

Addressing the Interconnected Impacts of Climate Change on Vulnerable Communities through Integrated Policy Interventions and Emerging Technologies for Equitable Climate Adaptation

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1. ABSTRACT

Climate change is reshaping where and how vulnerable communities are able to live, while unequal access to mobility, energy and adaptive resources shapes their capacity to respond. This paper thus attempts to ask; what are the interconnected impacts of climate change on vulnerable communities, and how can integrated policy interventions leverage emerging technologies to advance equitable climate adoption? It draws on a collaborative section based qualitative analysis of government, UN, and academic secondary sources, and examines climate-induced migration through Sundar Sarukkai's framework of lived experience freedoms; to be a part of, to leave, and to modify an environment. This exhibits how caste, gender, and household wealth can shape who is able to migrate, who is left behind as a "trapped population", and who benefits from remittance-funded adaptation. It then traces how the same structural inequality shapes energy insecurity in India, and by means of a comparative case study, in Nigeria, where climate driven mobility *redistributes* rather than resolves energy demand. The paper thus evaluates the capacity of emerging technologies; GIS, remote sensing, digital twins, and artificial intelligence, to move adaptation planning across tangents from being reactive in nature to anticipatory in practice. It however also acknowledges that technological maturity is consistently outpaced by institutional and data constraints, and AI governance introduces its own risks around bias, privacy, and accountability that must be managed alongside its benefits. Synthesising these findings, the paper proposes an integrated policy framework of five interdependent pillars; vulnerability mapping, mobility planning, climate energy planning, anticipatory technology governance, and equitable AI governance. These, put together, argue that equitable adaptation depends less on developing new technology than on embedding it within functioning, accountable and public centred institutions.

Keywords: Climate-induced migration; Energy insecurity; Emerging technologies; AI governance; Climate adaptation policy; Vulnerable communities; India–Nigeria comparative analysis

2. INTRODUCTION

Climate change is no longer a distant scientific projection, it is actively reshaping how and where people across the world are able to live. The IPCC's Sixth Assessment Synthesis Report confirms that human-caused warming has already reached roughly 1.1°C above pre-industrial levels, and that these impacts are felt unevenly, with the poorest and most marginalised communities bearing the greatest burden despite having contributed the least to the crisis (IPCC, 2023). This imbalance sits at the core of the climate justice debate, and it is nowhere more visible than in human mobility. By the end of 2024, more than 83 million people were living in internal displacement worldwide, the highest figure ever recorded, and disasters alone triggered a record 45.8 million new displacements that year, driven mostly by storms and floods (Internal Displacement Monitoring Centre, 2025). Since 2008, weather-related hazards have caused over 400 million internal displacements globally, occurring across nearly every country but landing hardest on regions with weak infrastructure and limited adaptive capacity (IOM, 2026). Alongside sudden disasters, slow-onset stressors such as drought and sea-level rise continue to erode livelihoods gradually, pushing global governance frameworks like the UNFCCC to reframe adaptation and displacement as connected challenges rather than separate ones.

It is within this global picture of unequal responsibility and escalating displacement that India's own climate story unfolds. Highly impacted by climate change by virtue of its population size, vast area, rapid urbanisation, and existing socio-economic inequalities, India sees 80% of its population at risk from climate induced disasters and is ranked 9th globally in the Climate Risk Index. Flooding is among the most significant risks: rainfall intensity interacts with riverine exposure reveal the drainage system, settlement in flood prone areas, and in 2024 roughly 2.5 million pupils were displaced in Assam alone, accounting for half of the displaced population that year; with communities along the Brahmaputra facing repeated displacement. Extreme heat is becoming an ever-greater threat to mortality and morbidity, Indian cities experiencing temperatures 3–4°C above their surrounding areas, while a long

coastline exposes the country to cyclones, storm surges, and sea-level rise that destabilize the livelihoods of ocean-dependent communities.

