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Review

Development of Ladakh: The Issue of Integrating Renewable Energy and Tourism Based Economy with Pastoralism and Ecology

SURENDRA P. SINGH*[,1], RIPU DAMAN SINGH[2] AND RANBEER S. RAWAL[3]
[1]*Central Himalayan Environment Association (CHEA), Dehradun, 248007*
[2]*Department of Forestry & Environmental Science, DSB Campus, Kumaun University, Nainital,263001*
[3]*G.B. Pant National Institute of Himalayan Environment & Sustainable Development, Kosi-Katarmal, Almora, 263643, Uttarakhand, India*
E-mail: surps@yahoo.com; spsecology@gmail.com; ripuds4777@gmail.com; ranbeerrawal4@gmail.com
ORCID ID: 0000-0003-3139-9301 (SPS), 0000-0002-2875-2664 (RDS)
***Author for correspondence**

ABSTRACT
With less than 1% of geographical area (~6 M ha) under human use, Ladakh, the India's new Union Territory is a cold desert where human presence (density 4.6/km^2) is dwarfed by nature's immensity. This article gives an outline of Ladakh, based on physiography, ecology, culture, natural resources, and discusses the sustainability issues involved in transforming the pastoral life style into one based on renewable energy and tourism. Uncertainties in view of the rapid climate change, which has already depleted several glaciers, pose challenges to sustainable development. Ladakh has a long history embedded in Buddhism in which humans along with their goats and sheep have lived together in a harmony with nature for thousands of years. The rangelands are rich in wild mammals (36 species), like snow leopards, and Tibetan argali. The region has a huge potential for the generation of renewable energy (e.g., solar energy estimated at 35 GW) from over 320 days of sunshine, and geo-thermal sources with implications for India's carbon neutrality. However, harnessing the sources and transmitting electricity to economic centres through snow covered mountains is a daunting task. Tourism which contributes about 50 percent to the GDP, too has a some of caveats. So, addressing the conflict between infrastructural development for tourism and energy generation on one hand, and sustaining the integrity of rich culture and of rangeland ecosystems on the other, would be of critical importance in a changing climate which threatens the glaciers and other cryosphere components.

Key words: Cold desert, Glaciers, Sustainable development, Solar and geothermal energy, Trans Himalaya.

INTRODUCTION

The promulgation of Carbon Neutral Ladakh by India's Prime Minister, has brought sustainability to a centre stage of its development. India's announcement at the COP26 summit on climate change in Glasgow, Scotland on transitioning to net zero emissions by 2070 has been widely acclaimed world over. There are reasons to believe that the Union territory of Ladakh will not only achieve carbon neutrality, it will also meaningfully contribute to the carbon neutrality of the country as whole.

In view of carbon neutrality goal, the term net zero emission is referred to frequently. The net zero emission, in simple terms means no addition of new emissions of greenhouse gases to the atmosphere. In this, the emission of greenhouse gases would be balanced by withdrawal of an equivalent amount of them from atmosphere. In general, to achieve carbon neutrality a country or region needs to focus on (i) increasing non-fossil fuel share, promotion of negative-emission technologies, (ii) giving importance to low-carbon development, (iii) strengthening of green market, and (iv) protecting natural carbon sinks and promoting CO_2 capture, utilization and storage (Wang et al. 2021, Liu et al. 2022). These steps require a major socio-economic transition at various levels, involving carbon literacy and justice at grassroots level (Singh 2023).

The realization path of carbon neutrality can be quite tricky (Wu et al. 2022). It is in view of this, Ladakh is seen as a special region of India. The rapid growth of tourism, its impact on rich culture, aspiration of youth, some already trained and

educated young persons from prestigious institutions of different parts of the world, influx of people from outside to manage work related to infrastructures development, all are interconnected variously, and are capable of generating complex socio-cultural and ecological problems.

Needless to say, the sources of renewable energy of Ladakh would contribute to giving us the direction of moving away from fossil fuels. While it is possible to achieve carbon neutrality at the country level, the challenges are many. Some of the most polluted cities of the world are in India and pollution related mortality is high (Gupta 2022). We have to manage food for 1.4 billion population which will continue to grow several more years before it starts declining. Transmission distribution and storage of energy from renewable sources like solar radiation would need rapid improvement. It may be pointed out that task is very challenging as India's peak CO_2 emission is to occur by 2045-50. The enormous scope for harnessing solar energy and geothermal energy sources from Ladakh have given impetus to the carbon neutrality of India's development. The idea is not only to harness the renewable energy sources, but also to create carbon neutrality as a kind of citizen movement. This may call for spreading renewable energy literacy at various levels.

While electric vehicles, use of solar cooking devices, and green buildings and airport are seen as integral parts of future Ladakh, they would need to be combined with path of sustainability with focus on the protection of fragile landscapes and their precious biodiversity and cultural features. Efficient use of water and conservation of ecosystems, and aspiration of youth, particularly in relation to employment, all need to be given importance for a balanced development, in which carbon neutrality is a keystone factor.

