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Pastoral lands and the green transition: opportunities and challenges

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The green transition—the global response to the climate and biodiversity crises—is generating demand for land to implement renewable-energy and carbon-sequestration projects. Rangelands have been attractive to investors because of their large extent, their high potential for wind and solar energy and for carbon sequestration and storage, and the perception that they are currently misused and easily available. In theory, green-transition projects could benefit pastoralists, but many projects alienate pastoralists' land, undermine their rights, and weaken their livelihoods. A few projects have been implemented in ways that respect or strengthen pastoralist rights, engage pastoralist communities in meaningful consultation, and ensure equitable benefit sharing. These experiences demonstrate that pastoralists are not inevitable victims of the green transition and do not need to be excluded from green transition opportunities. A just green transition depends on upholding pastoralist rights, enabling their effective participation, and ensuring equitable allocation of benefits.

KEYWORDS

green transition, just transition, land, pastoral, rangeland

Introduction

Climate change and global biodiversity loss are driving a move towards a low-carbon, resource-efficient economy that contributes to sustainable development and is commonly referred to as the green transition (UNEP, 2011). The green transition has implications for pastoralists, creating both opportunities and threats that have not been systematically examined. Pastoralists and their rangelands have historically been undervalued and starved of much-needed investment, leading to poor performance against human-development indicators and to high levels of poverty among the pastoralist communities (McGahey et al., 2014). This creates a clash of opportunities and constraints: pastoral lands offer a significant opportunity to invest in the green transition, but underdevelopment leaves pastoralists vulnerable in the face of those opportunities and they risk becoming casualties of land alienation and displacement by green-transition projects (Waters-Bayer and Wario, 2022).

Pastoralists' territories are usually marginal for crop production and face climatic extremes, such as high or low temperatures, aridity and seasonal water scarcity, combined with high levels of climatic uncertainty. Their lands are among the areas worst affected by the impacts of climate change, with temperature increase, changing precipitation patterns, and an increasing frequency and severity of extreme climate events (Oba, 2020). Climate change is projected to increase climate extremes and the severity of climate hazards and to amplify

uncertainty, which will place strain on pastoral systems, which are often already stressed by population growth, resource loss and other threats (Davies et al., 2015b; Herrero et al., 2016).

Most pastoralists use herd mobility as an adaptive management strategy, but this has been viewed by some policymakers as retrogressive and environmentally destructive. Lands that are used seasonally have been labelled as underused and unclaimed and this, combined with prejudice against pastoralists' cultural identity, has been used to justify dispossessing them of their land, withholding development investment and enforcing laws that have weakened their societies and economies (Johnsen et al., 2019; Scoones, 2021). Pastoralists can identify as Mobile Indigenous Peoples according to the United Nations (United Nations General Assembly, 2007) although not all pastoralists identify as such, and not all governments recognise pastoralists as Indigenous peoples. Pastoralists are ethnic minorities in several countries and are politically underrepresented. Many pastoralist societies face weak land tenure and have lost valuable land to other uses, such as wildlife conservation and crop farming (Davies et al., 2016).

Pastoralists have a long history of land alienation. Crop-farming communities have expanded into pastoral rangelands in many countries, often aided by public policy and research and development into drought-resistant crops and technologies. Pastoral land has also been annexed by governments—colonial and post-colonial—for irrigation projects, protected areas, urban growth, infrastructure development and other purposes, usually with no recognition of the existing rights of pastoralists and no compensation (IUCN, 2011; Johnsen et al., 2019; UNCCD, 2024). Now climate change is driving governments and private companies to seek new land for green transition investments, posing new threats to pastoral lands (Gabbert et al., 2021).

This perspective paper examines evidence of the potential of pastoral lands to support green-transition projects, including renewable-energy and carbon-sequestration schemes. We map renewable-energy potentials in the rangelands and present recent research into opportunities for carbon sequestration in rangelands. The paper examines selected green-transition projects particularly from India, Kenya and Mongolia to illustrate the risks to pastoralists and the opportunities for projects to secure the resource rights of pastoralists and to enable their sustainable management of rangelands. This paper relies on published experiences, and the cases that are used may require closer scrutiny to verify their impacts. The purpose of the paper is to emphasise the potential contribution of pastoral lands to the green transition, highlight that the green transition is likely to perpetuate demands for pastoral land, and show the approaches and policies that need to be developed if a just green transition is to be achieved.

Implications of the green transition for pastoral lands

The Intergovernmental Panel on Climate Change (IPCC) reports that human activities have unequivocally caused global warming, primarily through greenhouse gas (GHG) emissions arising from unsustainable energy use, land use and land-use

change, lifestyles and patterns of consumption and production. Human-caused climate change has been shown to affect weather and climate extremes in every region, leading to widespread adverse impacts on nature and people. Vulnerable communities contribute least to climate change and are disproportionately affected. Adaptation measures have progressed in all sectors and regions, with mixed results and with maladaptation in some sectors and regions. Further deep, rapid and sustained reductions in GHG emissions are needed to limit climate change to 1.5 °C (IPCC, 2023). At the same time, all global indicators on the state of nature show a decline. Monitored wildlife populations have shrunk by 73% on average and more than half the Sustainable Development Goal (SDG) targets will not be achieved by 2030, with 30% of them stalled or declining from the 2015 baseline (WWF, 2024).

Growing concern over climate change, biodiversity loss and other environmental threats has led to a substantial increase in policies and investments to develop green economies (UNDP, 2023). Inevitably, the green transition has generated interest in pastoral lands (rangelands) as potential targets for renewable-energy, biofuel and carbon-sequestration projects (McGahey et al., 2014; Johnsen et al., 2019). This in turn raises important questions over the scale of opportunity for rangelands to contribute to the green transition and the opportunities and risks this presents to pastoralists. The 2015 Paris Agreement introduces the idea of a just transition, focusing on the creation of “decent work and quality jobs in accordance with nationally defined development priorities” (UNFCCC, 2015). Consideration of a just green transition reflects concerns that many of those most vulnerable to the impacts of climate change and environmental degradation are poor and are largely excluded from global economic progress (King and Harrington, 2018).

Several dimensions of injustice have been identified in green-transition projects and programmes, including injustice around distribution of benefits, recognition of rights, and participation of citizens. Injustice can be viewed along two axes: social equality to inequality and ecocentrism to anthropocentrism. Green-transition projects that give strong moral primacy to nature but contribute to social inequality lead to environmental injustice (Stevis and Felli, 2016). Examples of this kind of environmental injustice include the annexation of pastoral land to create national parks in several countries (Yilmaz et al., 2019) and the use of pastoral land for afforestation projects to offset GHG emissions (Briske et al., 2024).

Environmental injustice can also stem from geographical power imbalances and the relations between rich and poor countries and between central authorities and vulnerable communities in less developed countries. Injustice also arises when the rights of capital take precedence of democratic process (Stevis and Felli, 2016). However, much of the literature on just transitions is based on experiences in industrialised countries, while evidence of the impact of power dynamics on just transition outcomes in developing countries is comparatively weak (Wang and Lo, 2021).