These impacts are deeply interconnected. As the paper's analysis of climate-induced migration shows, the environment is not a neutral backdrop but a lived experience, shaped by the differential access that determines who can protect their right to life, who can leave when conditions become insufferable, and who is rendered immobile; the "trapped populations" left to adopt with locally available resources when remittances from migrating household members fund adaptation back home. The same logic extends to energy: India's energy system is transforming rapidly: electricity peak demand rose from 148GW in 2014 to approximately 250 GW in 2024, while non-fossil sources crossed 50% of installed capacity in 2025, five years ahead of target. Yet this transition produces winners and losers, benefiting some rural communities through decentralised solar while exposing coal-dependent districts to job and revenue losses. The Nigerian case study included in this paper shows how climate-induced rural-urban redistribution can relocate, rather than resolve, energy insecurity, and also emphasises on a distinction of climate migration relationships, differential capacities of energy vulnerabilities, variance in governance and coping models and a resulting gulf in adaptation capacities via technological adaptations.

Emerging technologies: artificial intelligence, GIS, remote sensing, digital twins, and IoT; are increasingly central to the response. Their promise is substantial: cumulative climate-induced internal displacement in India between 2008 and 2023 has been estimated at over 56 million people, and GIS, AI-driven early warning systems, and vulnerability mapping can identify at-risk populations and deliver interventions before extreme events occur. Yet the literature is equally clear that AI could enable action on 134 of the 169 UN Sustainable Development Goal targets while inhibiting 59, and that technology availability alone does not guarantee adoption, impact, or equity. The main challenge lies not in developing these technologies but in aligning them within policies, and in converting the approach from reactive disaster management to anticipatory climate adaptation.

This paper confronts that challenge directly. Through qualitative thematic and comparative analysis with a body of secondary source literature and a collaborative, section-based analysis, it asks: *What are the interconnected impacts of climate change on vulnerable*

communities, and how can integrated policy interventions leverage emerging technologies to advance equitable climate adaptation? Each section addresses one layer of the question: climate-induced migration and the freedoms of lived experience; energy insecurity in India and, comparatively, in Nigeria; the capabilities and limits of emerging technologies; the governance of ethical and accountable AI; and a comparative analysis that situates the Indian experience globally. Grounded in the Indian context, the paper argues that equitable adaptation requires an integrated framework — one that centers the public through a bottom-up approach, embeds technology within functioning institutions, and treats equity, energy access, and mobility as parts of a single climate governance challenge

3. METHODOLOGY

This research examines the critical question of ‘What are the interconnected impacts of climate change on vulnerable communities, and how can integrated policy interventions leverage emerging technologies to advance equitable climate adaptation?’ through qualitative thematic and comparative analysis. It is based on a body of secondary-source literature, divided into four clear categorical groups, namely, peer reviewed academic literature, international organisations / multilateral institutions, government sources, policy/institutional/ technical reports, selected for thematic, geographical and empirical relevance to the paper’s interconnected questions of climate vulnerability, mobility, energy insecurity, adaptation, technology and governance. Sources were identified through targeted searches of academic and institutional literature and through reference tracing of relevant studies and reports.

The selection of these sources is owed to their thematic relevance to the scope of the study. The analytical dimensions of the paper revolve around climate vulnerability, climate induced migration and displacement, livelihood adaptation, energy insecurity and energy transition as well as technological responses such as GIS, AI, remote sensing and digital twins, all of which are directly fed by the corpus of selected literature for the study. This scope of investigation is exhibited in the way the bibliography moves from Sharma, Ertold, Jha and

Pradhan on vulnerability and migration, through IEA, MNRE energy literature, and then into Vinuesa, Riaz, Therias, CEEW, Sethi and related technology and governance literature.

