

Solar Parks: Threat to Biodiversity and Ecosystem in the Thar Desert of Western Rajasthan, India

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Abstract

India's push to install 500 GW of renewable energy by 2030 has made the Thar Desert of western Rajasthan a major hub for utility-scale solar development. The 2,245 MW Bhadla Solar Park, which covers more than 5,700 hectares, is the most prominent example. Much of this land has been allocated cheaply because state revenue records describe it as unproductive wasteland (*banjar*), a label that masks its ecological and cultural value. This paper presents findings from field surveys conducted between 2021 and 2024 across Jodhpur, Phalodi, and Jaisalmer districts, combining botanical assessments, key-informant interviews, and focus group discussions with a review of published ecological, wildlife, and legal literature.

The findings show that solar park construction is causing serious and lasting damage to this fragile ecosystem. Mechanical clearing strips away biological soil crusts, releasing windblown dust that reduces panel efficiency by 20 to 35 percent and forces bi-weekly washing using groundwater drawn from non-renewable fossil aquifers. Thousands of mature Khejri trees (*Prosopis cineraria*), the ecological backbone of the Thar, have been felled at construction sites, with developers paying a legally permitted fine of just Rs. 100 per tree. High-voltage transmission lines running through bird habitats near Pokhran and Ramgarh kill an estimated 84,000 birds each year, including the critically endangered Great Indian Bustard (*Ardeotis nigriceps*), whose total wild population is now below 150. Sacred community forests known as *Orans* are being enclosed and cleared without the knowledge or consent of the pastoral communities who have protected them for centuries.

The paper also provides with policy recommendations based on the current situation which include mandatory Environmental Impact Assessments for all solar projects above 1 MW, formal legal protection for Orans, underground transmission cabling within bustard habitats, and a shift toward agrivoltaics and waterless panel-cleaning technology.

Keywords: *Prosopis cineraria*; Great Indian Bustard (*Ardeotis nigriceps*); Orans; Utility-scale solar energy (USSE); Bhadla Solar Park; Biological soil crusts; Environmental Impact Assessment (EIA).

1. Introduction

Climate change is one of the most pressing problems the world faces today. Reducing dependence on fossil fuels is widely accepted as an urgent priority. Countries everywhere are investing in renewable

energy, and India has set some of the most ambitious targets of any developing nation. Under the Paris Agreement and its updated Nationally Determined Contributions, India has committed to sourcing 50% of its installed power capacity from non-fossil fuels by 2030. The overall target is 500 GW of renewable capacity, with net-zero emissions by 2070 (Akella et al., 2009; Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025; Supe et al., 2024). Solar photovoltaics is the leading technology in this drive. Installed solar capacity is expected to grow from about 70 GW in 2023 to close to 280 GW by the end of the decade (Supe et al., 2024).

The environmental case for solar energy is straightforward. Over its full lifetime, a solar panel generates only about 14 g of CO₂ per kilowatt-hour. A gas-fired power plant produces more than 608 g for the same unit of electricity (Hernandez et al., 2014). On that measure alone, the shift to solar makes obvious sense. The problem is land. Ground-mounted solar installations need between 6 and 8.9 acres per megawatt of installed capacity (Bhushan and Hemberg, 2012; MNRE, 2013; Supe et al., 2024). When roads, drainage works, inverter cabins, substations, and perimeter fencing are included, the total footprint can reach 2.5 times the area of the panels themselves (Dressman, 2024; Hernandez et al., 2014). Meeting India's solar target of 280 GW would require transforming more than one million hectares of land. That is an area larger than twice the combined footprint of India's ten biggest cities (Supe et al., 2024).

Scientists and planners have begun to describe this tension as the "green-green dilemma." The phrase captures a real conflict where the land needed to fight climate change can be the same land that biodiversity depends on (Madhusudan and Sinha, 2025; Sloan and Sayer, 2015; Tinsley et al., 2024). In practice, the two goals can work against each other.

To keep costs down and speed up development, planners have focused on dry and semi-arid regions for large solar parks (Hernandez et al., 2014, 2015). Deserts have clear advantages. They receive strong sunlight throughout the year. The terrain is mostly flat. Cloud cover is rare. And the human population is sparse compared to fertile agricultural zones (Hernandez et al., 2015; Wale and Dejenie, 2013). In India, all of these factors have pointed planners toward the Thar Desert of western Rajasthan. Rajasthan is the largest state in India by area. It also has the highest installed solar capacity in the country. The Bhadla Solar Park in Phalodi, covering more than 5,700 hectares with a capacity of 2,245 MW, is one of the largest solar parks in the world. Large projects also operate in Jaisalmer, Bikaner, and Barmer (Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025; Supe et al., 2024).

The justification for choosing these sites rests on a flawed assumption that desert land is ecologically empty and socially unoccupied. In fact, the Thar is the most densely populated desert on Earth. It has roughly 84 people per square kilometre. The region supports a remarkable variety of plant and animal life that has evolved over thousands of years to survive extreme heat, minimal rainfall, and nutrient-poor soils (Prakash, 2001; Roy and Roy, 2019). Its flora includes 682 vascular plant species, with an endemism rate of 6.4 per cent (Bhandari, 1978, 1990). That is higher than the endemism rate recorded in the Sahara (Roy and Roy, 2019). Calling this land "wasteland" is not just inaccurate. It is ecologically significant.