The current low-carbon transition taking place globally may be delivering environmental and economic benefits but does not guarantee a more just world. Indeed, the current transition may create new injustices and increase vulnerabilities, undermining

claims of sustainability. Important questions must be addressed about the impact of the green transition and the distribution of benefits. The concept of a just transition is not new, but the rapid emergence of climate action is raising new questions across several dimensions of justice, including labour, income, energy access and others (Wang and Lo, 2021).

The profound transition in energy systems towards large-scale, low-carbon energy systems is helping to reframe energy justice, improve understanding of the resistance to energy projects, and mitigate potential or perceived injustices (Van Uffelen et al., 2024). A just green transition in rangelands does not relate exclusively to renewable energy but to transition of the agriculture sector (encompassing pastoral livestock production). The issues overlap, since energy poverty is high in rural areas, with 1.1 billion people globally considered to be energy impoverished (Min et al., 2024). However, green transition in the agriculture sector encompasses questions about the environmental impacts of food production, and the sector faces pressure to reduce its environmental footprint. Significant questions of justice arise since many agricultural communities face underlying challenges to their wellbeing, rights, opportunities for workers, and collective power. Crop farming and pastoralism are more than livelihoods: they represent ways of life and culture for communities, raising questions not only of distribution of benefits, but also recognition of rights and participation of citizens (Chatterjee and Swarnakar, 2023).

The threats of climate change can aggravate existing social injustices, particularly among communities reliant on climate-sensitive production and with constraints to their adaptive capacity due to low economic development: features that are common to many pastoralist societies. Achieving a just transition will require strengthening the capacity of pastoralists with respect to finance, technology development and innovation, skills training and education, and access to information. Communities need stronger capacity to self-organise and navigate the green transition and its opportunities and threats. Underlying risk factors need to be addressed, such as regenerating soil health, restoring degraded land, protecting natural ecosystems and biodiversity, and developing markets (Mapfumo et al., 2025).

A just green transition of the pastoral livestock sector should ensure environmental sustainability while delivering fairness and inclusiveness. The sector needs to meet future consumer demand while managing increasing frequency and severity of climate change hazards, while meeting targets for emissions, water, biodiversity, social resilience and economic development. This requires further consideration not only of the impacts of a just transition *on* pastoralism, but a just transition *of* pastoralism, raising difficult questions over the contribution of pastoralism to environmental threats and what responsibilities rest with pastoralists.

Livestock is the largest contributor to agrifood systems GHG emissions, accounting for 26% of sector emissions in 2023 (4.3 out of 16.5 Gt CO₂e). Livestock-sector emissions grew by 22% from 2001 to 2023, with the strongest growth (80%) recorded in supply chain and consumption processes (FAO, 2025). Measures exist to help pastoralists adapt to climate change and reduce emissions, but major information gaps and uncertainties persist

around the contribution of pastoral livestock to GHG emissions and carbon sequestration and storage. Nevertheless, the sector offers significant opportunity for carbon sequestration in pasture soil and biomass and grassland management (Thornton et al., 2025).

A just transition of the pastoral livestock sector also raises questions over risks to livelihoods along value chains, workers' rights, increasing the voice of marginalised producers and other complex issues. Several measures can be found that address the dimensions of injustice discussed earlier (Stavis and Felli, 2016). Procedural justice can be advanced through improved participation in decision making, respect for local knowledge, and improved monitoring and evidence. Distributive justice can be strengthened through better distribution of resources, opportunities and responsibilities. Recognition justice can be strengthened through legal avenues, addressing power imbalances, reviving human-nature relationships, and enabling adaptation of local actors (Thornton et al., 2025).

The green transition can, in theory, contribute to the sustainable development goals of pastoralists. UNEP's definition of a green economy, cited above, emphasises human wellbeing and social equity, yet fears have been raised about historical injustices towards pastoralists being repeatedly perpetrated by green-transition projects. In practice, the green transition raises fears of a new wave of rangeland acquisitions in places where resource rights are poorly protected and where pastoralist communities have faced decades of prejudice, impoverishment, governance failures and marginalisation (McGahey et al., 2014). There is a contrast between projects motivated by the pursuit of land to deliver global environmental benefits and projects motivated by the pursuit of local sustainable development outcomes. The latter is consistent with what is generally considered a just green transition (Tavares, 2022).

Development opportunities that could be created through green transition are at risk of being lost on account of the insecurity of pastoralists' land rights and pastoralists' low political representation (Waters-Bayer and Wario, 2022). Social equity can be assured only if green-economy investments deliberately address the underlying weaknesses in pastoralists' capabilities and traditional rights and contribute to pastoralist resilience. A just green transition requires that projects do not leave poor and marginalised groups further behind but instead create opportunities to protect them and to accelerate their development (Davies, 2024).

Green transition opportunities in pastoral lands

Several sectors involved in the green transition have identified significant opportunities in pastoral lands, including renewable energy, carbon sequestration, and biofuel production. Global funding for renewable energy is similarly growing, illustrated by the 30% climate spending target and EUR 4 billion earmarked for climate finance by the European Union and its member states (European Commission, 2023). The Africa–Europe Green Energy Initiative, launched in 2022, aims to increase renewable-energy generation by 300 GW and secure access to affordable, reliable and sustainable energy in Africa. This

is likely to lead to a growing number of large green-transition projects using blended finance and creating further opportunities and risks for pastoralists (Davies, 2024).

Renewable-energy potentials in the rangelands

Methodology for mapping wind- and solar-energy potential in rangelands

Expansion of renewable green energy is at the centre of decarbonisation efforts, particularly expansion of solar and wind power (IRENA, 2025). Rangelands have emerged as the prime sites favoured for generating solar and wind power, turning them into new economic frontiers with adequate spaces that can be utilised for the much-needed energy for industrialisation, particularly in developing countries (Mosley and Watson, 2016; Lind et al., 2020, 202).

Pastoral lands offer considerable potential for generating renewable energy from solar and wind power. To explore this potential, we overlaid maps of global solar and wind potential with a map of the global distribution of rangelands. This allows us to identify pastoral areas that are well-suited for renewable energy development and to compare rangelands and non-rangelands in terms of renewable-energy potential.

We compare global datasets for photovoltaic (PV) power potential and wind power potential with a global map of rangelands as developed by the International Livestock Research Institute (ILRI, IUCN, FAO, WWF, UNEP, and ILC et al., 2021). The rangelands shapefile uses the World Wildlife Fund (WWF) terrestrial ecosystem dataset, identifying ecoregions using keywords in the ECO_NAME and G200_REGIO fields. Keywords used to identify rangeland ecosystems include grass, grasslands, savanna(h), shrublands, scrub, deserts, xeric, tundra, steppe, parklands and for South America we included caatinga, matorral, chaco, monte, espinal, puna, and pampas.

We estimate the solar-energy potential of rangelands using Practical Photovoltaic Power Potential (PVOUT). PVOUT provides an estimate of how much electricity can realistically be generated per year by solar panels. This is a more useful indicator of solar-energy potential than measuring how much sunlight reaches the ground (raw solar irradiance). PVOUT (kWh/kWp) reflects annual electricity generation per unit of installed PV capacity while incorporating system-level performance losses. To highlight the differences in the PV potentials, we distributed the PV potential between five categories: <3, 3–4, 4–5, 5–6 and >6. Categories <3 and 3–4 are classified as low potential, whereas 4–5 represents moderate potential and above 5 signifies high potential (World Bank Group and Solargis, 2020).