The selection of sources and the subsequent analysis were weighted towards India while allowing a following comparison with Nigeria and selected relevant international cases where those cases illuminate the broader relationship. India was treated as the principal geographical context because the paper's central scope is equitable climate adaptation in the Indian context. Nigeria was selected as a comparative case specifically for the analysis of energy insecurity, allowing the study to examine how similar climate and development pressures interact with a different institutional, energy and socio-economic context. The Nigerian example has been used comparatively for thematic differentiation on a few parameters not as a second equally extensive case study. For the comparative analysis, India and Nigeria were examined through a common set of dimensions: climate and socio-economic vulnerability, institutional capacity, adaptation and energy policy, access to relevant technologies, financing constraints, and implementation barriers. The comparison is therefore illustrative and analytical rather than intended to establish statistical equivalence between the two countries.

Preference was given to sources that provided empirical evidence, documented policy frameworks, institutional assessments, country level data, or evidence of technology deployment and implementation barriers. When discussing emerging technologies, the study distinguished between documented applications and proposed or prospective applications. The study thus juxtaposes these secondary sources, not just as a compilation of individual experiences or data, but explores the convergence, divergence and contradiction in the various fields. Instead of a gross generalization of collected data, this research seeks to provide a grounded and relevant understanding of Climate Justice and Climate Governance in the Indian Context, with a small section of comparative analysis in the international context through the lens of Nigeria for broader understanding, as well.

4. RESEARCH AND DISCUSSION

Vulnerability from the lens of migration

What is ‘natural’? Is it the resources and landscapes around, which sum up earthly existence, or is it the state of sacred, unhindered naturalism, which uses and abuses itself (nature) to provide a body of knowledge, including bonds, locations, and landscapes, for determining individual–collective identities and relationships, in an ecological setting? (Mukul Sharma, 2022)

Nature thus is not a question that concerns physical geography, so we take it as a question of politics and we understand it with the broader term *environment*, which exhibits human-nature relationships and provides more direct political connotations. So now, what is harmed by ills that affect humanity, like soil erosion, like water degradation, like sewage waste, rising atmospheric pollutants and global warming, isn’t merely *philosophical* ‘nature’, but rather, it is the environment, shared by all, owned by none.

But there is more to the argument, the environment, by this definition is something that people experience through their everyday lives. It is not merely an existing force in the social strata, it constantly impacts lives, decisions, livelihoods, economies, and provides material conditions through which people are able to eat, live, breathe and thus, exist.

In the words of Sundar Sarukkai (2019), there are three important characteristics of lived experiences: one, the *freedom to be a part of an experience*; two, the *freedom to leave any time* if the experience is not satisfactory; and, three, to *modify the experience*, if necessary, to suit one’s needs. And when we put the ‘*environment*’ in these very characteristics given by Sarukkai, they aren’t merely philosophical as he noted, but what we find are interesting anomalies.

1.1 Environment as a lived experience

1.1.1 Freedom to be a part of the experience

Since we are studying the environment as a political question, we need to fathom that in the Indian case for example, the constitution enshrines one key right, ‘*to life*’. Who ensures us

that we live healthy lives? Our surroundings, air that is clean, water that isn't contaminated, fields that produce rice and wheat, and our pockets that are full enough to buy us food so that one doesn't starve to death. So this very human right to life, isn't merely protection from murder or suicide; it is an assurance that one won't starve to death or get choked by pollutants in the air.

And to that, we now look around. Does everyone get what is enough and required to sustain this life? Clean water, full pockets, fresh air, enough food?

This implies that the right to life is universal, but the environmental and economic conditions necessary to sustain that life are not. Throughout the less developed and rural societies, there's probably no meaningful difference - the environment is the direct source of people's livelihoods. (Conisbee & Simms, (2003)). With the same connotation, a change in environment thus directly impacts how people's livelihoods get shaped in any particular area.

Now picture this: the Indo-Gangetic Plain (IGP) region is considered a 'bread-basket of South Asia'. However, the region is highly vulnerable to climate change due to its huge population, a largely agrarian economy, a relatively limited and depleting resource base, and projected large changes in climatic risks. (Bhatta, Datt (2016))

This vulnerability isn't merely subjective to the region, affecting everyone equally. It is rather objective to its population in effect, impacting them distinctly due to their differences, which are social, economic and political. A multitude of unequal accesses define how climate and environment impact the people, at face value it seems to be about safe habitation conditions for all, but the prime question lies in, what happens if there are not. Which people then, in such conditions, are able to still protect their '*right to life*' and which ones are not.