Converting this ecosystem into energy infrastructure has caused serious damage. Clearing and levelling the land strips away biological soil crusts. These crusts hold the sandy soil in place and fix atmospheric nitrogen. Without them, dust is released in large quantities. The dust settles on solar panels and reduces their output. To compensate, operators must wash panels frequently. That washing draws heavily on groundwater from aquifers that take centuries to replenish (Supe et al., 2024). At the same time, thousands of mature Khejri trees (*Prosopis cineraria*) have been felled at active construction sites. Khejri is the most important tree species in the Thar ecosystem. Sacred community forests known as *Orans* have been

enclosed and cleared. High-voltage transmission lines have been built through the breeding grounds of the Great Indian Bustard (*Ardeotis nigriceps*), a bird whose entire wild population is now below 150 individuals (Bishnoi et al., 2024; Madhusudan and Sinha, 2025; Misra and Agbaitoro, 2025).

Previous studies have examined pieces of this problem. Some have looked at the engineering of solar installations. Others have focused on land rights and pastoral communities. A few have modelled bird collision risks (Akella et al., 2009; Misra and Agbaitoro, 2025; Madhusudan and Sinha, 2025). What is lacking is a study that connects the on-ground destruction of plant communities with the wider consequences for soil, water, wildlife, and people. This paper attempts to provide that account. We draw on fieldwork at six sites across western Rajasthan: Bhadla, Askandra, Baru, Noore ki bhurj, Baori-Barsinga, and Degrai Mata Oran. These observations are combined with published data on soils, remote sensing, and environmental law. The aim is to give an honest, grounded assessment of what is being lost, and what policy changes are needed to prevent further damage.

2. Study Area and Research Methodology

2.1 Study Area

The study covers the arid belt of western Rajasthan, focusing on three districts which are Jodhpur, Phalodi, and Jaisalmer (See figure 1). The Thar Desert is situated between 23°3' to 30°12' N latitude and 69°30' to 78°17' E longitude, bounded on the east by the ancient Aravalli Range and extending westward into the Cholistan and Indus basins (Biswas and Rao, 1953; Prakash, 2001; Roy and Roy, 2019; Tyagi and Baqri, 2005).

The Climate of the study area is dominated by low and uneven monsoon rains (July-September) with a wide range in annual rainfall. The temperatures range from below freezing (- 2.5 0C) in the winter night to over 49-50 0C during the summer season (Bishnoi et al., 2024; Poonia and Rao, 2013). Evaporation rates are high, and a large moisture deficit occurs. These soils were developed from coarse sands that are highly permeable and low in organic matter (< 0.1-0.2%), but lie beneath is calcium carbonate or gypsiferous hardpans (kankar) that occur between 5 and 60 cm in depth (Wale and Dejenie, 2013). The focal study sites comprise:

1. **Bhadla Solar Park Complex:** Located in Phalodi tehsil (formerly Jodhpur district), spanning > 5,700 hectares (> 14,000 acres) with an installed capacity of 2,245 MW across four operational phases.
2. **Askandra, Baru, and Noore ki bhurj:** Agricultural and pastoral village settlements in Jaisalmer district situated adjacent to large-scale operational and under-construction private solar parks (including the 235 MW Joyamati sacred land installation; Bhushan and Hemberg, 2012).
3. **Baori-Barsinga Site:** An under-construction utility-scale solar power project in Jodhpur/Phalodi district where mechanized clearing of native tree covers triggered community protests in 2022 (Bishnoi et al., 2024).
4. **Degrai Mata Oran (Sanwata Village):** An expansive sacred community forest spanning > 60,000 bighas (~10,000 hectares) in Jaisalmer district, serving as a pastoral commons and critical foraging habitat for the Great Indian Bustard (Misra and Agbaitoro, 2025).