Land suitability for wind energy can be assessed by measuring the wind power density or meteorological potential, the geographic potential and the technical potential of a region (Jung and Schindler, 2021). While referring to wind energy, there are different classes of wind turbines to be considered. Typically, a wind speed above 6.5 m/s is considered commercially viable at 80 m height (Center for Sustainable Systems, 2025). However, the typical cut in speed at which a

turbine starts generating energy ranges between 3 and 4 m/s, and peak power generation is reached between 10 and 15 m/s, depending on the class of turbine (Lledó et al., 2019).

The International Electrotechnical Commission (IEC) classifies wind-resource conditions, which are used to categorise wind-speed regimes for utility-scale wind-energy development (IEC, 2019). Given that 98% of rangelands receive wind speeds less than 10 m/s, and commercial viability usually starts above 6, we have divided wind speed into five classes (<6 being very low and ≥ 9 being very high). This gives us an overall potential of wind-energy development at 100 m in rangelands while considering the seasonal variation by providing a yearly average for wind speed (IEC, 2019; Lledó et al., 2019; Center for Sustainable Systems, 2025).

Solar-energy potential of rangelands

Our results show that over 82% of rangelands fall into a moderate to high range of solar electricity production (4–6 kWh/kWp) (Figure 1). In simple terms, this means that many pastoral areas receive enough sunlight to make solar power a viable option. Large solar installations also require wide, open land with little shading, a condition that is common in rangelands.

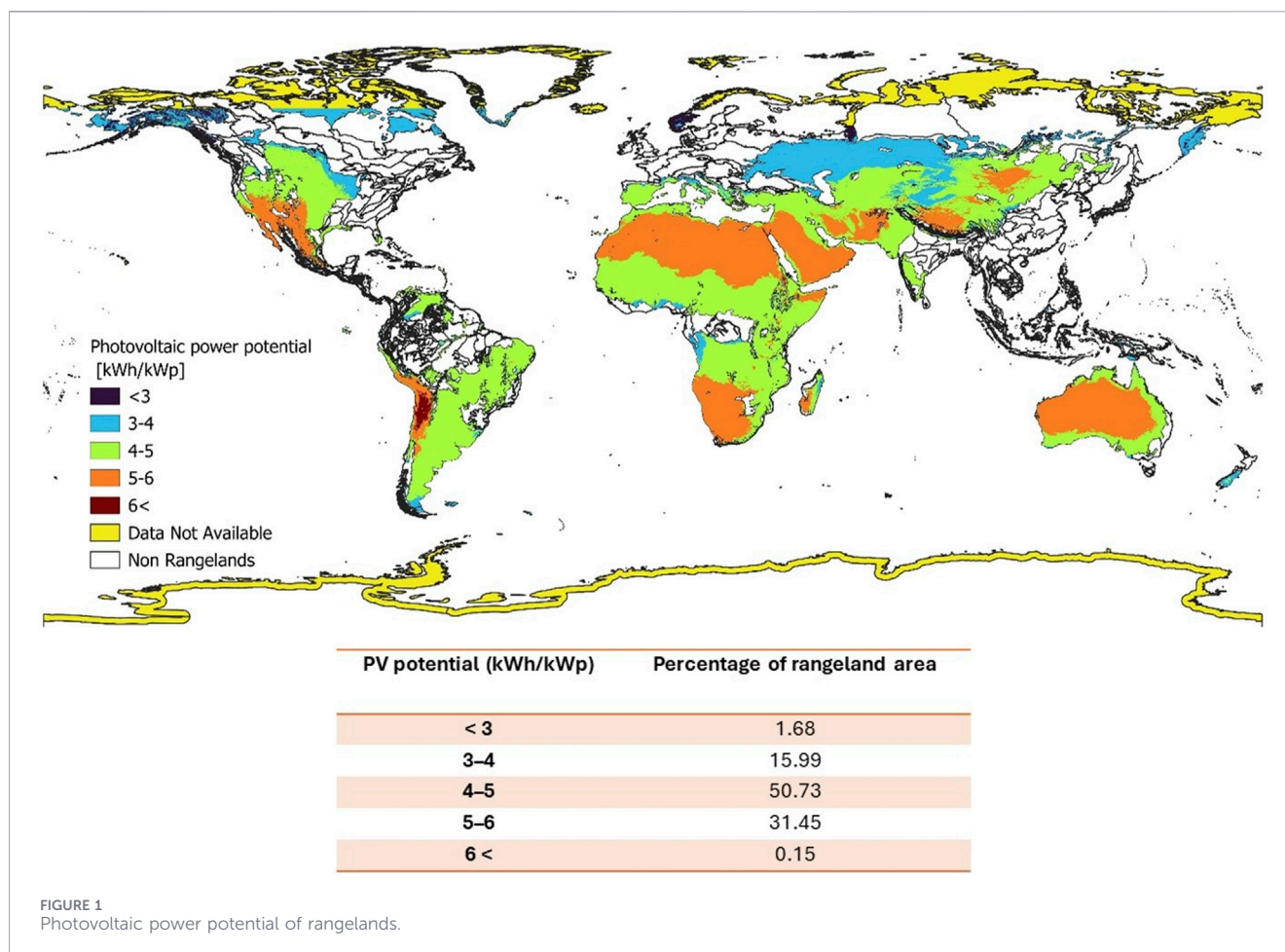
Wind-energy potential of rangelands

Our results show that around 60% of global rangelands are commercially viable for wind energy at 100 m hub height (Figure 2). These estimates represent a conservative estimate, as wind speed typically rises with height. For instance, India's wind potential stands just above 300 GW at 100 m hub height, while it is above 1150 GW at 150 m hub height, signifying nearly four times increase (National Institute of Wind Energy, 2018; National Institute of Wind Energy, 2023).

Surface-power density and renewables

Another useful concept in understanding the linkages between pastoral land and renewable energy is surface-power density: how much land different energy sources need to produce power. Surface-power density is measured in watts per square metre (W/m^2) and describes the amount of power obtained per unit of the earth's surface used by any specific energy system. Fossil fuels generate a large amount of energy from relatively small areas, while solar panels and wind turbines need more space to produce the same amount of energy. Fossil fuels have high surface-power densities—hundreds of W/m^2 (e.g., fossil gas 482 W/m^2). On a comparative scale, solar power has a median surface-power density of 6.63 W/m^2 while wind has a median surface-power density around 2–3 W/m^2 (Smil, 2016; van Zalk and Behrens, 2018). While this may vary with turbine types and panel/site infrastructure, these are the typical values for a utility-scale plant.

Since rangelands cover approximately 54% of the earth's land area (ILRI, IUCN, FAO, WWF, UNEP, and ILC et al., 2021), and are often sparsely populated, they offer significant space for solar and wind development. While surface-power density does not itself determine the feasibility of renewables, it is critical for



understanding the land requirements for the switch to renewables. As demonstrated, rangelands are some of the most viable spaces in terms of feasibility of renewables, for both solar and wind energy.