Being a highly populated country with average density of 382/km^2 (Census 2011), in India developmental issues have been strongly anthropogenic in orientation. In contrast, in the new Union Territory of Ladakh (created in December 2019), the vastness of snow-clad mountains and rangelands dwarfs the human presence (population density 4.6 km^2). There is little past experience in India of strategizing the development of such a region.

Our first objective was to piece together scattered information on Ladakh to develop a coherent picture of its natural resources, and ecology. The second was to provide an outline of sustainability issues associated with harnessing natural resources to generate renewable energy, and those with the rapidly growing tourism. As for renewable energy production, here our focus is on solar and geothermal energy sources which if realized to their potential are slated to significantly improve India's carbon balance. Similarly, tourism issues would be discussed in view of Ladakh's ecological specificities not on the detailed tourism planning. The paper is more of a commentary on the issues of sustainable development of Ladakh than a rigorous analysis of economic growth and environmental parameters.

MATERIAL AND METHODS

Study area

Ladakh is situated on the western edge of the Himalaya bounded in the northeast by Tibetan Autonomous Region of China, and in the northwest by Pakistan (Fig. 1). Located within the expansive rain shadow of the Tibetan Plateau, the region belongs to the Trans-Himalayan cold desert bio-geographical zone of India, represented by provinces of Ladakh Mountains, and Tibetan Plateau. Among the inhabited regions of the Himalaya, Ladakh is the highest (in elevation), coldest with the largest cover of snow and ice, sunniest (over 320 days of sunshine), and sparsest in population. The UT includes, Ladakh Range, a south eastern extension of the Karakoram Range, and the upper Indus river valley, known as central Ladakh. This cold desert landscape is blessed with the Indus, and its tributaries the Shyok from the north, and the Zanskar from the south. The well-known Pangong Lake is in the east of the central Ladakh, and in the south eastern Ladakh lies Rupshu, an area of brackish lakes.

The annual rainfall (113 mm in Leh) is scanty, but is well distributed across 12 months. The mean annual temperature is 7.3°C (at Leh), with the extremes of 34.8°C in summer and -27.9°C in winter (Chevuturi et al. 2018). From 1991 to 2000, the rainfall increased at the rate of 0.127 mm/yr during summer, and at the rate of 0.42 mm/yr during winter possibly under the influence of climate change