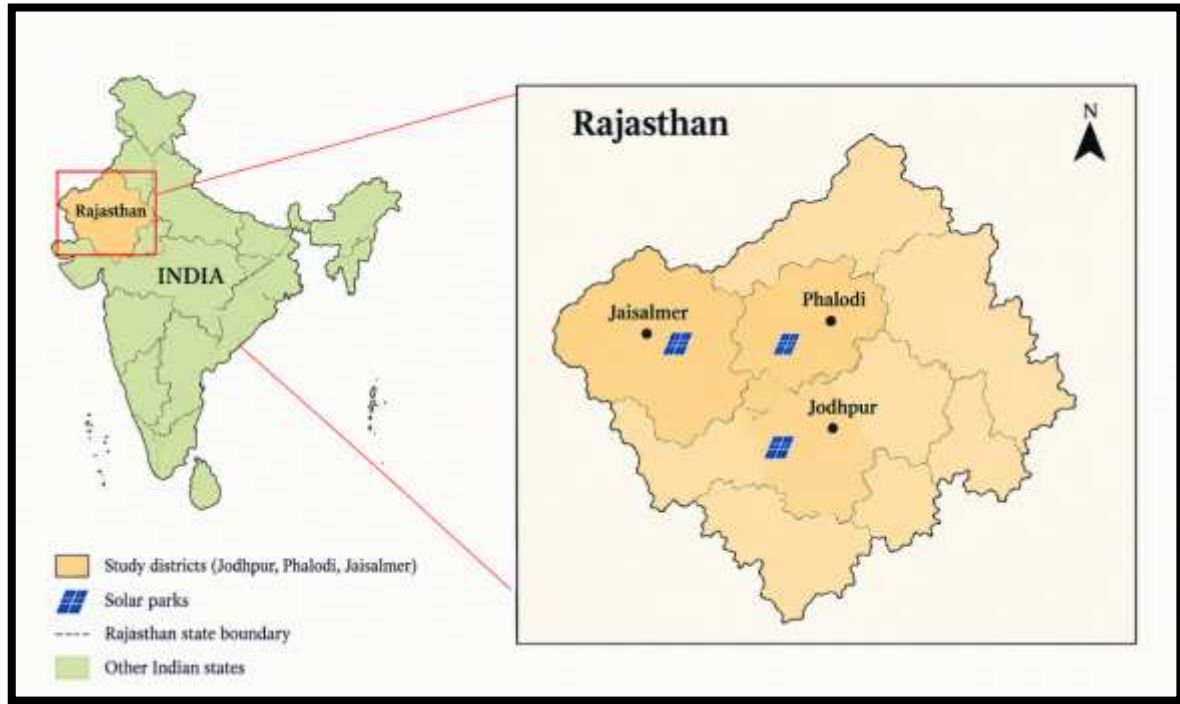


Figure 1. The detailed inset map illustrates the three primary study districts (Jaisalmer, Phalodi, and Jodhpur) with blue icons denoting the approximate locations of the surveyed solar parks (Map is not accurately to scale).

2.2 Methodology

The study uses a mix of both direct field observation and community interviews on one hand, and a review of published scientific, legal, and remote sensing material on the other. The two streams were designed to complement each other. Field data gave ground-level evidence of what is actually happening at specific sites, while the secondary synthesis placed those findings within a wider ecological and policy context. To understand on ground impacts, we carried out fieldwork across project sites and adjacent village lands in Jodhpur, Phalodi, and Jaisalmer. We walked boundary perimeters and internal roads to assess vegetation loss, recorded tree felling, and sampled plant recovery for ground flora under panels and in open corridors. We also conducted semi-structured interviews with village elders, pastoralists from Maldhari and Raika communities, farmers, site workers, and local conservationists, alongside group discussions in Askandra, Baru, Baori-Barsinga, and Sanwata to document grazing restrictions, groundwater pumping, and sacred grove (*Oran*) enclosures. To place these local findings in a broader framework, we paired our field data with published Thar Desert botanical and soil studies, satellite land-cover records tracking infrastructure expansion, Wildlife Institute of India bird mortality surveys, and relevant court judgments and state revenue documents.



Figure 2. Field interview with members of the Bhil tribal community in Baroo village, Rajasthan, India.

3. Results and Discussion

3.1 Land Conversion and Desert Soil Disturbance

Solar farms require extensive tracts of land for their installation. Synthesizing information from 18 operating photovoltaic (PV) power plants in India, the Centre for Science and Environment (CSE) estimated a land footprint of 7.58 acres (3.06 ha) per megawatt (Bhushan and Hemberg, 2012). The MNRE guidelines stipulate a minimum land area of 6 and 7 acres per MW for the crystalline silicon and thin-film solar panels, respectively (MNRE, 2013). Indeed, in western Rajasthan, thousands of acres of barren desert have been converted into industrial energy complexes. The Bhadla solar park alone covers > 5,700 hectares (> 22 (square) miles) of contiguous surfaces, equivalent to ~1/3 the area of Washington, D.C. (Gawande and Chaudhry, 2019).

The initial step in the construction process typically involves 'scalping', where contractors remove all vegetation and grade the arid landscape into a uniform surface with a slope < 3% to accommodate the solar panel support structures (Hernandez et al., 2014). Such disturbances have detrimental effects on desert ecosystems that may last for decades:

- 1. Effects on Biological Soil Crusts:** The active layer of sandy soils in arid lands hosts a diverse microbial community of cyanobacteria (*Microcoleus vaginatus*, *Nostoc commune*), fungi, lichens, and mosses, collectively referred to as biological soil crusts (biocrusts). These organisms help stabilize sand dunes and contribute to nutrient cycling in desert soils, fixing atmospheric nitrogen (the major limiting nutrient in arid lands) through nitrogen-fixing bacteria present in the biocrusts (Hernandez et

al., 2014; Li et al., 2007; Wale and Dejenie, 2013). The removal of vegetation and mechanical disturbance during the scalping process destroys the biocrusts, and it may take several decades to centuries for the desert soils to recover (Hernandez et al., 2014; Lathrop and Archbold, 1980).

2. **Alterations in Soil Carbon and Nutrient Contents:** The removal of vegetation and the loosening of the topsoil accelerate nutrient cycling and limits organic matter accumulation. For example, studies in similar arid shrublands showed that vegetation clearing reduced total organic carbon and nitrogen contents in the top 5 cm of soil by ~25%, and these values remained ~30% lower than the reference plots 15 years after disturbance (Hernandez et al., 2014; Li et al., 2007).
3. **Waterlogging and Gully Erosion:** The compaction of the topsoil and removal of vegetation during the construction of solar farms can disturb its permeability and water retention capacity (Hernandez et al., 2014). Therefore, solar farms create conditions conducive to waterlogging and preferential flow during the rainy seasons, leading to the formation of gullies and rills around the margins of the PV installations (Hernandez et al., 2014).

Native plants like *Calligonum polygonoides*, *Crotalaria burhia*, and *Capparis decidua* slow down the wind and keep sand in place. Once they are cleared, bare soil sits exposed to desert winds that regularly exceed 30–40 km/h (Bishnoi et al., 2024; Kashyap et al., 2025; Wale and Dejenie, 2013).