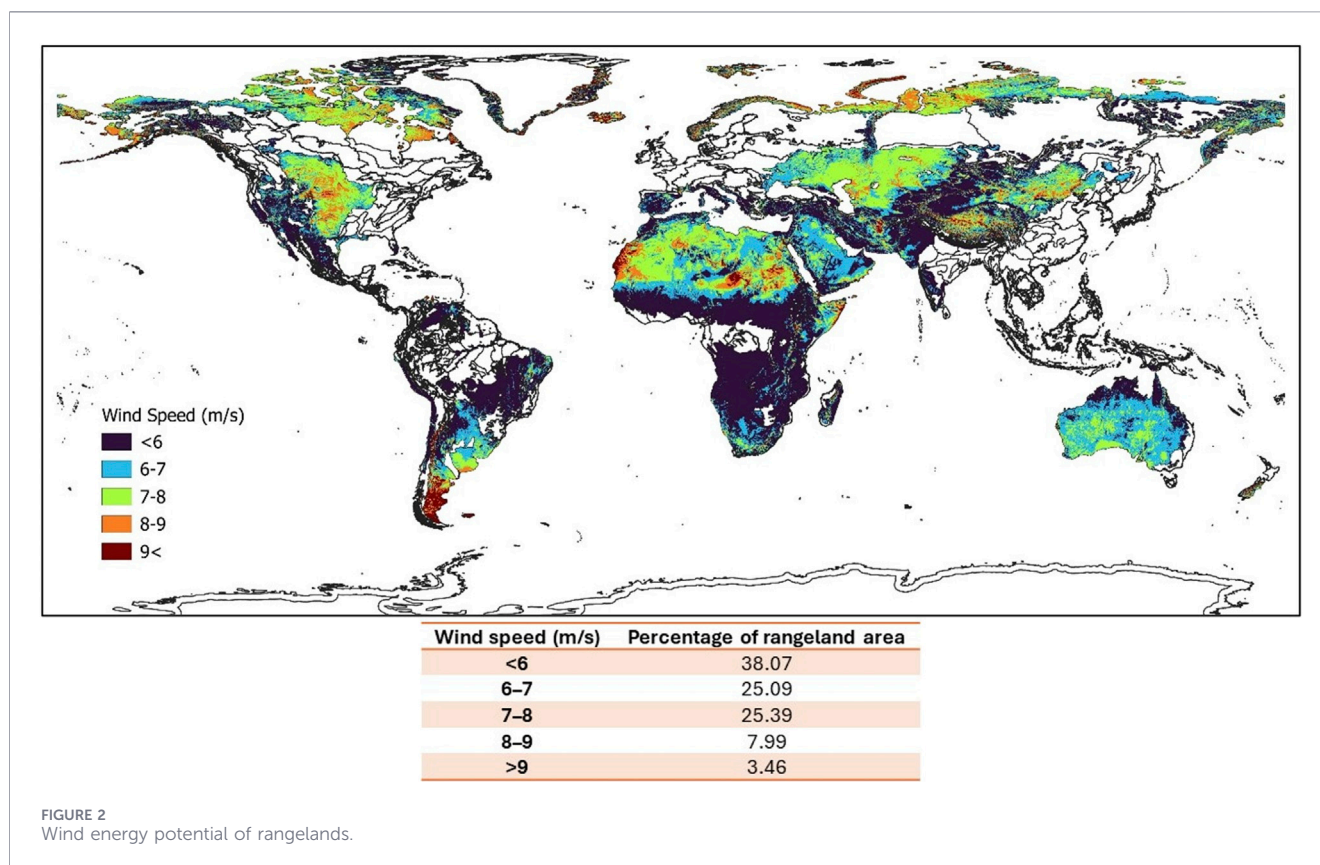
The evidence presented above indicates where renewable energy could be produced, but it is equally important to consider where energy is most needed. While these maps illustrate the potential for producing solar and wind energy in pastoral lands, they may underestimate the importance of demand, since a significant proportion of rangelands is found in developing countries with the greatest energy deficits. For example, Africa has the greatest regional demand on account of comparatively low production of energy *per capita*, and renewable-energy solutions offer opportunities to leapfrog dependency on fossil fuels. The continent has particularly high wind-energy potential, and the highest-potential countries—Algeria, Egypt, Libya, Mauritania, Morocco, Nigeria, South Africa, Sudan and Tunisia—are all dominated by rangelands (Mentis et al., 2015).

Carbon sequestration

Restoring and protecting rangeland multifunctionality can contribute to climate change mitigation and biodiversity conservation while maintaining production of high-protein

foods for marginalised populations (Briske et al., 2024). Many studies on carbon sequestration focus on the grassland area, which accounts for approximately two thirds of the estimated global rangeland area (ILRI, IUCN, FAO, WWF, UNEP, and ILC et al., 2021). Grasslands store an estimated third of the global terrestrial carbon stocks and can act as an important soil carbon sink; improved grassland management could sequester between 240 and 2000 million tonnes of atmospheric carbon per year (Smith, 2008; Tennigkeit and Wilkes, 2008; Gerber et al., 2013; Bai and Cotrufo, 2022).

Global estimates of carbon sequestration potential are typically based on estimation of net primary production (NPP). NPP is influenced by climate factors; non-climatic natural factors such as soil property, landforms, and biomes; and land-management practices. Land-management practices can be manipulated to improve carbon sequestration, and global potential for carbon sequestration can be estimated according to the gap between current land-management and optimal land-management practices. Grasslands have the highest global carbon gap of all land uses because they have the highest carbon gap density ($138.3 \text{ gC m}^{-2} \text{ yr}^{-1}$) and cover the largest area of land (46.97 million km^2). The global carbon gap of grasslands has been estimated at 6.5 PgC yr^{-1} , which represents approximately half the global carbon gap. Grasslands also



respond more rapidly to human activities than do forests and other woody vegetation. The high potential for carbon sequestration combined with the high rate of impact mark grasslands out as high-potential target areas for carbon-sequestration projects (Sha et al., 2022).

Global estimates of carbon-sequestration potential in grasslands face methodological challenges, including difficulties in interpreting remote sensing data to gauge the state of rangeland health and the restoration potential (Zhang et al., 2025). Methodologies for estimating NPP and extrapolating below-ground biomass using a root-to-shoot ratio (RSR) have been developed for forest biomes and have not been well adapted to grasslands. Below-ground plant biomass is an important measure of ecosystem health and organic carbon storage potential, and grasslands store comparatively more carbon below ground than standard models predict. Mean RSR in some subtropical grasslands was approximately five times higher than the global average. When global estimates were regenerated using more suitable NPP and RSR figures for subtropical grasslands, they were found to store 2.7 times more plant organic carbon than would be predicted using global defaults (Slooten et al., 2026).