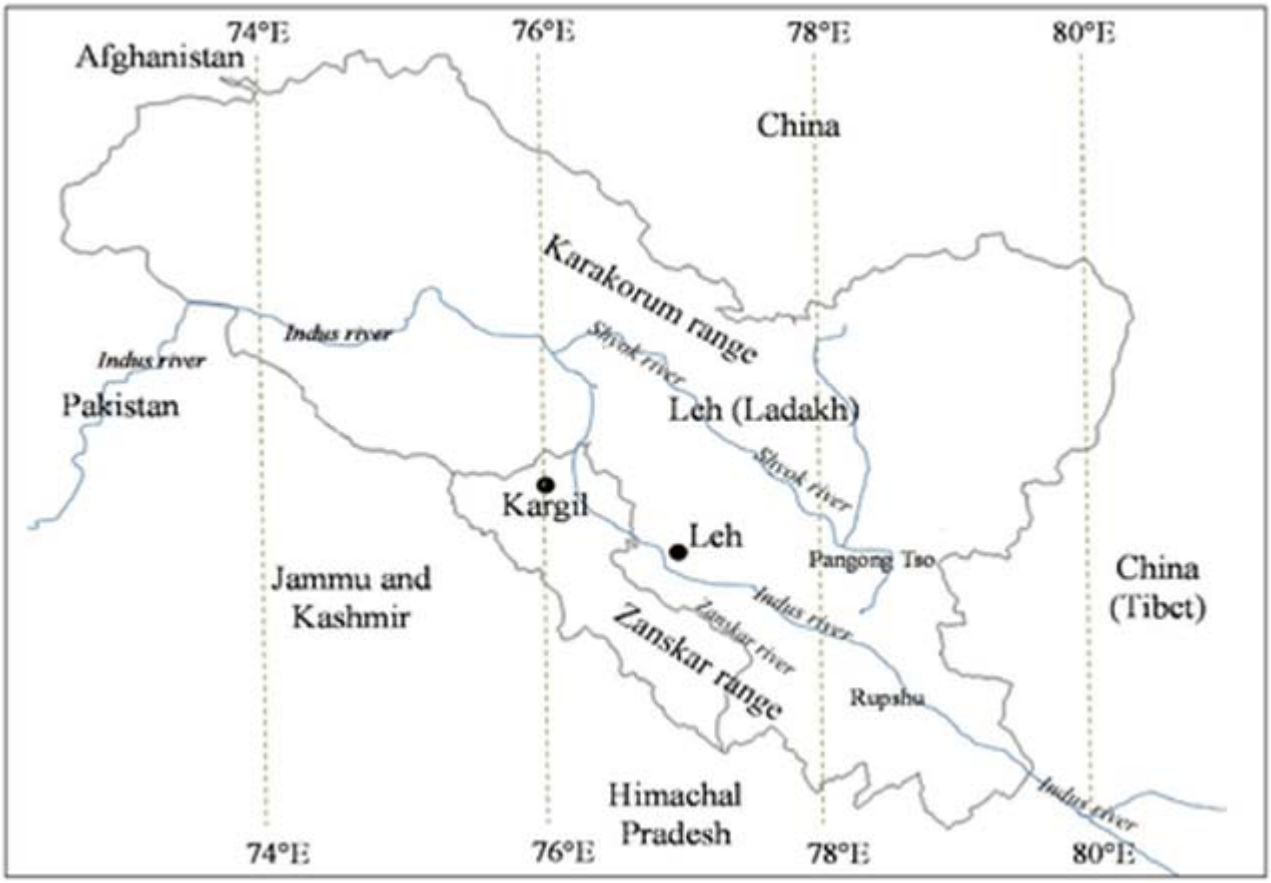

Figure 1. Geographical features of Ladakh Union Territory (under Indian administration).

(Shafiq et al. 2016). There are indications from south Pullu valley that winter precipitation increases with elevation, the amount being 620 mm at 5000 m elevation compared to 47.5 mm at the valley bottom (Thayyen 2020).

Much of the original juniper forests of Ladakh have disappeared. The common cultivated trees include willows (*Salix* spp.), poplars (*Populus* spp.), and apricot (*Prunus armenica*) with about 50 varieties. Ladakh has agro-pastoral life style, the eastern plateau is known for nomadic herders, Changpas and their pashmina goats and sheep. The principal agriculture crops are barley, wheat, millet, buckwheat, peas, beans, and turnips, however, about 85% of the requirement of food is met from outside (Anonymous 2019). The biggest ethnic group is Buddhist with 77% of total population (largely in Leh), followed by Muslims (Shias) with 13.8% (largely in Kargil) and Hindus with 8.2%. In Leh, pastoralists trade dairy, wool, and pashmina goat fibre, while in the other district, Kargil the focus is on small cottage industries.

Surprisingly, this cold desert has a long unbroken history. Over two thousand years ago, People, called Dards were known to collect gold from the sand of the river Indus. Only a special attraction like this might explain why humans settled down at a location with nearly half of the global mode of ~13°C MAT when the world was sparsely populated (Xu et al. 2020). In the 8th century, the people were largely merchants and traders living in huts (Minorsky 1982). It is Namgyal kings (meaning victorious) who gave stability to Ladakh in mid15th century, and developed Buddhist Gompas and shrines, including the famous Hemis Gompa. For centuries, Ladakh's culture has been characterized by cooperation, compassion, community level cohesion, and place identity (Barrett and Bosak 2018). A Buddhist farmer of Leh will not spray pesticides even today.

Culturally old and rich Ladakh, has two main religions, Budhism in Leh and Islam (Shias) in Kargil, however Buddhism characterizes the region. Tourism that began with the government initiative only in 1974, has now emerged as a major economic

enterprise in Ladakh, where people largely depended on subsistence farming and agro-pastoralism until recently.

Methods

The approach we followed has three major components: (i) understanding pulse of planning in Ladakh UT (i.e., interaction amongst Members of Planning Board of Ladakh, Chaired by Lieutenant Governor, on March 1, 2020); (ii) assimilating inputs from domain experts (i.e., participants of 'Carbon Neutral Ladakh- a New Beginning' summit, 2-5 March 2020 at Leh, Ladakh); and (iii) gleaning the information about Ladakh through published and un-published literature.

We participated in series of online conferences/ meetings involving experts and departmental representatives in India and discussed on vegetation types, and its carbon storage, water sources, glaciers, climate change perceptions, scope of promoting apricot varieties, Pashmina goats, rise of tourism, life style and culture, renewable energy sources, and wildlife and livestock conflicts.

Overall, our approach was to determine the relevant issues of development and make opinion about them and for that we raised questions, recorded responses of scientists and grass roots workers, and then analyzed those keeping in view developing this article.

RESULTS AND DISCUSSION

The issues of sustainable development of renewable energy from natural resources and tourism should be seen in the context of constraints that cryosphere fragility under climate change impact can impose, and challenges to conserve integrity of wildlife and other ecological components and cultural roots. In view of this we briefly shed light on cryosphere components of Ladakh, and associated hazards, wild life features, and cultural issues.

