the addition of elevation and ruggedness. A quadratic transformation was applied to elevation, ruggedness, and mean temperature of the wettest quarter. Additionally, the trap success of ungulates (as a metric of prey availability), enhanced vegetation index (EVI), and ruggedness were used as detection covariates (see Table S1 for the expected relationship with these variables). Akaike's information criterion, corrected for small sample sizes (AICc) was used to rank all combinations of the covariates in the global model using the *MuMIn* package. All models within 4 delta AICc of the top model were assessed for accuracy. We chose the highest ranked model (lowest AICc) that included a quadratic term for elevation for our species distribution model. This is because, while snow leopard presence increases with elevation it tends to drop off after 5200 m, beyond which lies the permafrost region (see Suryawanshi et al., 2021 for further explanation). A quadratic, rather than linear function captures this relationship more meaningfully. The output from the chosen model was used to generate the snow leopard habitat suitability (on a scale from 0 to 1, with 0 being very low suitability, and 1 being high suitability) at the point location of each proposed solar plant location.

2.3.2. Predictive performance testing

We used a holdout partitioning method (Kellner et al., 2023) to test the predictive accuracy of our top model. The data were randomly partitioned into testing (1/10; 24 camera trap location) and training (9/10; 217 camera trap locations) sets. The accuracy of the model was determined by building confusion matrices to derive the sensitivity (true positive rate), specificity (true negative rate), misclassification rate, and the area-under-curve (AUC) from the ROC plots (Pearce and Ferrier, 2000). This process was repeated 10 times to resample the test and training sets, and the accuracy metrics were averaged (Table S2).

Additionally, we tested the predictive performance of the model against presences and absences of snow leopards from a different, more recent dataset - a single year (2021) of camera trapping data from Spiti (2.3.2). We obtained 84 snow leopard detections in 26 cameras out of 35 that were installed. This area is a known high quality habitat area for snow leopards (Suryawanshi et al., 2021), and we expected an accurate model to have highly sensitive predictive performance for these data.

2.3.3. Applying the mitigation hierarchy

The mitigation hierarchy calls for defining a goal in terms of a desired change in biodiversity, accompanied by a quantitative target against which the mitigation measures can be evaluated. We define our overarching conservation goal for this study to limit negative impact on snow leopard habitat from the development activities of setting up the mega solar park. Based on the results of the species distribution model and our positionality which is that of place-based conservation that results in least harm to snow leopards and their habitat, we list potential options under the mitigation hierarchy steps. Where possible, we discuss feasibility and considerations. We choose to take a positionality-driven qualitative approach to apply the mitigation hierarchy because of the data limited nature of our study system and lack of natural and quantifiable counterfactuals. We acknowledge this is just one of several ways of applying the MH in this context.

2.3.4. Overall output

Fig. 1 displays how various pieces of information described in Sections 2.2 and 2.3 come together, to first understand the habitat suitability of snow leopard which is overlaid on the locations of the 13 solar sites. Based on this output, the MH is used to define potential policy steps with aim of reconciling snow leopard conservation and green development.

3. Results

3.1. Snow leopards and solar parks in Spiti

3.1.1. Proposed solar plant sites

All of the proposed solar plant sites fall within areas that are well suited for snow leopards (> 0.5). Most sites have a suitability close to 0.6, with two of the sites having higher suitability (Paldar and Cho-Cho Kanghilda). The site furthest to the west, Tanve, has the lowest suitability, but still has a suitability value above 0.5 (Fig. 2, Table S3). Generally, all sites are within areas that are likely to have snow leopards.

3.1.2. Predictors of snow leopard habitat suitability

The top model included elevation (as a quadratic term), ruggedness, isothermality, and Mean Diurnal Range (MDR) (Table 2). Suitability for snow leopards was generally positively correlated with isothermality (approaching significance), and mean diurnal temperature range

Table 2
Top ranked models within 2 ΔAICc of the top model.