Various approaches have been tested to boost carbon sequestration and soil organic carbon stocks in grasslands. Soil organic carbon can be increased by increasing plant species diversity, modifying grazing management, and restoring biodiversity. The potential for soil organic carbon sequestration in global grasslands has been estimated at 2.3–7.3 billion tons of carbon dioxide equivalents per year for biodiversity restoration, 148–699 megatons of CO₂e yr⁻¹ for

improved grazing management, and 147 megatons of CO₂e yr⁻¹ for sown legumes in pasturelands (Bai and Cotrufo, 2022). However, improving carbon sequestration through land conversion is not widely acceptable, and what may be perceived by some as the optimal land-management practice may conflict with the socioeconomic goals of local land users (Sha et al., 2022).

Uncertainties over the state of grassland carbon, the opportunities to increase carbon stocks, and the suitability of land-management practices are among the factors that contribute to underinvestment in rangeland carbon. Knowledge gaps persist in relation to the net carbon balance, taking into consideration ruminant emissions as well as the role of ruminant management in carbon sequestration. The evidence gap is exacerbated by a historical bias towards research in sedentary land-use systems and prioritisation of tree planting over rangeland rehabilitation (Briske et al., 2008; Henry et al., 2024). Deeper insights from transdisciplinary research are needed to better manage the complexity and multifunctionality of rangelands to boost carbon sequestration as one among a number of co-benefits of sustainable rangeland management (Mgalula et al., 2021).

Despite the uncertainties, rangelands are beginning to attract higher levels of carbon finance due to their large areas and significant rates of primary productivity (Lorenz and Lal, 2018). Carbon sequestration in rangelands can be enhanced in various ways, including grazing management, restoration of degraded areas, sowing favourable forage species, fertiliser application and irrigation. Pastoralists' herd management mimics the natural ecological relationship between ungulates

and grasses and contributes to rangeland restoration and sustainable management that captures and stores carbon (Briske et al., 2025). Carbon finance may offer the means to incentivise sustainable rangeland management that delivers the range of benefits highlighted above (Davies et al., 2015a).

However, adoption of carbon-sequestering management and technologies can be hindered by underlying land-degradation processes, institutional weaknesses, changing climate, and data and capacity gaps (Ghosh and Mahanta, 2014). There is a persistent risk that climate change mitigation projects promote afforestation, which is detrimental to the health of rangeland ecosystems and can lead to biodiversity loss, decline in ecosystem functions, impoverishment of land users and, in some cases, an overall loss of carbon from the system. Evidence of the ecological importance of rangelands, the damage that land-use change can cause to ecosystem integrity, and the existing carbon-holding capacity of these lands is driving interest in rangeland carbon-sequestration projects (Briske et al., 2024).

Growing interest in projects that increase soil carbon, as opposed to vegetation, may further increase interest in rangelands and may help improve methodologies for measuring the climate impact of rangeland-restoration projects (Lal, 2007). It may be possible to restore as much as 700 million hectares of Africa's rangelands through sustainable livestock-management and other practices, which would make a significant contribution to mitigating climate change (UNECA, 2022). Nevertheless, concerns persist over what approaches to carbon sequestration are appropriate and what impacts they will have on pastoralists. Carbon schemes in Africa have raised fears of exacerbating inequalities in pastoral areas and some in East Africa have been reported as coercive and non-consensual, prone to corruption and aggravating land conflicts (Kubitza et al., 2025). Some schemes have alienated pastoralists' land and promoted afforestation, leading to social, economic and environmental failures (Briske et al., 2008; Henry et al., 2024).

Selected experiences of the green transition in pastoral lands

Renewable energy

The surge in investment in renewable energy has driven up demand for pastoral lands around the world, although the approach to acquiring or using land differs greatly between projects, even within the same country. Examples range from large-scale land acquisition without consent, to small- and large-scale leasing arrangements with different degrees of impact on pastoralism and widely varying rents and co-benefits.

The most disruptive projects for pastoralists have ignored the complex use and access rights of different ethnic groups and favoured one ethnic group over others in consultations and benefit sharing (Hughes and Rogei, 2020; Wanyoro, 2021; Drew, 2022). Benefit sharing has been minimal in some projects, and pastoralists have not been adequately compensated for land occupied by energy projects or for the disruption during construction (Waters-Bayer and Wario, 2022; Schilling and Werland, 2023; Hughes and Rogei, 2020). For example, geothermal-energy projects in Kenya have occupied

significant areas of land, blocked access to water resources and contributed to pollution of drinking water (Hughes and Rogei, 2020).

Kenya has made significant and rapid progress in developing renewable energy with numerous projects in rangelands, several of which have impacted negatively on pastoralists. Renewable-energy projects have stimulated competition among local actors to capture the benefits and have fuelled insecurity and resource competition in several areas (Greiner, 2022). Wind-farm projects in rangelands have driven up land values, creating a rush to claim private land titles and increasing tension between and within communities (Cormack and Kurewa, 2018). The heavily criticised Lake Turkana Wind Power Project has annexed large areas of pastoral land, blocked migration routes and denied access to sites of cultural importance. Benefit sharing from the project has been negligible and token benefits, such as employment as security guards, has favoured certain ethnic groups, fostering conflict with other ethnic groups that have claims over the same land (Waters-Bayer and Wario, 2022).

Pastoralists can face challenges in defending their resource rights where rangelands legally belong to the State. In some cases, the State may declare pastoral lands as degraded and abandoned and use this as justification for annexing the land for power projects. This has been reported in Mongolia, for example, where the public sector has allocated significant areas of land to renewable-energy projects (Nilsson et al., 2021).

India has identified significant areas of rangelands considered suitable and available for renewable energy. Much of this land is legally designated as "wasteland", which allows investors to overlook the prior occupation and to discount the economic value of established land uses such as pastoralism. Large-scale solar-energy projects have taken land out of pastoral production, created unfavourable microclimates around the installations, caused loss of land productivity, and reduced livestock health and productivity (Hemalatha, 2019; Patel, 2024; Rathore and Zargar, 2024).

Livestock farmers and pastoralists in several Indian states have protested against the proposed renewable-energy projects, arguing that they will endanger livestock and contradict efforts to protect community grazing lands. Protests in Gujarat led to the return of project land to community ownership and agreement by the company to enter into a 25-year lease agreement (Patel, 2024). However, other pastoralist groups have been denied their land rights on the basis of their nomadic culture, and compensation payments have been set low because of the undervaluation of pastoralist livelihoods and the social as well as economic costs (Hemalatha, 2019). A significant part of the commons used by the pastoralists in India is identified as wastelands and is under the State's control. These *de facto* commons are vital to the pastoralists' livelihoods. The Ladakh State Administration is planning a pilot solar-power project designed for livestock grazing to gain the trust of the local community ahead of a much larger solar-power project (U. Gupta, 2025).

In the United States, various advantages were observed when solar-panel installations allowed sheep grazing between and beneath the panels. For example, sheep benefitted from the shade of solar panels and were observed to graze more than sheep on open rangelands. Solar panels also affected vegetation through improvement of shade and soil moisture, increasing forage digestibility and protein content (Kampherbeek et al., 2023). The

potential to graze within solar installations can reduce their impact on pastoralists and has been exploited in India, where community consultations led to modification of the installation to allow controlled grazing (U. Gupta, 2025).