Unstable chryosphere under the influence of climate change and geodynamics

Ladakh is a product of the collision between the Indian and Eurasian plates (Clift et al. 2002) that occurred between -60 and -50 Ma (the beginning of Eocene). The region lies entirely in the upper catchment of Indus which originates from Mansarovar Lake at the elevation of 5182 m (in the vicinity of Mount Kailas). The Indus drains through Karakoram region, Ladakh Batholith and the tectonic units of ISZ. The ~350 km stretch of the Indus River in the Ladakh region exhibits varied configurations of valley cross sections from wide U-shape to deeply incised V-shape gorges (Kumar and Srivastava 2017). Glaciers, permafrosts, ice- and snow-covered grounds and rivers (during winters) and highly erodible surfaces are common features of Ladakh and all of them are threatened because of global climate change.

Glaciers

The glaciers in Ladakh are high (above 5200 m, Schmidt and Nüsser 2017), and small, 90% being less than 0.75 km^2 largely because of the aridity (Chudley et al. 2017). The glacier volume in river basins tended to increase with elevation (Fig. 2). The glaciers of Shyok (231.3 km^3) and Nubra (204.3 km^3) river basins together accounted for about 60% of total glacier volume (720 km^3) of Ladakh distributed across 16 river basins. Mostly occurring on the northern aspects, the glaciers are clean, (free from debris cover) and fed by snowfall, as opposed to the glaciers of Karakoram, which are debris-covered and stable or swelling because they gain from snow distributed through avalanches. Based on a study of 864 glaciers in Central Ladakh covering 402.3 km^2 area, Chudley et al. (2017) have shown that the glaciers of Ladakh have shrunken by 12.5% between 1991 to 2014, which is less than the rate of decrease in typical Himalayan glaciers.

The upper Shyok valley had 2123 glaciers in 2002, mostly debris free with a total area of 2978±95 km^2. The mean size of glaciers in the valley was 1.4 km^2, slightly larger than that of Ganga (1.1 km^2) and Bramhaputra (1.2 km^2) (Bajracharya and Shrestha 2011). The mean glacier elevation in Shyok valley (5830 m) was higher than those of Bhagirathi, and Alakhnanda catchments of Uttarakhand (4432-5629 m). Many glaciers in Shyok valley and Karakoram region (40% of glaciers) are surge type which advance at a very high rate for a short active period, ranging from 1 to 15 m/yr, followed by a long period (10-100 yr) of stationary phase (Bhambri et al. 2017). A mass balance study of five years (2010-2014) on