For categories like the Dalits, in a scenario of deeply rooted caste differentiation, Mukul Sharma notes "they are denied access to basic natural resources—their women spend many hours each day waiting for a faint trickle of dirty water from the polluted municipal tap or contaminated well." Thus, this becomes multifaceted; there is water, *shared by all, owned by none*, yet Dalit women have to suffer to acquire it, and when they do, it is dirty, contaminated and unfit for use. But for another family living in the same area, who can afford water

purifiers, the same environment produces differing outcomes. The latter is less prone to deadly diseases than the former.

So if access to a clean habitable environment is the '*lived experience*' as per our analytical lens, differential and unequal access *alters that experience* and prevents some sections from exercising that freedom.

What happens when things don't go as planned, when conditions to live aren't proper and even worse for the more vulnerable section? When the very freedoms to be a part of the experience are getting curtailed, when it gets difficult to live there? The people make arrangements for themselves, they adapt; sometimes forcibly, their adaptation varies amongst staying and adjusting, or leaving altogether, or trying to leave but forced to stay by their inability to do so. Then, their freedom to be a part of the lived experience gives way to their '*freedom to leave*'.

1.1.2 Freedom to leave

Substantial alterations in the living environment forces people to leave their traditional habitat because of affected quality of life. "Sea level rise and salt water intrusion were, for instance, first felt by farmers in the south-west of Bangladesh, not in terms of complete loss of livelihoods, but in terms of slowly decreasing yields that make it more difficult to sustain a purely agricultural-based life (Pouliotte et al., 2009; IOM, 2010)". "For agriculturally-based livelihoods, environmental stress is particularly acute when the soil quality deteriorates, when land has to be given up, or when it is lost completely. Given the absence of alternative livelihood options in many rural areas, permanent displacement is then the *logical and often the last* consequence (cf. IOM, 2010; Poncelet et al., 2010; Penning-Rowsell et al., 2013)."

Their homelands haven't become uninhabitable; they have become insufferable. The land produces enough to lure them not to sustain them.

Freedom to be in the right, healthy living environment gets overridden by inequalities amongst vulnerable groups like Dalits and women. But when such conditions exist and people aspire to walk out of an environment that is not satisfactory, then, these very inequities change the course of whether they are able to do so or not.

A report by the Food and Agriculture Organisation of the United Nations (FAO) in 2017, highlights the multifaceted nature of how migration happens and creates impact as an adaptation strategy to climate change. It quotes, “Migration as an adaptation strategy to climate change presents both opportunities and challenges to rural communities, and can increase the climate resilience of vulnerable rural populations dependent on agriculture.”

Analyses like these wrestle with the nature of migration both as an *adaptive strategy* and a *consequence* of climatic change. Yet, whichever happens, again varies with the income capacity of the household which is again governed by a multitude of factors including not just the nature of livelihoods but also group and category specific vulnerabilities within the same sample size of population.

For example, in the previously considered case of Bangladesh, “anticipating a disaster, many flee to save their lives, while others (have to) remain behind for social, cultural or purely economic reasons. Members of some poorer households migrate after an environmental event and can indeed cope with its immediate effects, while others experience significant barriers to migration that exist irrespective of environmental hazards. (cf. IOM, 2010; Poncelet et al., 2010; Penning-Rowsell et al., 2013)”

Individuals from larger households have a higher probability of engaging in temporary migration, whereas the probability to undertake permanent migration decreases as household size increases. (Kumar, Viswanathan, 2013). And a migration that so happens does not occur due to ruined crops and saline soil. Rather, it happens when sons of rich landowners study in the city; it is temporary migration. These sons would never leave the village completely because they wouldn’t leave their lands to termites, thus, they tend to come back. Their migration is *more than seasonal, it is strategic*.