Projects may provide benefits alongside negative impacts or may inadvertently deliver benefits to pastoralists. Solar projects in Morocco, for example, have improved living conditions in adjacent communities (e.g., Noor Solar Power Station) and have stimulated regional socioeconomic and infrastructure development. However, these projects also exacerbated social conflict, rivalry and feelings of envy between communities, exclusion of local stakeholders, powerlessness in decision-making and decreased water security in the community (Terrapon-Pfaff et al., 2019). Some pastoralist communities in Kenya have benefited from improved road access and employment opportunities from energy projects, although these benefits have also aggravated tensions by favouring one ethnic group over others (Achiba, 2019; Drew, 2022).

Some renewable-energy projects have reported more favourable outcomes for pastoralists through compensation or through effective consultation with herders over installation plans. Mongolian wind-farm projects, such as the Sainshand Wind Park, have compensated herders by identifying alternative seasonal residences, building animal shelters and wells, and assisting herders to register the new land. Herders usually retain grazing access to all land apart from the small areas where turbines are constructed, although residences are usually prohibited within 500 m of the turbines to safeguard against falling ice. Communities that temporarily lose pasture access during construction have been compensated with replacement fodder and, in the case of both the Sainshand Wind Park and the Salkhit Wind Farm, the company provided new wells to the community (Oyunchimeg and Wall, 2017; Sukhbaatar, 2018).

Solar installations use more land than do wind farms to generate the same power. Therefore, the impact on herders may be greater, although the scale of solar farms in Mongolia has thus far been relatively small and not greatly disruptive to pastoralists. A 2020 project in Mongolia to construct five new renewable-energy facilities reported that construction would not entail permanent or temporary land acquisition, land-use restriction, demolition or structures, or relocation of people (ADB, 2021). Herders have tended to welcome new installations because they expect to benefit from improved energy supply (e.g., Darkhan Solar Farm) or they have influenced construction to minimise impact on their livelihoods. For example, Sermsang Khushig Khundii Solar Power Plant and its transmissions lines were re-sited after communities raised concerns during consultations over access to important salt ponds (TGC, 2019).

Kenya's Kipeto Wind Farm stands out for being developed through a significantly more equitable approach. The project leases the land occupied by turbines and transmission lines from the local community. Project developers hired a local lawyer to carry out negotiations with community members, in view of the complexity of the negotiations, and established a community implementation committee. A community trust holds a 5% share in the wind farm, and landowners also receive 1.4% of the gross revenue of each turbine located on their land (Sena, 2018; Kazimierczuk, 2019).

Households in Kipeto that were required to relocate their homestead were compensated with newly constructed homes with

solar power, and the project also established a health centre and other corporate social responsibility projects. It should be noted that the land in Kipeto was formerly privatised, and some agreements have been reached by individuals within the community. The County Government has not insisted on a formal change of land use (i.e., from grazing land to industrial wind park), avoiding an increase in land rates that might otherwise have been payable by the landowners (Sena, 2018). This example demonstrates that land acquisition for development projects does not need to result in dispossession and that co-existence of energy projects and pastoral livelihoods is a viable approach that provides opportunity for the project's social acceptance and better economic returns (Ndi, 2024).

Despite the large scale of many renewable-energy projects, many pastoralists remain off-grid and energy projects typically fail to address pastoralists' energy security (Schilling and Werland, 2023). Small-scale options are available, and greater attention to appropriate energy solutions for pastoralists is needed as part of the bigger conversation about a just transition. As an example, Mongolia has achieved considerable success in rural electrification, which has been decentralised since 2000 through the 100,000 Solar Ger Programme that provides portable solar home systems to pastoralists. These systems are designed to meet household energy needs for lighting, radio, TVs and satellite dishes. An estimated 95% of all people living in rural areas of Mongolia were reported to have access to electricity by 2018 (Shippe, 2021).

Carbon sequestration and storage in pastoral lands

Sequestering carbon emissions has become an established mechanism for reducing the rate of increase of atmospheric concentration of carbon dioxide and is an important component of the global effort to mitigate climate change. Carbon-sequestration projects include approaches to capture carbon in biomass and soil and have proven to be cost-effective natural processes that bring numerous co-benefits, including restoration of biodiversity and ecosystem functions (Lal, 2007).

Rangeland ecosystems store more than a third of the world's soil carbon, and restoring degraded rangelands can significantly enhance soil carbon storage. Rangeland restoration can be incentivised through investments that enhance pastoralist livelihoods and provide investors with profits as well as social and environmental impacts (Sircely et al., 2025). Voluntary carbon markets (VCM) currently stand at an estimated USD 3 billion per year and are projected to grow by 10–30 times by 2030. The VCM allows actors to voluntarily offset their GHG emissions through the purchase of carbon credits, which are commonly from reforestation but can theoretically be any carbon-removal initiatives, including rangeland restoration. Projects must be registered under a carbon-crediting standard and audited by an independent body to ensure delivery of results and compliance with standards, which include equitable benefit sharing and avoiding the conversion of natural grassland into forest (VERRA, 2024; UNCCD, 2025).

Rangeland carbon projects face specific challenges, for example, related to their spatial scale and the complex and often insecure land-tenure arrangements involved. Rangelands include large areas with high rainfall variability and uncertainty, where restoration outcomes can be unpredictable in the short term. These

challenges can be addressed with sufficient evidence, establishing effective local institutions, and ensuring due diligence. Published experiences indicate strong technical quality of rangeland carbon projects but variable quality of social engagement and highly variable costs and risks. Effective projects depend particularly on the quality of regulatory frameworks (Sircely et al., 2025).

Some carbon-finance projects have failed to consult pastoralist communities and, in some cases, have delivered little or no benefits to land users. Certification methodologies have sometimes failed to respect the rights of land users and have not secured their consent. Concerns have been raised about the relative importance of trees and grasses in generating carbon credits for rangelands and the risks associated with afforestation projects, which can drive ecosystem change in a direction that is unsuitable for pastoralism (Davies, 2024).

India may have significant opportunity to restore rangelands using carbon finance. Approximately 17% of the country is covered by savanna grassland, and an estimated 20 million hectares of grassland were lost between 1880 and 2010. Much of this former savanna grassland has been converted to other land uses, such as forest projects, irrigated agriculture, biofuel plantations, and urban and industrial uses, but the country has nevertheless significant scope for grassland restoration (Paul and Vanak, 2020).

Carbon-finance projects in India have historically favoured afforestation, driven by the misconception that grasslands are degraded forests (Ratnam et al., 2016). Major Indian grasslands have existed as open-canopy tree-grass mixtures for thousands of years (Pillai et al., 2018) and, rather than grasslands being the result of human cultivation and settlement, it is now thought that agropastoralism in places like the Deccan Plateau was possible due to the pre-existence of grasslands and savannas (Riedel et al., 2021). The misperception of grasslands as degraded ecosystems originates from the colonial period in India and led to native grasslands being allocated for plantations of exotic trees. In some cases, these trees became invasive in grasslands, causing biodiversity and habitat loss. Nevertheless, grasslands continue to be perceived as wastelands despite documented economic and ecological failure of afforestation (Joshi et al., 2018).