What follows is a damaging cycle that feeds on itself:

- **Dust Release:** With no plant cover to hold it, the loose soil turns to dust, raising PM2.5 and PM10 levels in the air and spreading soil-borne pathogens across the region (Hernandez et al., 2014).
- **Dust on Panels:** Windblown dust coats the glass surface of solar modules quickly. In dry desert conditions, unclean panels can lose 20–35% of their power output within weeks, dropping by 0.3% to 1.0% each dusty day (Hernandez et al., 2014; Kimber et al., 2006).
- **Groundwater Pumping:** To meet the terms of their power purchase contracts, operators have to wash panels every 10 to 15 days, which means pulling huge amounts of water out of already-stressed aquifers (see Section 3.6).

3.2 Eradication of Keystone Flora: *Prosopis cineraria* (Khejri) and Associated RET Taxa

Among the plants harmed by solar development, nothing comes close to the scale of damage done to **Khejri** (*Prosopis cineraria*; Fabaceae), Rajasthan's official State Tree (Bishnoi et al., 2024).

The survival of the Thar ecosystem depends heavily on the specialized biology of mature Khejri trees. Their deep taproots penetrate 20 to 30 meters underground to draw water from deep aquifers. Through hydraulic lift, these roots redistribute moisture into the upper soil layers, nourishing surface grasses during dry spells. Symbiotic *Rhizobium* bacteria in their root nodules fix atmospheric nitrogen, enriching the impoverished soil with organic carbon and phosphorus. Uniquely adapted to extreme drought, Khejri produces fresh green foliage, flowers, and edible pods called *sangri* during the hottest summer months when most other vegetation is dormant. Each tree provides 25 to 30 kg of protein-rich dried fodder (*loong*, containing 14 to 18 percent crude protein) annually to keep livestock alive through the lean season, while its wide umbrella canopy lowers midday ground temperatures by 5 to 10°C to create a vital thermal shelter for desert wildlife.

Khejri is the cornerstone of the Thar's ecology (Bishnoi et al., 2024; Bhandari, 1990):

- **Deep Roots and Water Sharing:** Mature Khejri trees send their taproots 20 to 30 metres or more into the ground, reaching water well below the compacted hardpan layers. Since its lateral roots are sparse near the surface, it does not compete with shallow-rooted crops like bajra (*Pennisetum glaucum*) or cluster bean (*Cyamopsis tetragonoloba*), or with native grasses like *Cenchrus ciliaris* and *Lasiurus*

sindicus. Instead, through a process called hydraulic lift, Khejri draws moisture from deep layers and releases it into the upper soil, actually helping the crops and grasses growing nearby (Bishnoi et al., 2024).

- **Soil Enrichment and Shade:** *Rhizobium* bacteria in Khejri's root nodules fix nitrogen from the air, noticeably enriching the soil beneath with organic carbon, nitrogen, and phosphorus. Its wide canopy lowers ground temperatures by 5–10°C and gives shade to wild deer, birds, and grazing animals during the brutal summer heat (Bishnoi et al., 2024; Gawande and Chaudhry, 2019).
- **A Lifeline During Drought:** What makes Khejri truly remarkable is that it leafs out, flowers, and produces its pods (*sangri*) between March and June when almost every other plant in the desert has dried up or dropped its leaves. Herders harvest its leaves as *loong*, a fodder containing 14–18% crude protein that keeps their sheep, goats, and camels alive through droughts. The dried pods (*sangri*) sell for Rs. 800–1,000 per kilogram in local markets (Bishnoi et al., 2024).

Despite all of this, solar developers routinely cut every tree on a site simply to stop any shading on their panels (Bishnoi et al., 2024; Gawande and Chaudhry, 2019). Our fieldwork found evidence of large-scale tree clearance at several locations:

- **Baori–Barsinga (Phalodi/Jodhpur):** During construction, we found that mature Khejri trees had been felled and their trunks buried in trenches, apparently to hide the true scale of the clearance. In June 2022, Bishnoi community members started the *Khejri Bachao Andolan*, a protest movement against the felling of more than a thousand mature trees in Phalodi tehsil for a solar plant (Bishnoi et al., 2024).
- **Askandra, Baru, and Noore ki bhurj (Jaisalmer):** Large-scale clearing for solar facilities and transmission corridors uprooted centuries-old Khejri stands from common grazing lands and fields (Bhushan and Hemberg, 2012).

A significant factor contributing to this widespread clearance is an outdated statutory provision. Under Section 84 of the *Rajasthan Tenancy Act, 1955*, the penalty for unauthorized felling of a Khejri tree remains set at Rs. 100 per tree, an amount unchanged since the legislation was originally framed (Bishnoi et al., 2024). In the context of large-scale, capital-intensive solar infrastructure, this nominal sum provides little financial deterrence against site clearing during construction (Bishnoi et al., 2024). While tree translocation is occasionally suggested as an alternative, its practical efficacy remains limited. Deep-rooted desert phreatophytes experience severe physiological shock during uprooting, resulting in post-translocation survival rates typically under 5 to 10 percent in hyper-arid conditions (Bishnoi et al., 2024; Hernandez et al., 2014).

Beyond Khejri, site clearing wipes out many other rare and threatened plants. Among them is **Rohida** (*Tecomella undulata*; Bignoniaceae), an endangered desert timber tree already in serious decline (Arya et al., 1992; Patra et al., 2026), along with the medicinally important **Guggul** (*Commiphora wightii*; Burseraceae), the climber *Ephedra ciliata*, and several salt-tolerant plants that grow in low-lying areas (Arora et al., 2010; Patra et al., 2026; Rajpurohit et al., 1979; Singh, 2004).