The poorer ones do so due to differing reasons. Their migration is far removed from merely strategy; *it is seasonal, it is sustaining, it is required*. The ones who migrate from these families send remittances back to the members who don’t. The latter live off these remittances.

In conclusion, freedom to leave inhospitable experiences becomes increasingly selective, sometimes due to the abundance, other times due to the scarcity. Yet, when people

can't leave, what are they left with? Can they alter the inhospitable environment enough that they can sustain themselves in it?

1.1.3 Freedom to modify

Leaving is the simplest, most immediate consequence of environments becoming increasingly inhospitable due to degradation. But then emerge the involutions within it. Migration does not appear as a simplistic idea. For instance, not every household migrates as discussed earlier. Additionally, not every member of that household migrates. Here emerges the idea of *differential access* because migration is not an impulsive decision. The migrating ones require *access to systems, resources and information* that enables this migration.

This brings us to a study by the National Institute of Industrial Engineering, Mumbai (Jha, Gupta, 2018) which evaluates the link between climate/weather change and farmer migration in Bihar, India. "Older farmers feel a greater sense of responsibility for ensuring sustained livelihood sources for their families and therefore either migrate themselves or encourage other household members to migrate, not only to reduce dependency but also to ensure remittances to the home region." (Jha, Gupta, 2018). The dependence on domestic remittances has increased in Bihar since the 1990s (Tumbe, 2011). This particularly increasing dependence on remittances by migrating members, in effect, sustains the families of the migrants.

The same study points out how remittances from the host region reduce credit constraints on the adoption of adaptation strategies (Patnaik and Narayanan, 2015), thus scaling up the adaptive capacity and resilience of the home region. This implies the migration, in turn, also *funds the adaptation of the non-migrants* in many cases. These results indicate that members of migrating households have a higher adaptation capacity as they are able to take up more resilience strategies due to support from host regions in the form of remittances, knowledge, resources and networks.

Interestingly enough another study points out another side of the situation. Non-migrant households, with no members sent outside, are not able to perform such types of practices including newer technology, information and credit based adaptation that migrant households have access to. This is consistent with the important correlation that migration funds better adaptation back home.

But what about the ones without that access to the *means to migrate*? Due to uncertainty related to climate-sensitive occupations, such households engage in livelihood diversification, a major coping strategy for various economic and environmental challenges (Bhatta et al., 2015b). The increase in income from diversified livelihood sources allows farmers to enhance their adaptive capacity to cope with climate risk (Cunguara et al., 2011; Tripathi, 2017; Patnaik and Das, 2017).

The Bangladesh study (Etzold, 2014) highlights, “Many migrants from Kurigram have established ties to employers in these agricultural regions. Moreover, they need good personal relations to so-called Sadars – “migration entrepreneurs” who negotiate wages with employers and who facilitate transport, accommodation and food for a group of labour migrants. Access to such networks enables a more secure migration, which is an important factor for a labourer’s migration decision.”

The absence of these networks therefore does more than constrain mobility; it also prevents households from accessing the remittances, information and other resources that migration can generate for those who remain. In the same study’s Khanpara sample, “only two of these “extremely poor” households had migrants in their family. Both migrants were sons who worked as day labourers in Dhaka. Most families living under conditions of extreme poverty cannot benefit from migration to cope with hunger or to improve their situation in the longer term. They neither have adult male family members who could work as labour migrants, nor the required resources to facilitate migration, nor the access to the necessary migration networks. These “trapped populations” (cf. Poncelet et al., 2010; Black et al., 2013) are forced to adapt to adverse effects of increasing rainfall variability with the resources that are locally available to them.” These include selling off of savings and assets when needed, or acquiring loans from shop owners or moneylenders, supported by food aid or institutional support from the government and NGOs. (Etzold, 2014)

These illustrate the complexity of the freedom to alter and modify, to suit one’s needs. These adaptations ensure that those left behind due to socio-economic factors are not rendered entirely powerless, while not necessarily empowering them either, as these very measures can introduce other constraints such as debt and the liquefaction of assets. They are, nevertheless,

coping mechanisms through which non-migrant households sustain themselves in conditions that have become increasingly inhospitable, yet not entirely uninhabitable.