Afforestation has been promoted as a nature-based solution in Rajasthan in line with India's national afforestation targets. Afforestation has been proposed in areas affected by desertification, which is exacerbated by climate change and unsustainable land use. These projects identify land degradation and desertification as threats to agricultural production and water availability and promote a range of response measures, including silvopastoral regeneration, highlighting the benefits for re-integrating trees into crop-farming and pastoral landscapes in arid regions (Gupta et al., 2024).

Carbon finance has been used for rangeland restoration in the Makame Savannah Project in Tanzania. The project is implemented in a wildlife-rich savanna and dry forest area adjacent to the Tarangire National Park, where conversion of rangeland to cropland is threatening wildlife migratory routes. It is implemented in a Wildlife Management Area (WMA) covering 104,065 ha, involving five village communities and 15,000 people. The project is implemented with local communities through participatory resource planning, with the WMA providing a legal land-use plan that reflects community land-use and herding practices. Revenue from the project supports both land protection and livelihood development

for the local Maasai community, including establishment of village schools, improving health services, community development initiatives, salaries for Village Game Scouts, boosting local governance, and enforcing village bylaws (Davies, 2024).

The Northern Kenya Rangeland Carbon Project of the Northern Rangeland Trust follows a comparable approach and is also implemented in a biodiversity-rich landscape that hosts several large conservation areas, and where pastoralists generate revenue from biodiversity-related enterprises (e.g., ecotourism) alongside livestock production. The Northern Kenya Rangeland Carbon Project is implemented through community conservancies and provides investment in those local organisations to enhance community rangeland management and deliver other services to pastoralists. Revenue from the carbon project is used for salaries for scouts and guards, strengthening local governance and enforcing bylaws, and implementing community projects to improve health and education services. Communities receive 60% of revenue from carbon projects, while 40% is received by the project operator and the local government. Community rangeland management institutions are the primary decision-makers on grazing and rangeland management, with variable influence of projects or project implementers. Community institutions have the authority to regulate rangeland management and are strongly influenced by customary leadership of participating ethnic groups (Sircely et al., 2025).

At the time of writing, Verra has suspended the issuance of credits to the Northern Kenya Rangeland Carbon Project. The initial suspension followed a report by a human rights group identifying flaws in the process for obtaining consent from participating communities and breaches of the Community Land Act (Counsell, 2023). This suspension was lifted following a review that identified areas in need of improvement (VERRA, 2023). The project was re-suspended following a local court ruling that discredited the process of establishing two of the 43 community conservancies involved in the project (KEELC, 2025).

Carbon finance projects in Mongolian rangelands have also followed community-driven approaches, including a "carbon-plus" approach in which carbon-sequestration projects contribute to livelihood benefits, nomadic herders' wellbeing, conservation of biodiversity, and other ecosystem services. This approach collaborates with more than 100 nomadic households, covering 77,000 ha, and targeting 100,000 t CO₂ sequestration over 4 years through improved grazing-management practices. The project emphasises community responsibility and the active participation of herders in restoration and supports herder groups to secure their land-tenure rights over seasonal pastures in line with legal provision such as the 2002 Land Law. Fair and equitable resource access, including for the poorest and most vulnerable, has been enshrined in agreements developed by the participating herder groups (Plan Vivo, 2020).

Mongolia's Scaling up Climate Ambition on Land Use and Agriculture (SCALA) programme proposes a Carbon Crediting and Market Mechanism for carbon sequestration through sustainable rangeland management that will also deliver livelihood benefits to herder communities. Mongolia could sequester approximately 4.69 million tons of carbon per year if restoration approaches are widely adopted, with a rate of 0.103 t C/ha annually (Enkhtaivan and Dolgorsuren, 2024). Research indicates that herders may be willing to adopt appropriate practices if the

incentives are sufficient. The level of awareness of carbon sequestration among herders is low, but up to 60% of herding households were willing to participate in carbon schemes if projects enhanced household income and came with adequate subsidies, and if the schemes responded to a call for ecological environment protection from the government (Zhao et al., 2018).

Rangeland restoration delivers several of the objectives of the green transition, including contributing to climate-change mitigation, restoring and protecting biodiversity, strengthening adaptive capacity and reducing poverty. It is an example of a “nature-based solution”. Nature-based solutions are defined as actions that “protect, sustainably manage and restore natural and modified ecosystems in ways that address societal challenges effectively and adaptively, to provide both human wellbeing and biodiversity benefits” (IUCN, 2020). Rehabilitation of degraded rangelands can contribute simultaneously to the goals of the United Nations (UN) Framework Convention on Climate Change, the UN Convention on Biological Diversity and the UN Convention to Combat Desertification (Akhtar-Schuster et al., 2016), which could make it attractive to governments and private investors alike.

Biofuels

Biofuels can play a role in combatting global warming and reducing GHG emissions. Companies and governments have argued that biofuel production can contribute to agricultural growth and economic development in pastoral lands while addressing climate change and, in the early 2000s, pastoral lands were identified as high-potential areas for biofuel production (Exner et al., 2015; Sulle and Nelson, 2009). However, expanding biofuel production often competes with land needed for food production and creates land-use conflict that can lead to deforestation, soil degradation and loss of natural habitats, exacerbating GHG emissions (Rial, 2024). In common with earlier attempts to annex pastoral lands for other uses, proponents of biofuel production have underestimated the existing value of the land and the legitimacy of pastoralism as a land-use practice (Sulle and Nelson, 2009).

Land acquisitions for biofuel projects in Tanzania have led to migration and resettlement of pastoralists. The drive to increase biofuel production has created tensions between private, local and government actors over the right to use and allocate land. A 2009 report found that companies had applied to produce biofuel, particularly from jatropha, sugarcane and oil palm, on over 4 million ha of land in Tanzania. While 640,000 ha had been allocated by 2009, companies had only been granted formal rights of occupancy on 100,000 ha (Sulle and Nelson, 2009).

Biofuel investments have contributed to landlessness, food insecurity and environmental degradation in Tanzania. Compensation payments under Tanzania’s Village Land Act of 1999 have been insufficient to allow alternative livelihood opportunities, and the compensation process has been unreliable, poorly understood by many landowners and badly implemented by many companies (Veit, 2019). Resettlement of pastoralists by biofuel schemes has triggered new conflicts. Biofuel schemes have also diverted water resources away from the rangelands while the

incoming crop-farming communities have placed new pressure on natural resources such as wood fuel (Johansson, 2013).

Lessons for a just green transition in pastoral lands

Rangelands clearly have high potential for generating renewable energy and sequestering carbon and this, combined with the perception that they are large, underutilised areas that are easy to acquire, has made them attractive to investors. Not only do pastoralists face the threat of new investors attempting to acquire their land, but an ‘economy of anticipation’ may be driving people within pastoral areas to secure legal title over communal lands with a view to capturing benefits from potential future investments (Drew, 2022). Pastoral lands offer many opportunities for the green transition, and green-transition projects—implemented the right way—could offer opportunities to pastoralists. However, if land governance remains weak and pastoralist rights are not upheld, projects are likely to have harmful consequences for pastoralist livelihoods, resource rights, and political and social relations (Lind et al., 2020).