3.3 Biological Invasions: Colonization by *Prosopis juliflora*

Clearing large areas of land and disturbing the soil opens the door for invasive plants to take hold. Prakash (2001) noted long ago that disturbing the soil and introducing surface moisture pushes desert vegetation succession backwards, replacing native plants with aggressive weeds and alien invaders.

At working solar sites across western Rajasthan, we saw this happen through two main pathways:

1. **Takeover by *Prosopis juliflora* (Vilayati Kikar):** This thorny shrub, originally from Central America, spreads rapidly along disturbed tracks, drainage channels, and cleared fence lines around solar parks. Its leaves contain chemicals that seep into the soil and stop the seeds of native grasses like *Lasiurus indicus* and *Cenchrus ciliaris* from germinating, giving *P. juliflora* an unfair advantage over native species (Prakash, 2001; Roy et al., 2022). Once it gets a foothold, it forms thick, impenetrable thickets that push out Khejri and other native plants (Prakash, 2001).
2. **Weed Growth Under Panels:** Each time panels are washed thousands of litres of water run off along drip lines at the panel edges. This creates narrow strips of moist soil that would never normally exist in the desert, and weeds and water-loving invasives quickly take advantage (Armstrong et al., 2014; Prakash, 2001). Over time, native sand-loving plants like *Calligonum polygonoides*, *Haloxylon salicornicum*, and *Dipterygium glaucum* lose ground and are pushed out from the edges of the solar arrays (Prakash, 2001; Roy and Roy, 2019).

3.4 Barrier Effects, Perimeter Security Fencing, and Habitat Fragmentation

To protect equipments from theft or livestock damage, developers fence the entire perimeter of their solar parks with 2-metre galvanized chain-link fencing topped with razor wire. At large sites like Bhadla, Fatehgarh, and Nokh, these fences stretch without a gap across tens of square kilometres (Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025).

Desert animals evolved to roam freely across open rangeland, following seasonal rains and temporary water ponds (*tobas*). Continuous fencing cuts right across these movement patterns:

- **Animals Blocked from Grazing Areas:** Chinkara (*Gazella bennettii*), Blackbuck (*Antelope cervicapra*), and Nilgai (*Boselaphus tragocamelus*) cannot cross these fences to reach the grazing areas they have always used (Gawande and Chaudhry, 2019). Animals that end up pacing the fence perimeter often get caught in the razor wire, or are cornered by feral dogs and killed (Madhusudan and Sinha, 2025).
- **Habitat Cut into Pieces:** Desert Fox (*Vulpes vulpes pusilla*), Asiatic Wildcat (*Felis lybica ornata*), and Caracal (*Caracal caracal*) each need between 5 and 15 km² of continuous territory (Anjanappa, 2024; Roy and Roy, 2019). Large fenced solar clusters cut these territories into fragments too small to be viable, reducing the ability of animals to move through the landscape and making local extinctions more likely (Ewers and Didham, 2006; Hernandez et al., 2014).

3.5 The Great Indian Bustard (*Ardeotis nigriceps*) Crisis

The rapid growth of solar energy projects throughout western Rajasthan poses an existential threat to the Great Indian Bustard (*Ardeotis nigriceps*), locally called the Godawan. The bird is classified as Critically Endangered by the IUCN and included in Schedule I of the Wildlife (Protection) Act, 1972. The wild population of the Great Indian Bustard has dwindled to less than 150 individuals (Madhusudan and Sinha, 2025; Roy et al., 2022). About 90 percent of the surviving population resides in the area of Jaisalmer, primarily the Desert National Park and the unprotected grasslands surrounding it (Madhusudan and Sinha, 2025).

The natural history of the species predisposes it to the risk of overhead power lines. The Great Indian Bustard, weighing 15 to 18 kg with a wingspan of more than two meters, is one of the heaviest flying birds in the world. The load per unit area of wings causes slow ascents and makes it impossible to make sudden turns or stops to avoid obstacles (Madhusudan and Sinha, 2025). Additionally, the bustard's eyes are located laterally on its head, providing excellent vision while foraging on the ground but creating a considerable blind zone in front of the bird (Dressman, 2024; Madhusudan and Sinha, 2025). Since female

bustards reach sexual maturity late and have only one egg per clutch, a population decline may occur if the adults' death rate climbs above 1 or 2% per year (Madhusudan and Sinha, 2025; Roy et al., 2022).

The evacuation of power from the solar farms has required the installation of thousands of kilometres of high-tension power lines (33 kV to 765 kV) across bustard habitat (Anjanappa, 2024; Madhusudan and Sinha, 2025). Comprehensive surveys conducted by the Wildlife Institute of India (WII) estimate 84000 birds killed by power lines in a 4200 km² area (Madhusudan and Sinha, 2025; Rahmani, 1997; Roy et al., 2025). In the case of the bustard, WII's population model for the species suggests that 16 individuals die per year from collisions with overhead lines or electrocution, which constitutes more than 10% of the total population (Madhusudan and Sinha, 2025). The adult female bustard was found burnt at Degrai Mata Oran near Devikot after colliding with a high-tension power line in 2022 (Madhusudan and Sinha, 2025). The mortality event led to public interest litigation before the Supreme Court of India (M.K. Ranjit Singh & Ors. v. Union of India & Ors.), which directed all power lines in the priority (3163 km²) and potential (28675 km²) ranges of the bustards to be buried underground (Madhusudan and Sinha, 2025; Misra and Agbaitoro, 2025). The renewable energy developers and the Ministry of Power objected to the orders, citing the high costs and technical challenges of the undergrounding, which stalled the execution. The Supreme Court stayed its April 2021 order and set up a committee to look into the alignment of the power lines, and excluded the power lines in the potential bustard habitats from the April 2021 orders in March 2024 (Madhusudan and Sinha, 2025).