Model	AICc	ΔAICc	Weight
p(.)Ψ(Elev2+Iso+Rug+MDR)	2069.887	0	0.24
p(.)Ψ(Elev2+Iso++MDR)	2069.979	0.104	0.16
p(.)Ψ(Elev2+Iso+Rug^2+MDR)	2070.55	0.663	00.13
p(.)Ψ(Elev2+MTWQ+MDR)	2070.615	0.728	0.13
p(.)Ψ(Elev2+MTWQ+Iso+Rug+MDR)	2070.905	1.018	0.08
p(.)Ψ(Elev2+Iso+MTWQ+MDR)	2070.96	1.073	0.08
p(.)Ψ(Elev^2+MTWQ+Rug+MDR)	2071.17	1.283	0.06
p(.)Ψ(Elev2+MDR)	2071.478	1.591	0.06
p(.)Ψ(Elev2+MTWQ+Rug2+MDR)	2071.63	1.743	0.03
p(.)Ψ(Elev2+MTWQ+Iso+Rug2+MDR)	2071.651	1.764	0.03
p(.)Ψ(.)	2086.223	34.947	0

MTWQ: Mean temperature of the wettest quarter, Rug: ruggedness, Iso: isothermality, Elev: elevation, MDR; mean diurnal range.
This table includes only models without detection covariates, as the inclusion of detection covariates did not improve the fit.

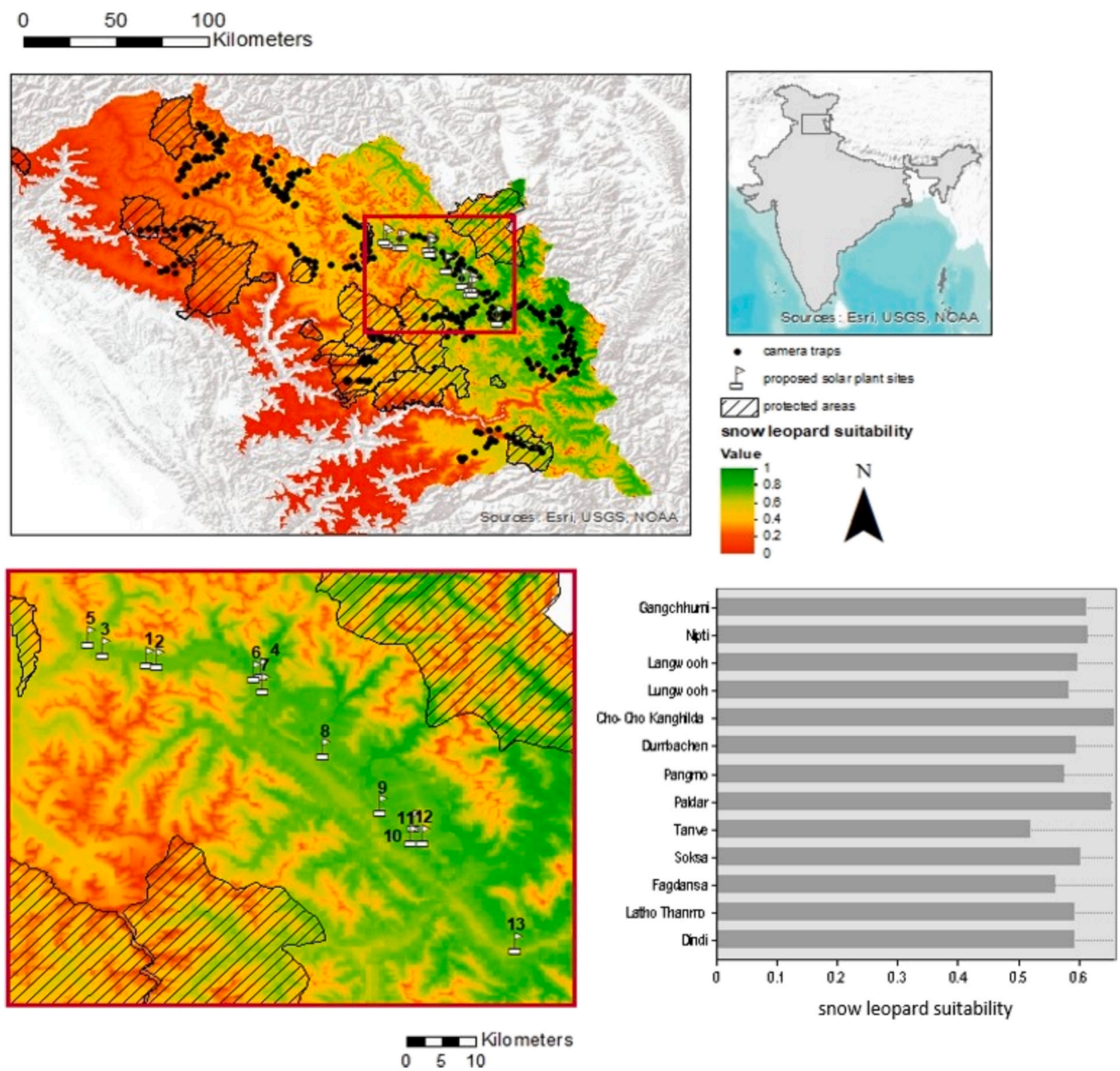

Fig. 2. Map displaying the habitat suitability for snow leopards along with proposed solar plant sites. All sites fall within areas of good suitability for snow leopards, which Paldar (6) and Cho-Cho Kanghilda (9) falling within higher suitability. The black dots represent the 241 camera trap locations across Himachal Pradesh.