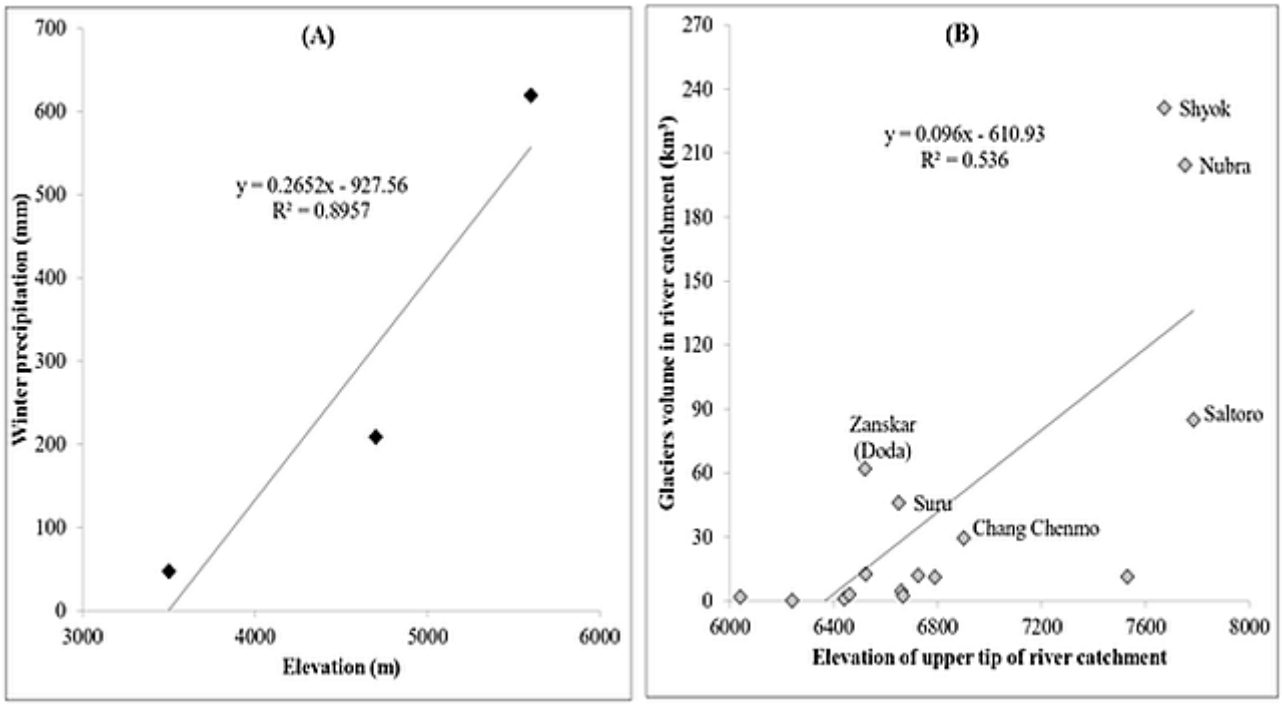

Figure 2. Effect of increase in elevation on (A) winter precipitation (from Thayyen and Gergan 2009), and (B) glacial volume (derived from GSI inventory of Ladakh 2009).

two glaciers, namely Phuche, which feeds Leh stream, and Khardung which feeds Rubra valley also indicated that glaciers are shrinking in Ladakh (Thayyen et al. 2015). The continuous mass loss of Khardung glacier is already a cause of water scarcity in Nubra valley.

Permafrost

Permafrost, defined as an unconsolidated sediment or bedrock that remains frozen for at least two consecutive years (Gruber 2012), estimated to be about 1 million km^2 in area, about 10 times of the area under glaciers in the Hindu Kush Himalaya. Because of very high temperature lapse rate (TLR) in the arid climate of Ladakh (-8.4^{o}C/100m to -1.41^{o}C/100m, compared to 0.53^{o}C/100m elevation in humid Sikkim; Joshi et al. 2018) area under permafrost is high. In a catchment study in Ladakh, permafrost with active layer thickness from 0.1 m to 4.2 m, and mean annual temperature between -10°C and -0.55°C was found to cover 93% of area above 4900 m (Thayyen 2020). The thawing of permafrosts due to climatic warming results in water supply (Wani et al. 2020), but it is also a major source of carbon emission, land subsidence and landslides.

Flood outburst and other natural disasters

Natural disasters due to landslides, and glacier-related disturbances are common in Ladakh. In Landslide Dam Outburst Floods (LDOFs), a landslide blocks the river, resulting in the formation of a lake. Since the lake formed cannot hold water rise for long, the rising water leads to an outburst. For example, the "Great Indus Flood" of 1841 was caused by an earthquake-induced landslide. A lake, 64 km long and 300 m deep was formed, and then emptied in a day time, devastating hundreds of villages and thousands of people on the way. LDOF of the Phutkal river, Zanskar (in 2015) occurred several months after the lake formation, affecting some 40 villages. In Ladakh landslide is triggered by permafrost thaw, snow melt water seepage and mass movement of loose debris.

Glacial Lake Outburst Floods are principal flood generating mechanism in a glacial region. They result when water dammed by glaciers or moraines are released suddenly. Most of the glacial areas in Ladakh are witnessing a rapid glacial lake formation. Glacial Surge Dam Outburst Floods occur because surging glaciers flow at an extraordinary speed in the front (Meier and Post 1969). When surging

glaciers advance across a major headwater stream, they may cause catastrophe by damming rivers. For example, the Kundan Lake (16 km long and 120 m deep) was formed as 2.4 km long ice barrier blocked the river (Ayyen communication to MoEF&CC). The flood that resulted from its bursting devastated several areas in the Shyok and Indus valleys up to 1194 km downstream of its origin. In Karakoram ranges surging type glaciers cover more than 40% of total glacier area. Because of the incidence of cloudburst and flash flood in Ladakh 14 disasters have occurred since 2005.

Sparse vegetation and threatened wildlife

Ladakh is almost treeless, only small patches of *Juniperus macropoda,* and *J. indica* occur as relict stands in remote river gorges (2489 km^2 area, FSI 2019). *Hippopheae* and *Salix* species occur along the river courses (Hartmann 1990). Because of the lack of wood, people used dried cow dung for cooking, which is rare in the Himalayan region. Despite being arid, and cold with nutrient-poor soil and high pH (8.5), some parts of Changthang rangelands (spread over 24,000 km^2; 4400-5000 m asl) are fairly species rich, with plant cover between 28% and 90% and above ground biomass between 32-210 g/m^2. The rangelands have 232 vascular plant species of 101 genera with *Poaceae* (39 species), *Asteraceae* (27 species) and *Cyperaceae* (25 species) being the important families (Rawat and Adhikari 2005).