The green-transition implies complicated social and technological changes that will have a profound social impact. Rangelands are shaped by existing sociocultural inequalities along the lines of gender, caste and class. Vulnerable groups may lack individual land ownership and are disproportionately dependent on commons. An in-depth understanding of local realities should be integral to any green-transition projects to respect rights and ensure equitable benefit sharing. Further, the transition must avoid reproducing the environmental and socioeconomic injustices and inequalities that are intrinsic to the existing energy regime (Wang and Lo, 2021).

Examples presented in this paper demonstrate the harmful impacts on pastoralists when projects do not respect their rights. Green-transition projects have led to alienation of land, fragmentation of rangeland landscapes, displacement of communities, conflict between and within communities, weakening of customary institutions and erosion of cultural identity. Renewable-energy projects have been implemented without adequate compensation to land users and in violation of their human rights. In some cases, renewable-energy projects have stoked local conflicts and led to loss of life and property (Waters-Bayer and Wario, 2022). Such outcomes should be anticipated when investors underestimate the existing value of rangelands and fail to accept the legitimacy of pastoralism as a land-use practice (Exner et al., 2015; Sulle and Nelson, 2009).

Some large-scale renewable-energy projects have been developed in rangelands without adequately consulting land users and right holders. Weak stakeholder analysis has allowed investors to consult one claimant over communal resources at the expense of others, creating new conflicts or aggravating underlying resource competition. Some large-scale investments have not been required to secure free, prior and informed consent (FPIC) by governments and, in some cases, governments have allocated pastoral land to investors while ignoring legal requirements to consult right holders (Waters-Bayer and Wario, 2022).

Carbon finance could be a source of revenue for pastoralists to rehabilitate and sustainably manage their rangelands to sequester and store carbon. Rangeland rehabilitation can often be achieved through adaptation of herding strategies, implemented by pastoralist communities and contributing to increased productivity, conservation of biodiversity and enhanced resilience. Such projects can play an important role in climate change adaptation. They rely on local and indigenous knowledge and depend on strengthening local governance (Louhaichi et al., 2022). However, some rangeland carbon-finance projects have been developed without consulting communities and, in some cases, with no benefit flowing to the land users. Certification methodologies have failed to respect the rights of land users, including their FPIC (Davies, 2024). Concerns have also been raised over the use of carbon credits to fund afforestation in rangelands, which is neither ecologically nor socially acceptable (Briske et al., 2024).

The projects discussed in this paper that have been received more favourably by pastoralists are those that have been more recognisant of pastoralists' land rights and have engaged local communities in meaningful negotiations over project implementation. Where resource rights are not legally recognised, projects may be designed to contribute to strengthening tenure and thereby promoting pastoralist development. Projects can strengthen local governance by working through community institutions, actively developing their capacity, and effectively consulting community members. Several projects have negotiated lease arrangements with pastoralist communities, which implicitly recognise both the land rights and the value of the land on which the projects are implemented. In the best-case scenario, consultations are treated as ongoing dialogue rather than one-off events. Dialogue has helped to reinforce local governance for effective decision-making and can strengthen local institutions. Participatory rangeland-management planning has been an important part of implementing carbon-sequestration projects.

Incentives to pastoralists from green-transition projects have ranged from co-design and co-ownership of projects to sometimes trivial and tokenistic gifts or incidental benefits (e.g., roads or water infrastructure built to serve the project). While some projects have placed greater emphasis on material incentives, all the successful projects demonstrate effective engagement with relevant local stakeholders, respect for local resource rights, and willingness to adjust investment plans according to consultations. Projects can also provide meaningful economic reward to hosting communities, although this is not always in-kind (i.e., electricity supply). For example, communities have been compensated through investment in infrastructure projects and rural services. The Kenyan case (Kipeto Wind Power) in which the community became a shareholder in the wind farm is unusual but could inspire similar projects that deliver significant development co-benefits around energy projects.

The cases reviewed for this paper hint at other incentives that could be developed through green-transition projects. For example, projects could support local associations to enhance community capacity to govern and manage natural resources, to negotiate with investors and to protect cultural institutions. Stronger support can be given to communities to restore and sustainably manage

rangelands through sustainable grazing within project sites, generating greater environmental and social co-benefits of green-transition projects. Whether green-transition projects translate into opportunities or threats to pastoralists may depend on whether pastoralists' land rights are respected, or indeed strengthened, whether pastoralists are adequately consulted in project development, whether the project development does not have adverse effect on pastoralist livelihoods, and whether projects deliver meaningful benefits to pastoralist communities.

This perspective paper does not attempt a thorough framing of a just green transition for pastoralists. The intention was to examine how a global green transition may impact on pastoralists and their land and to what extent those impacts would present threats or opportunities. Further examination of a just green transition in the pastoral sector is warranted, to understand green-transition pathways in the livestock sector including mitigation of emissions from livestock value chains and promotion of benefits through rangeland carbon sequestration and storage. Climate change and biodiversity loss already have adverse effects on rangelands and pastoralists, and global measures to address these threats are advancing rapidly. Pastoralists need tailored support to ensure a just green transition in the pastoral livestock sector, including finance, policy, technical support, research and development, and monitoring to incentivise new or modified practices at scale (Thornton et al., 2025).

Conclusion

Evidence has been presented that the green transition offers opportunities for pastoralists and that projects could be implemented in ways that are consistent with a just green transition, providing those projects are motivated by the development needs of pastoralist communities and not only by global environment goals. Projects that ignore pastoralist rights and fail to ensure equitable benefit sharing are likely to aggravate loss of resources and increase poverty and marginalisation. A just green transition does not depend exclusively on developing innovations for pastoralists, but it requires implementation of basic development and rights that have historically been denied to pastoralists. Guidance on implementing FPIC is available from FAO's Governance of Tenure series (FAO, 2014).

Green-transition projects should be developed as part of a multifunctional land-use strategy in rangelands. Further consideration should be given to combining approaches—for example, carbon sequestration in rangeland rehabilitation alongside green-energy investments—in ways that secure pastoralists' rights and contribute to their livelihood resilience and conserve biodiversity. Rather than exploit loopholes and governance vacuums, projects should explicitly aim to strengthen the voice and agency of pastoralists and enable them to negotiate desirable outcomes (Waters-Bayer and Wario, 2022).

Pastoralist livelihood systems and resource rights must be legitimised and protected by governments and private investors to ensure a just green transition. Pastoralist resource rights can be complex, and several communities may have overlapping rights, requiring detailed stakeholder analysis and conflict sensitive consultation, not as a one-off event but as a continual process that respects the existing land-tenure mechanisms. Guidance is

available for implementing the FAO Voluntary Guidelines on Responsible Governance of Tenure in pastoral lands (Davies et al., 2016). Consultations should be informed of the need to protect seasonal resource access and migration routes, and key resources and corridors need to be safeguarded. Projects should develop and equitably share incentives that contribute to pastoralist livelihood resilience and reflect a fair estimation of the value of foregone resources. The best projects will go beyond benefit sharing to involve pastoralists as core stakeholders and development partners.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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