3.6 Solar Development and Groundwater Depletion

Although photovoltaic panels do not require water for cooling, keeping them free of desert dust requires substantial amounts of water. In western Rajasthan, high dust levels mean modules must be cleaned every ten to fifteen days to maintain efficiency (Supe et al., 2024). Field data indicates that cleaning consumes roughly 110 milliliters of water per kilowatt-hour generated, or 2 to 2.5 liters per panel for each wash cycle (Bhushan and Hemberg, 2012; Supe et al., 2024). A standard 10 MW solar installation uses between 165,000 and 200,000 liters of clean water every month (Gawande and Chaudhry, 2019; Supe et al., 2024). At ultra-mega complexes like Bhadla (2,245 MW), annual washing demand exceeds 40 to 50 million liters. Most of this water is drawn from deep, non-renewable sandstone aquifers or hauled in by tanker trucks from Indira Gandhi Canal supply points (Bhushan and Hemberg, 2012; Supe et al., 2024).

This heavy water demand intensifies existing resource competition across arid tracts. Supe et al. (2024) evaluated the national Solar-Agriculture-Water nexus and found that regions with high solar capacity often overlap with areas experiencing severe groundwater depletion. Natural aquifer recharge across western Rajasthan is minimal, averaging less than 5 to 10 mm per year due to extreme potential evapotranspiration (Wale and Dejenie, 2013). Intensive pumping for solar parks accelerates water table decline, increases salinity in remaining wells, and reduces water availability for local pastoralists and rainfed farming communities dependent on traditional village ponds (*tobas*) (Supe et al., 2024).

3.7 Encroachment on Sacred Groves (*Orans*) and Ethnobotanical Erosion

Western Rajasthan contains roughly 600,000 hectares of sacred community forests known as *Orans*. Dedicated to local deities such as Degrai Mata, Joyamati Mata, and Ramdevra, these groves have been protected by customary religious sanctions for over five centuries (Bishnoi et al., 2024; Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025).

Because felling green wood and hunting are strictly prohibited, Orans serve as vital biodiversity refuges. They support dense stands of mature *Prosopis cineraria* (Khejri), *Anogeissus pendula* (Dhok), *Capparis decidua* (Kair), and *Ziziphus nummularia* (Ber), offering undisturbed foraging ground for chinkara, desert

foxes, and bustards (Joshi et al., 1991; Misra and Agbaitoro, 2025; Sankhala and Jackson, 1985). Furthermore, these groves are traditionally centered around natural water catchments (*tobas*, *nadis*, and *beris*) that collect seasonal rainfall and recharge shallow aquifers, while functioning as shared grazing reserves for pastoral communities such as Maldharis, Raikas, and Meghwals during prolonged droughts (Fisher, 1997; Misra and Agbaitoro, 2025).

Despite their cultural and ecological significance, Orans suffer from administrative misclassification. In post-independence land surveys, state revenue departments frequently failed to record these community commons as protected groves, cataloguing them instead as *Sivay Chak* (unoccupied government land) or general pasture (*charagah*) in village registers (Misra and Agbaitoro, 2025). Under the *Rajasthan Land Revenue Act, 1956*, the state claims authority over all unallocated *Sivay Chak* lands. State renewable energy authorities and district administrations have utilized this legal loophole to allot expansive tracts to private developers without consulting local pastoralists or obtaining their Free, Prior, and Informed Consent (Misra and Agbaitoro, 2025). In response, commercial developers fence off the commons with razor wire, remove standing trees, disrupt natural drainage channels, and route transmission infrastructure across sacred grounds (Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025).

These enclosures have triggered sustained local resistance across the desert region. In Askandra village, Jaisalmer district, a 235 MW solar project was allotted over sacred land dedicated to Joyamati Mata, prompting local protests when corporate contractors began bulldozing centuries-old Khejri trees (Bhushan and Hemberg, 2012; Gawande and Chaudhry, 2019). Around the Degrai Mata Oran in Sanwata, where energy installations encroached on sacred pastures, pastoral leader Sumer Singh Bhati led the *Oran Bachao Yatra*, a 225-kilometer march to Jaipur demanding that all community groves be formally registered as Deemed Forests (Misra and Agbaitoro, 2025). The courts have occasionally intervened to protect these commons. In *Kalyan Singh & Ors. v. State of Rajasthan & Ors.* (2021), the Rajasthan High Court set aside a 900-acre land allocation to a private solar developer, ruling that traditional sacred commons cannot be transferred for commercial energy projects without formal statutory de-reservation and suitable community compensation (Misra and Agbaitoro, 2025).

3.8 Solar Waste and Ecological Risks

Beyond direct land clearing and habitat loss, utility-scale solar parks introduce secondary environmental hazards that will compound over coming decades.