(Fig. S1, Tables S4 and S5). Elevation was positively correlated with suitability until an inflection point at approximately 4200 m, after which the correlation became negative. Higher habitat suitability also correlated with high and low extrema of ruggedness.

3.1.3. Predictive accuracy

Overall prediction accuracy was high (mean: 0.75; SD: 0.07). The variation in the accuracy metrics between different iterations of the test and training sets was higher in the ability to predict true positive (mean: 0.42; SD: 0.17) than in the ability to predict true negatives (mean: 0.90; SD: 0.11); overall specificity was higher than sensitivity. While the data was relatively balanced (39 % presences), the higher number of absences was reflected in the ability to predict absences more accurately (Salas-Eljatib et al., 2018). As expected, when the model was tested with the 2021 data collected from Spiti, the model had high sensitivity (0.96; correctly predicted all presences), but very poor specificity (0) (Table S2), classifying most of the area as having high suitability for snow leopards.

3.2. Mitigation hierarchy

Given our interest in place-based wildlife conservation, we prefer no impact from development to occur in a region which is the best habitat for snow leopards in Himachal Pradesh. Therefore, to "avoid" would be to cancel or relocate (to less biodiverse area) the construction of all 13 solar sites as they are currently all in high conservation value area for snow leopards (suitability >0.5). These are also areas with the highest snow leopard populations in Himachal Pradesh (Suryawanshi et al., 2021). To "minimise" could be to ensure not to construct solar sites 9 (Cho Cho Kanghilda) and 6 (Paldar) as they are in the highest suitable area (>0.6), while use measures to minimise impact from sites that are constructed such as potentially decreasing their sizes. Although we wouldn't want any damage to snow leopard habitats, we understand that some amount of development is required and may even be desired, perhaps by the local people. To "remediate" would allow for the construction all solar plants however use construction methods and material so as to allow snow leopards to live and breed in the area. This can be aided by improving key habitats within the solar sites for snow leopard (e.g. interventions to increases their denning areas). There is impact on biodiversity but it is compensated for in the site of development. Nevertheless, we need to investigate the impact of the solar sites beyond the immediate site of construction and on other species such as the prey of snow leopards. Lastly, to "offset" would allow construction of all solar plants in Spiti. However, steps are taken to conserve snow leopards in another part of their range in the Indian Himalayas. We don't have enough information to meaningfully operationalize steps to "minimise" and "remediate", especially as there is also a need to understand the impact of the solar site beyond just the location of its construction. Additionally, "offset" does not align with our positionality of placed-based conservation which includes valuing Spiti as being irreplaceable for snow leopards. Therefore, our results encourage "avoiding" the construction of any sites, with a policy recommendation to shift them to areas of lower snow leopard suitability.

4. Discussion

We use a case study from the Indian Trans-Himalayan region of Spiti, Himachal Pradesh to discuss how development of a proposed large-scale solar project can be reconciled with wildlife conservation. Spiti is one of the first landscapes identified under the Government of India's Project Snow Leopard, launched in 2009, to conserve India's unique natural heritage of high-altitude wildlife populations and their habitats by promoting conservation through participatory policies and actions. Upper Spiti Landscape also is one of the 20 landscapes delimited by Global Snow Leopard and Ecosystem Protection Program (GSLEP) to conserve across the snow leopard global distribution (GSLEP, 2017). Using spatial-capture recapture, Suryawanshi et al. (2021) found snow leopard density of 0.3 (0.15–0.59) per 100 km^2 across Spiti (second highest in all of Himachal Pradesh) with an estimated population of 9 snow leopards using this region. All solar sites fall under high snow leopard suitability habitat (>0.5 habitat suitability). Our results suggest that the measure of "avoid" - i.e. no construction of any solar plants as they are all in high conservation value locations and shifting them to areas of lower snow leopard suitability, is likely the most effective in reconciling green energy developmental and conservation aims, while also aligning with our positionality. However, we also need to challenge indicator species concept of snow leopards so as to incorporate impact of such activities on biodiversity in general. However, we provide a blue print using the snow leopards which can then be expanded to incorporate other species.