1.2 Conclusion

These studies offer something crucial, as to what we were trying to infer by using the analytical lens of Sarukkai's freedoms associated with lived experiences. They provide an analysis of the complexity of migration as a concept in the context of climate change, not just as a consequence but also as an adaptation, not merely as necessity but also as strategy.

With the lens of Sarukkai's first, 'freedom to be a part', the question of *who* gets the access is attempted to be answered. Inequalities of access to the environment in the first place are highlighted with the example of Dalits' differential access to common resources. This raises the question that with already existing inequalities, *what happens* when conditions become inhospitable, not so much that the region becomes uninhabitable but enough that it becomes unsustainable. This invokes the second freedom as highlighted by Sarukkai, freedom to leave. Leaving (migrating) becomes important to discuss because that in itself isn't linear, it is a complex decision that wanders across subjective, strategic, voluntary, involuntary and even seasonal choices. These choices are shaped by socio-economic inequalities as well as by what happens not just in the home region, but also around it. This is exemplified by the poor migrant sons working as day labourers in Dhaka.

These poor populations, with their inability to migrate or rather inability to sustain even if they migrate, brings out their impotence of sustaining with migration as an effective adaptive strategy. Thus, their categorisation as 'trapped populations' gives way to their need to exercise their *'freedom to modify'*.

There is also another interesting distinction that is found between non-migrant and immobile populations. The non-migrating ones can also be members of a household where one member or two have migrated and send home remittances that in turn fund the adaptive capacity of the non-migrating members. But the immobile, on the other hand, *cannot* migrate or benefit from any aids of migration. They then resort to other ways of sustenance that more often than not endanger their existence.

The noted inequities in the society that give birth to differential access of resources, and also shape the decision of and the means to migrate, thus influencing vulnerability at large. Which leaves us with an intriguing question,

“If the access to environment is unequal, and the capacity to live or adapt is consequently differential as well, then the subsequent access to basic systems of infrastructure and resources upon which receiving and sending of these vulnerable communities depend shall also reveal another layer of inequality; energy insecurity.”

Energy Insecurity

Rapid transformation of India's energy systems and exponential developmental growth have generated unprecedented levels of demand have led to questions of sustainability of energy resources, technological resilience in production and dissemination of these sources and most importantly, growing dependence on volatile international energy markets to meet developmental needs. India's energy demand is expected to remain among the fastest-growing globally, driven by industrialisation, urbanisation, rising household consumption and increasing demand for cooling. Electricity peak demand, for example, increased from 148 GW in 2014 to approximately 250 GW in 2024 (IEA, 2025). This growing demand has historically been supported by coal for electricity generation and imported oil and gas for transport and industry. Such dependence creates structural vulnerabilities because international fuel prices and supply chains are increasingly influenced by geopolitical instability. India remains particularly exposed to disruptions in global energy trade, including those affecting maritime chokepoints such as the Strait of Hormuz (Bakshi, 2026). Consequently, energy security is no longer simply a question of securing sufficient fuel; it increasingly concerns diversification of supply, domestic energy production and resilience against geopolitical and economic shocks. India's response has been a significant expansion of renewable energy, particularly solar and wind. The country crossed the milestone of obtaining 50% of its installed electricity capacity from non-fossil sources in 2025, five years ahead of its original 2030 target (Ministry of New and Renewable Energy, 2025).

The development in the *National Green Hydrogen Mission* further demonstrates how renewable energy has become an important instrument of India's broader energy-security strategy rather than merely a climate-policy objective. It was brought into force 'To make India the Global Hub for production, usage and export of Green Hydrogen and its derivatives. This will contribute to India's aim to become Aatmanirbhar through clean energy and serve as an inspiration for the global Clean Energy Transition. The Mission will lead to significant decarbonisation of the economy, reduced dependence on fossil fuel imports, and enable India to assume technology and market leadership in Green Hydrogen.' (MNRE, 2023)

However, this analysis limits the scope of India's energy insecurity to merely structural, policy oriented and economic lens while subduing the sociological angle of it. The vulnerabilities so created in the prevailing geopolitical context can not be merely looked at as diplomatic or economic issues expecting resolution. The Indian response to expansion of renewable energy sources tends to ignore the question of dissemination of electricity on grounds such that it can answer whether all previously coal dependent rural households are able to get access to these renewable sources.