Ladakh has 36 species of wild mammals which include 8 species of ungulates, 11 rodents, 2 hares, 5 mouse hares, 3 felids, 3 canida, 1 ursid, and 4 mustelids (Fox et al. 1986, 1991a, b, Shawl and Takpa 2009). Urial, a sheep endemic to Ladakh is a threatened species, and Tibetan argali, the largest wild sheep (97-328 kg) is of near threatened category (Fox et al. 1991a). In Hemis Park, the region contains a pristine habitat of snow leopard, an endangered species (Fox and Nurbu 1990, Fox et al. 1991b). The Ladakh's Tibetan antelope (chiru known for its precious wool called shatoosh) population is its sole representative in India (Shawl and Takpa 2009). Tibetan gazelle is of near threatened category and the Tibetan wild yak belongs to vulnerable category (Fox et al. 1991a, 1994). The Himalayan brown bear, recognized as a critically endangered species, is represented here by a small population (Fox et al. 1994). The region also has a wild dog of endangered category and Pallas cat, a near threatened "cat" species. There are several wild animals with large populations: Tibetan wild ass, blue sheep or bharal, ibex the elegant goat, Tibetan wolf, Eurasian lynx, Tibetan fox, marten, pikas, and long tailed marmot (Fox et al. 1994). Among the birds, black-necked-crane (*Grus nigricollis*), a medium sized crane (5-6 kg weigh) is a major attraction (Fox et al. 1994). Since it nests on ground it is vulnerable, particularly because of feral dogs.

The pastoralists complain that forage availability and forage quality for their sheep and goats have been adversely affected by overgrazing by wild ass (*Equus kiang*). However, an investigation showed that this was not the case, as the density of kiang was (0.24/ km^2) only about 7% of that of domestic animals (11/ km^2). The biomass consumption from sedge-grass community by kiangs was only 10%, the rest was by goats (43%) and sheep (27%). Since 55% of Kiang's sighting is solitary (Table 1), local overgrazing due to kiang is unlikely to occur (Bhatnagar et al. 2006). A study based on experimental warming and simulated grazing in Tibet Plateau indicates that warming, rather than grazing decreases rangeland productivity and nutritive quality (Klein et al. 2007). Moreover, in cold dry regions grazing by livestock and other herbivores could be beneficial depending on local abiotic and biotic factors (Maestre et al. 2022).

Transboundary cooperation

There is a need for transboundary cooperation to promote harmony among the issues of wildlife, livestock, and tourism. It could be extended to developing corridors for the movement of wild mammals, sharing of river water, and disaster prevention. The Tibetan antelope (*Pantholops hodgsonii*, near threatened) is found in contiguous patches between India and China along the Changchenmo Plateau and Daulat Beg Oldi. A transboundary park can play a role in conservation and collaborative research.

According to Wasteland Atlas of India (2019), snow and glacial area (24%) and barren rocky/stony area (64.3%) together account for about 88% of entire Ladakh. Out of the 58,208 km^2 of wasteland area,

only 6% is suitable for carbon sequestration, estimated at about 66 $MtCO_2$-eq by 2030.

Renewable energy opportunities and constraints

The potential for solar energy generation in Ladakh is estimated at 35 GW. Even if a fraction of the potential is realized, solar energy along with geothermal energy can make Ladakh a contributor to India's Carbon Balance.

Solar energy

Developing large solar energy plants is quite tempting given that Ladakh has about 320 days of intense sunshine (Table 1), and extensive ground space for solar plant installations. However, there are several difficulties associated with the remoteness of the region, and long winters when the region is snow-covered, making very difficult to repair transmission lines and transport heavy equipment. The energy generated at a large scale has to be mainly used by economic activities located at far off places. Then, there are some serious technological limitations (Table 1). For example, manufacturing cement, steel and chemicals requires temperatures in the range of 800-1000°C, for which solar power may not be cost effective. One tentative option of utilizing a large amount of energy could be to do the mining of Bitcoin or other crypto currencies, which requires a huge amount of energy and space. Implementation of Bitcoin mining may have several other problems, but developing Ladakh based economic activities to utilize energy is certainly desirable.

Geothermal energy

The Puga valley of Ladakh has over a hundred hot springs ranging in temperature from 30°C to 84°C, with a cumulative discharge of hot spring of about 30 l/s (Razdan et al. 2008). Reservoir temperature has been estimated at about 250-265°C. The estimated power generation potential of the Puga geothermal fields ranges from 30 to 200 MW. Unlike solar and hydropower, the geothermal energy output does not depend on vagaries of nature (Gupta 2009). Storage is not required, and its cost is to drop rapidly with time from the high initial cost of Rs. 400 million per MW. There is a need to take the help of countries like Ice land which specialize in geothermal energy. About 90% of houses in Iceland and 30% in Lhasa, capital of Tibet are heated by hot water obtained after geothermal power generation or low grade geothermal reservoir.