In addition, it is key to note that each of the 13 solar sites do not have the same generating capacity and more information is needed to understand the different footprints for the proposed sites. Therein collaboration with other relevant stakeholders (e.g. engineers) is needed to choose sites to maximize energy generation and minimise conservation impacts. Such an analysis might result in different sites being suggested for cancellation than those currently listed. Based on this understanding, perhaps a more nuanced application of the MH can be achieved which is not simply to minimise the amount of suitable habitat affected by development. In particular, any attempts to relocate these solar sites to another area (outside Spiti for example) needs further investigation for which we currently lack information. Lastly, while the area impacted direct by the solar site is 3104 ha – relatively small – compared to the landscape used by snow leopards, it is important to note that other disturbances such as building of roads and increased human presence can impact a much larger area (Gibson et al., 2017).

Crucially, majority of the land on which these solar parks were proposed to be built, needs to be diverted under the Forest Conservation Act (1980). However, the cost of carrying out compensatory afforestation and providing the Net Present Value (NPV) fund for forest diversion has been a challenge for the developers. Without a request for such a large financial relaxation on the same, the project is financially unviable (Kapoor, 2022). It is ironic that a project advocating green development depends on diverting important snow leopard habitat by deeming it 'wasteland' and seeking holidays on preserving alternative plots of land - a provision that is already questionable.

Energy, mineral and other natural resource development associated with infrastructures and habitat modification is a threat to snow leopards and their habitat (Mishra et al., 2022). They have projected direct impacts on snow leopards through land use change and indirect impacts through habitat fragmentation (Li et al., 2016). We need clear pathways to ensure that development, particularly green development, occurring in these areas is aligned with conservation aims. Salafsky (2011) writes critically about integrating development with conservation, advocating for conservation organisations having strict conservation goals to which the developmental goals need aligning. While this makes sense conceptually, it is hard to operationalize this practically. This is where frameworks like mitigation hierarchy help chart out steps to achieve a predefined goal while being explicit with our positionality. However, there are limitations to this approach, for instance, setting quantitative targets against set indicators was hard to achieve given the data-limited nature of our case study. To improve the application of the mitigation hierarchy, it will be important to assess the feasibility of each step, particularly in terms of social and economic impact on energy generation and the people living in Spiti (Gupta et al., 2020). Additionally, like previous studies, setting a quantitative target was challenging for our case study, however we advocate for an adaptive approach iterating the framework over time as improved knowledge is developed. It is important to take an iterative approach when applying any framework, incorporating trust-building with stakeholders and updating new information (Schwartz et al., 2018). Such frameworks are crucial to reconcile conservation aims with development activities as across much of their global range, as in India, snow leopards are found outside formally protected areas, which remain vulnerable to land-use alterations (Fig. 2; Mishra et al., 2022).

As nations around the world work at enabling green development projects to meet climate targets, they ought to remain mindful of the social and ecological costs involved. The proposed solar park in Spiti falls on non-revenue wasteland – 75 % of the total geographical area of Lahaul & Spiti region is classified as wasteland (Wasteland atlas of India, 2019). However, this completely undermines the fact that these areas have supported resident agro-pastoral communities for generations, alongside elusive wildlife (Murali et al., 2017). It is critical to uphold the views, aspirations, and rights of local people in efforts to reconcile development with conservation. Not acknowledging the rights of communities to their traditional lands, and revising mechanisms to bypass the process of seeking their consent while planning large scale projects is misplaced (Brondízio et al., 2021).

Conservation efforts in large parts of the world historically have been perceived to be discriminatory by local people (Rai et al., 2021). Just as indigenous communities start to assert their voice for global conservation efforts to be more equitable and fair, it would be a travesty of justice if they are at risk of falling prey to green development. This becomes critical when considering India's push to scale so-called green energy with steps that dilute due diligence processes such as EIAs, particularly when there are clear ecological threats even to low-carbon energies (Gibson et al., 2017).

CRediT authorship contribution statement

Jenis Patel: Conceptualization, Data curation, Formal analysis, Writing – original draft. **Munib Khanyari:** Conceptualization, Visualization, Writing – original draft, Writing – review & editing. **Rumaan Malhotra:** Conceptualization, Data curation, Formal analysis, Visualization, Writing – original draft. **Udayan Rao Pawar:** Data curation, Formal analysis, Writing – review & editing. **Ajay Bijoor:** Conceptualization, Methodology, Writing – review & editing. **Deepshikha Sharma:** Conceptualization, Supervision, Writing – review & editing. **Kulbhushansingh Suryawanshi:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing.

Declaration of competing interest

None.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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