Solar photovoltaic panels have an operational lifespan of 20 to 25 years. Because utility-scale expansion across India gained momentum after 2010, large volumes of decommissioned panels will reach end-of-life status beginning in the early 2030s. Installing 100 GW of capacity is projected to produce roughly 7.76 million metric tonnes of electronic waste (Gawande and Chaudhry, 2019; Kumarankandath, 2016). Disposal presents severe ecotoxicological risks. Thin-film modules deployed across Rajasthan contain Cadmium Telluride (CdTe), a toxic heavy metal that bioaccumulates in food chains, while crystalline silicon panels contain lead solders, antimony, and fluorinated backsheets (Gawande and Chaudhry, 2019; MNRE, 2013). Currently, western Rajasthan lacks dedicated industrial recycling facilities for solar components. Damaged and discarded panels are frequently accumulated in unlined scrap yards or abandoned on village commons, where weathering risks leaching heavy metals into permeable desert sands and underlying groundwater (Gawande and Chaudhry, 2019).

Vast arrays of dark, anti-reflective solar modules alter regional optical landscapes. Because the smooth glass surfaces polarize reflected sunlight, large installations mimic the visual signature of open waterbodies from the air. Migratory birds traversing the Central Asian Flyway mistake expansive solar

fields for wetlands, descending rapidly only to suffer fatal collisions with panels or perish from heat stress on scorching surfaces (Dressman, 2024; Hernandez et al., 2014; McCrary et al., 1986). This polarized light also functions as an ecological trap for aquatic and semi-aquatic insects, including mayflies and water beetles. Attracted to the artificial reflection, insects attempt to oviposit on hot glass surfaces and die of thermal dehydration. In an arid ecosystem with low biological margins, the loss of these insect populations disrupts localized pollination networks and food webs (Dressman, 2024; Hernandez et al., 2014).

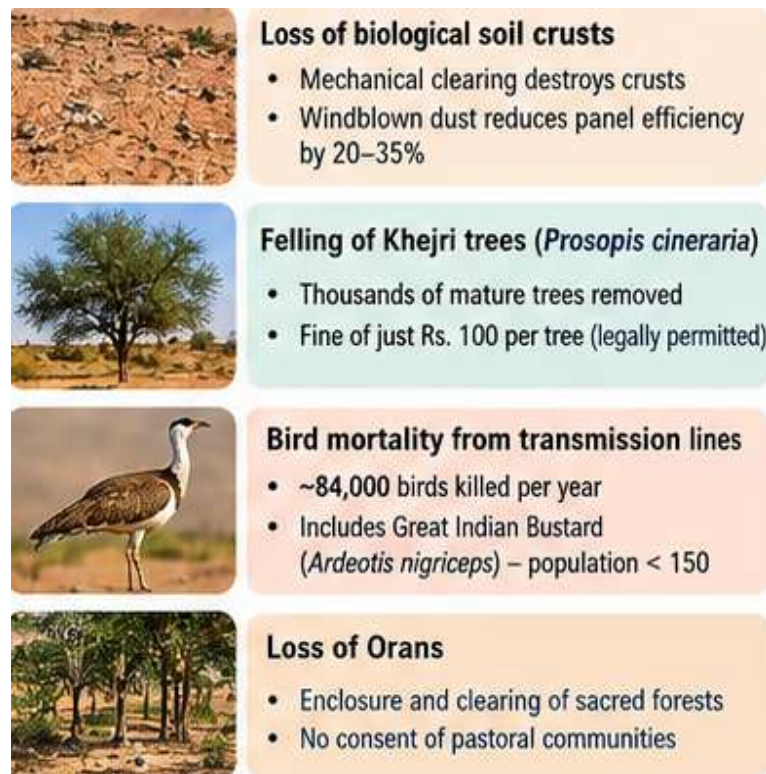


Figure 3. Environmental impacts of large-scale solar energy development in the Thar Desert, India.

4. Policy Analysis and Recommendations

4.1 Environmental Clearance and Regulatory Gaps

The root cause of these environmental and social conflicts is the regulatory anomaly wherein India's utility scale photovoltaics projects are completely exempt from Mandatory Environmental Clearance procedures (Anjanappa, 2024; Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025). Under the EIA Notification, 2006, large scale infrastructure projects require rigorous multi-seasonal ecological surveys and public hearings (Jansunwai) with affected villagers before implementation, plus installation of legally mandated Environmental Management Plans. To speed the transition to renewable energy, the Ministry of Environment, Forest and Climate Change has designated solar photovoltaics as a "White Category" of non-polluting industry (Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025). This categorization exempted solar power projects from formal environmental clearance procedures and mandatory pollution control permits as well as community consultations.

This regulatory approach has created an anomalous situation where a small scale 5 MW commercial workshop requires detailed formal environmental scrutiny whereas a 1000 hectare solar installation that pumps millions of liters of fossil groundwater, clears mature native trees and erects lethal transmission

corridors across endangered wildlife habitats can be installed with no environmental oversight (Anjanappa, 2024; Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025). This represents an inversion of global best practices (Table 2) wherein Germany's Federal Nature Conservation Act mandates strict spatial planning (Raumordnung) directing solar PV to former transport margins and built surfaces while requiring statutory ecological compensation (Eingriffsregelung) for any habitat loss (Anjanappa, 2024; Dressman, 2024; Hernandez et al., 2015). Similarly, Costa Rica's Strategic Environmental Assessments of energy projects strictly prohibit placement of power infrastructure within biological corridors (Anjanappa, 2024).

The latest legislation further erodes ecological protections with the Forest (Conservation) Amendment Act, 2023 restricting legal conservation to post-1980 forest records effectively nullifying the Supreme Court's 1996 Godavarman ruling and allowing large tracts of open natural ecosystems and unrecorded community Orans to be converted to industrial uses (Madhusudan and Sinha, 2025). Concurrently, shrinking budgets for wildlife conservation have led to understaffing of regional forestry departments, limiting their capacity to monitor transmission mortalities within the expanding desert solar energy footprint (Madhusudan and Sinha, 2025).