Wind energy

Because of low operation cost and potential to create jobs, the wind energy is the fastest-growing renewable energy source in the world. However,

Table 1. Solar energy development in the Union Territory (UT) of Ladakh: favourable conditions and constraints

Favourable conditions	Constraints
Over 300 days of high sun shine (7.5 $Wh/m^2/day$) in a year	Remoteness of sites, so transmission and transport costs would be very high
Sparse population (2,75,000) in 2011, so plenty of land is available for solar power plants	Solar plants require a large land area, this may affect age-old pastoralism and hence livelihood of nomads, and conflicts with wildlife conservation both in and outside protected areas
Since the energy consumption by local population will be low, a huge amount of energy can be supplied to other regions for economic activities	A large labour force from outside the UT will have to be ferried, and it may cause social conflicts
	Loose slopes would need to be compacted to construct transmission lines
So both environmental (renewable energy) and economic gains can be high	During winters when much of the area is under snow, repair of transmission lines and transport of equipment could be very difficult and costly
	Solar energy is not steady, and the grid cannot take fluctuations. Battery storage is costly; and transmission and distribution losses are high

large wind energy installations (potential 4 GW) also require sturdy and reliable evacuation infrastructure, which could be potential drawback for large scale deployment of wind energy in Ladakh. Ladakh is blessed with several snow-fed rivers which can be used to construct hydropower plants. However, the rivers and streams get frozen during winters.

Coherent traditional communities might be more adapted to climate change

A Vulnerability Index Analysis, indicated that the two districts of Ladakh were only marginally less vulnerable to climate change than neighbouring Kashmir districts (Ravindranath et al. 2011). However, because of the dependence largely on a rainfed agriculture, and high relative draft of ground water (tourism has added the stress) Ladakh is inherently weak with regard to climate change adaptation.

In a study on people's perception about climate change, which included a city site (in Leh) and a rural site, about 80% of the people recognized climate change as a threat. More respondents (78%) from the Leh city reported the decrease in water availability than the rural site (42%), because the rural site was located where several streams carried runoff water from a nearby glacier (Barrett and Bosak 2018). Fewer rural respondents (44%) considered climate change as negative factor than the city respondents (84%). There was a strong within community cohesion, connection to place and self-reliance in the rural communities which made them more adapted to climate change (Barrett and Bosak 2018).

According to TERI (2011) the annual per capita CO_2 fossil fuel emission in Ladakh was ridiculously low until recently (0.078 t/yr) compared to 2.4 t/capita/yr for India, and 6.3 t global average (also it includes landuse changes, United Nations Environment Programme 2022). The domestic energy accounted for ~90% total energy consumption of Ladakh.

Urbanization and Tourism

The Himalayan cities are getting unacceptably crowded with serious traffic problems. Unlike other mountain areas, Ladakh has relatively more gentle slopes, so, enough space could be allocated for roads, footpaths and lanes for pedestrians, and bicycle users. The population of Leh has almost tripled within two decades (Singh et al. 2020). Apart from the pressure of tourism, nomadic tribes have begun to congregate in Leh from rangelands.

Though tourism began only in 1974, it is already contributing 50% to the GDP of Ladakh. The number of tourists has risen to 327366 (in 2018), and is now largely domestic (85%, compared to 5% in 1974) (Anonymous 2019). The number declined subsequently due to COVID-19. Diversification of tourism both in regard to tourist destination and form is being suggested. International tourism could be increased by linking it with wildlife, as in open rangelands animal sighting can be high.

CONCLUSIONS

Can Ladakh be sustainably developed despite being a cold desert, by drawing upon its rich renewable energy sources and tourism? The answer to this question, analyzed in earlier sections is summarized below:

To sustain tourism and renewable energy production, efforts would be required to address their impacts on the natural fabric of Ladakh (Fig. 3). Climate change-induced hazards like glacier melt, erosion and flash floods can be very destructive, and difficult and costly to manage.

Traditionally rural communities in Ladakh have been, cohesive and socially resilient (Barrett and Bosak 2018), which could be carefully nursed to lay the foundation of future development.

A realistic assessment of the energy potentials is required in view of finance, technology, electricity transmission and likely clashes with biodiversity conservation (Fig. 3). For energy production the money transfer from the federal government can be justified in view of the likely gains in terms of carbon neutrality at the country level. Given the costs and problems of energy transmission to distant places through a snow-clad terrain, it would be prudent to develop high energy dependent industries like Bitcoin mining locally.

Tourism has already become a stronghold of Ladakh; the yearly number of tourists approaching the local population size, a feature associated with most preferred tourist destinations, like France