1. Contemporary Status: Renewable Energy and India's Energy Security

India's renewable-energy expansion represents a structural transformation in its electricity system. As of June 2026, renewable-energy capacity, including large hydro, stood at approximately 288.6 GW, of which solar accounted for 162.2 GW and wind for 57.4 GW (MNRE, 2026). The scale of this transformation is particularly significant when compared with 2014, when India's installed solar capacity was only around 2.8 GW. The growth has been supported by competitive auctions, renewable purchase obligations, rooftop-solar initiatives, domestic manufacturing incentives and increasing private investment. Renewables have therefore helped India address the energy-consumption problem in two interconnected ways. First, they diversify the electricity mix and reduce the marginal requirement for imported fossil fuels. Second, solar and wind resources are domestically available, allowing India to convert a portion of its energy expenditure from recurring fuel imports into domestic infrastructure and investment. Clean-energy investment in India reached approximately US\$68 billion in 2023, while 83% of power-sector investment went towards clean energy in 2024 (IEA, 2024, 2025).

Nevertheless, describing renewable energy as having completely “replaced” conventional energy would be analytically inaccurate. Coal remains important for meeting India's rapidly increasing electricity demand and for providing dispatchable power when solar and wind generation fluctuates. The challenge is consequently one of energy-system transformation rather than immediate fossil-fuel substitution. Renewable integration requires investment in transmission, storage, demand-side management and grid flexibility (IEA, 2021). The IEA structurally identifies grid infrastructure and the financial condition of distribution companies as important constraints on India's renewable expansion (IEA, 2025).

2. Effects on Vulnerable Communities

The social consequences of India's energy transition are complex because vulnerable communities experience both the benefits and costs of changing energy systems. Under the earlier energy model, households in rural and economically marginalised areas frequently faced unreliable electricity supply, limited ability to pay electricity bills and dependence on traditional fuels. Renewable technologies, particularly decentralised solar systems, have created opportunities to address these problems without relying entirely on large-scale grid infrastructure. Research on community-based solar initiatives in rural India indicates that decentralised systems can improve energy access while simultaneously creating local employment and entrepreneurial opportunities. Joshi et al. (2019), for example, found that community participation in solar programmes could support sustained energy access and livelihood opportunities, particularly through women's self-help groups. Similarly, research in rural West Bengal found that micro-solar installations improved beneficiaries' living conditions and women's participation in decision-making, mobility and financial autonomy (Bera et al., 2024).

These examples demonstrate a significant difference from conventional energy consumption: renewable energy can be produced and managed closer to the point of consumption, potentially allowing communities to become participants in energy provision rather than merely consumers. However, the transition also produces new forms of vulnerability. Communities dependent on coal mining and coal-based power generation may lose employment, public revenue and associated economic opportunities as the energy system gradually decarbonises. Ordóñez et al. (2023) demonstrate that the adverse economic

consequences of India's energy transition are likely to be concentrated in eastern and less wealthy coal-mining states, while employment opportunities from renewable deployment may be distributed more widely across other regions. This poses a question of geographical costs of transformation and development in general. Current transformation does not entirely weed out coal production and consumption, because the access also does not immediately reach the far flung areas of consumption.

Similarly, recent research identifies coal-dependent districts as particularly vulnerable to the socioeconomic consequences of coal phase-down (Minocha, 2025). There also exists a need to emphasise that looking at energy redistribution and insecurity vulnerabilities from the lens of only employment in production and consumption patterns reduces the issue to mere economic lines, while completely outcasting the sociological impacts of it, who gets to produce energy and thus faces the health risks, dangers and differential access and impacts that follow.