4.2 Protecting Orans and Native Trees

To address these issues, the Ministry of Ecology and the Rajasthan state government require policy corrections. First, the White Category exemption for photovoltaic projects of 1 MW and above must be rescinded. New solar plant sitemarks should follow a tiered review process with projects between 1 MW and 25 MW requiring state-level Environmental Management Plans whereas projects > 25 MW or within 25 km of protected areas or bustard habitats require multi-seasonal impact studies with public hearings (Gawande and Chaudhry, 2019; Misra and Agbaitoro, 2025). Assessments should evaluate cumulative project effects on regional water reserves, wildlife corridors and aeolian dust budgets rather than individual plot reviews.

State authorities need to secure customary land rights by surveying and recording all 600,000 hectares of Rajasthan's sacred groves as "Oran / Deemed Forest" entries within its land records (Jamabandis) (Misra and Agbaitoro, 2025). Recognition of Community Forest Resource titles under the Forest Rights Act, 2006 would empower Gram Sabhas to protect their commons. Further, Section 84 of the Rajasthan Tenancy Act, 1955 should be amended to increase the fine for Khejri tree felling from the current Rs. 100 to Rs. 50,000 to Rs. 1,00,000 per tree to provide a meaningful financial deterrent (Bishnoi et al., 2024).

4.3 Land Siting, Power Lines, and Agrivoltaics

Energy planners should follow the Carnegie Energy and Environmental Compatibility model using a spatial multi-criteria analysis (Hernandez et al., 2015; Tinsley et al., 2024). Strict exclusion zones should be placed over priority and potential bustard habitats (~31,800 km²), sacred Orans, communal grazing lands and key stands of mature *Prosopis cineraria* and *Tecomella undulata*. Ground-mounted installations should be directed to disturbed surfaces including degraded mining sites, highway margins, salt flats and industrial brownfields. Human-modified lands contain 19 times more area capable of hosting a Paris Agreement-compliant energy system than current desert solar developments, enabling India to achieve its clean energy goals without converting intact desert ecosystems to solar farms (Baruch-Mordo et al., 2019; Dressman, 2024; Hernandez et al., 2015).

Within designated solar energy zones, strict engineering standards should be enforced. In accordance with the Supreme Court of India's April 2021 directives, all transmission lines running through bustard habitats must be buried with cabling costs charged to the balance-of-system budget (Madhusudan and Sinha, 2025;

Misra and Agbaitoro, 2025). Perimeter security fencing should include a 40 to 50 cm ground clearance to permit passage of tortoises, lizards and other desert wildlife while maintaining connectivity between solar installation blocks. To prevent depletion of Rajasthan's desert aquifers, all western Rajasthan solar farms should adopt waterless robotic desoiling technologies within three years (Hernandez et al., 2014).

An additional incentive should be created for agrivoltaics and built environment solar by mounting photovoltaic arrays on 2.5-3.0 meter poles with increased inter-row spacing to permit continued cultivation of traditional rainfed crops and livestock grazing. The transpiration from intercropped vegetation will cool the solar panels, improving power production by 2 to 5 percent while reducing evaporation from the crop canopy and mitigating plant heat stress (Hernandez et al., 2014; Supe et al., 2024). Solar arrays mounted along the Indira Gandhi Canal and on commercial rooftops avoid land use conflicts, reduce canal evaporation and benefit from the cooling effects of the canal (Gawande and Chaudhry, 2019; Hernandez et al., 2014).

4.4 Solar Waste and Recycling

To manage the 7.76 million metric tonnes of photovoltaic waste projected for the current decade, the central government should create national decommissioning guidelines (Gawande and Chaudhry, 2019; Kumarankandath, 2016). Project approvals should require solar developers to establish a ring-fenced decommissioning security bond to fund site remediation and panel removal. Enforceable Extended Producer Responsibility regulations should require solar manufacturers to establish recycling facilities capable of recovering >95 percent of silicon, glass, copper, lead and cadmium from end-of-life modules with strict prohibitions against open-air disposal of retired photovoltaics (Gawande and Chaudhry, 2019). Open dumping of retired modules in arid environments (Gawande and Chaudhry, 2019).



Figure 4. Policy recommendations for ecologically responsible solar-energy development in the Thar Desert of western Rajasthan.

5. Conclusion

Moving toward renewable energy is an undeniable necessity, but how we carry out this transition matters just as much as reaching our capacity targets. In western Rajasthan, the rapid spread of utility-scale solar parks has treated the Thar Desert as empty wasteland. In doing so, it has cleared ancient trees, drained non-renewable groundwater for dust cleaning, enclosed sacred community groves, and pushed the Great Indian Bustard dangerously close to extinction. A clean energy project that destroys the ecological fabric of an entire region cannot truly be called green.

Protecting biodiversity does not require abandoning solar energy. India has vast areas of already-degraded land, abandoned mines, highway corridors, and urban rooftops that can host solar panels without harming intact ecosystems. Reforming environmental rules, placing power lines underground in wildlife corridors, legally protecting community Orans, and investing in agrivoltaics will allow solar energy to grow responsibly. With thoughtful planning, India can expand its clean power while safeguarding the unique desert landscapes and pastoral communities that make the Thar their home.

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