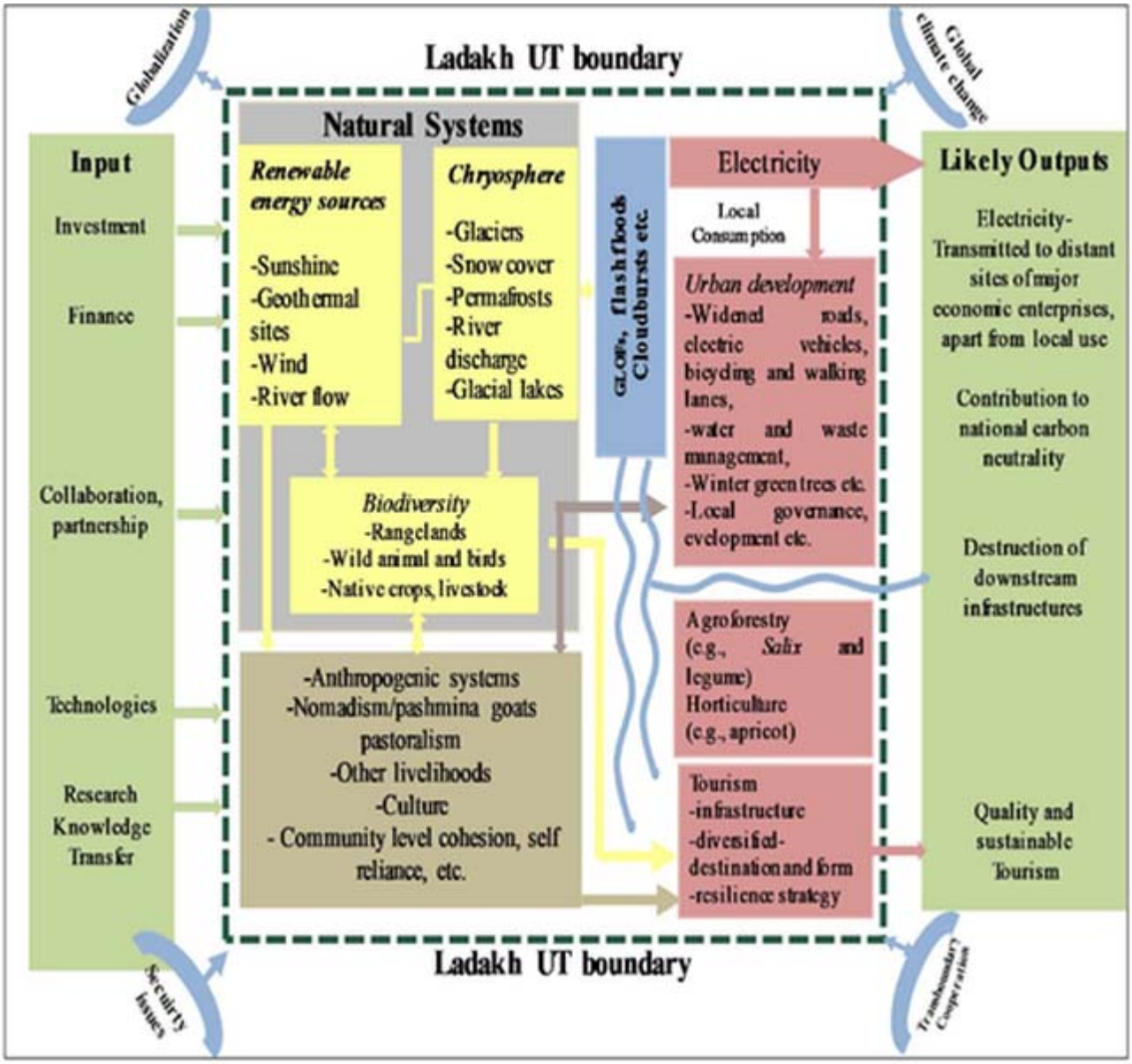

Figure 3. A schematic representation of interconnections among various systems and activities in Ladakh. Natural system is centrally located in a prominent way. Natural components combined with technology and human efforts and capital can produce high amount of renewable energy to meet local need as well as distant industrial and other scale economic activities. Water factor is important in several activities (shown in italics).

and Italy. How to advance its sustainability keeping in view the integrity of ecosystems and culture is challenging. How much diversification with regard to tourist destination, and kind of tourism (e.g., nature tourism, adventure tourism) is manageable?) The recent of experience of COVID-19 shows that tourism can be highly vulnerable to pandemics and other external factors. Climate change hazards too damage tourism. Here, we assume that in a long term, Ladakh's renewable energy production would progress enough to meet the energy needs of tourism as well as supplying energy to some major economic centre of Northern India. However, immediate energy needs are to be addressed particularly to develop quality and responsible tourism. Suitable policies would be required to facilitate equitable distribution of revenue generated by tourism.

Can rangeland based pastoral life be modernized by

applying drudgery saving tools, particularly Artificial Intelligence? Would young people adopt pastoralism in Changthang rangeland, if it were made drudgery-free and connected to tourism? Already the UT government has taken initiatives to provide houses to these people. How climate warming is to affect the thickness of pashmina wool, CO_2 stored in permafrosts, glaciers and river discharge? A backing of networked and collaborative research may go a long way to address these questions. Ladakh could become India's major ecosystem service provider, if its ecosystems and other natural assets were managed, through periodical monitoring. Climate change and the lack of transboundary cooperation can be serious impediments to the development of the region, hence deserve earnest efforts.

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