Thus, renewable energy does not automatically produce an equitable energy transition. Its benefits depend upon affordability, local participation, employment policies and mechanisms for redistributing the costs of structural change.

3. Conclusion: Energy Security in a Changing Geopolitical Order

The future of Indian energy security is becoming increasingly shaped by the interaction between domestic energy transition and global geopolitics. The conventional energy-security paradigm centred on oil, gas and coal is being supplemented by a new paradigm involving electricity grids, batteries, solar modules, critical minerals and clean-technology supply chains. The IEA notes that the geographical concentration of critical minerals and clean-energy manufacturing creates new vulnerabilities even as renewable energy reduces dependence on conventional fuels (IEA, 2024). India must therefore avoid replacing one form of external dependence with another. Reducing dependence on imported hydrocarbons while becoming excessively dependent on imported solar modules, batteries or critical minerals would merely relocate the vulnerability. These technologies also come with higher costs of installation and maintenance that in turn inflict again on economic and social vulnerabilities. Domestic manufacturing, diversified international partnerships, strategic reserves, stronger transmission networks and investment in energy storage coupled with an internal focus on

wider and equitable distribution of these technologies will consequently be central to India's future security.

Changing patterns of global trade also mean that India's energy diplomacy will become increasingly important. Energy security will involve not only securing physical supplies but also managing trade routes, technology partnerships, mineral access and international investment. India's transition should therefore be understood as both an environmental transformation and a geopolitical strategy. Ultimately, a secure Indian energy system will require a balance between affordability, reliability, sustainability and justice. Renewable energy provides an important pathway towards this objective, but its long-term success will depend on whether India can combine technological transformation with social inclusion and strategic autonomy.

The Indian case demonstrates how climate vulnerability, population movement and energy demand increasingly intersect within a rapidly urbanising and transitioning economy. However, the relationship between climate pressures, mobility and energy insecurity is not uniform across contexts; it is mediated by the availability of infrastructure, institutional capacity and existing patterns of energy access. The Nigerian case provides a comparative perspective through which this relationship can be examined under markedly different infrastructural and energy conditions.

Case Study: ENERGY INSECURITY IN NIGERIA

1. Introduction: Energy Security Developments in Nigeria, 2000–2026

Nigeria's energy-security challenge is very similar to that of India, increasingly shaped by the interaction between population redistribution, climate change, rising energy demand, and unequal access. Although the country possesses substantial oil, natural gas, hydropower, and solar resources, access to reliable and affordable modern energy remains highly uneven. Energy insecurity is therefore not simply a problem of insufficient energy production; it is also a problem of where people live, how populations move, how demand changes, and who can afford and access energy services.

Between 2000 and 2026, Nigeria's electricity system remained largely dependent on centralized gas-fired generation and hydropower. However, rapid population growth and urbanization have increased pressure on existing infrastructure. Recent modeling suggests that population growth, urbanization, and economic development will substantially increase Nigeria's energy demand, with the residential sector already accounting for about 42% of final energy consumption (Adeoye et al., 2026).

At the same time, Nigeria has experienced significant rural–urban redistribution. Rural populations affected by declining agricultural productivity, desertification, flooding, and livelihood insecurity increasingly migrate towards towns and cities. Recent research identifies northern Nigeria as particularly vulnerable to climate-related migration and projects that these risks will persist under future climate conditions (Frontiers, 2025). Migration can provide households with an adaptation strategy, but it also concentrates population and energy demand in receiving communities.

This creates an important connection between climate-induced mobility and energy insecurity. When populations move from rural to urban areas, receiving communities require additional electricity for housing, transport, businesses, cooling, water supply, and other services. Yet Nigerian cities already face electricity shortages and unreliable infrastructure. Consequently, population redistribution can intensify existing energy insecurity. The rural–urban divide is particularly significant. Ugwoke et al. (2020) describe Nigeria's energy-access problem as strongly associated with the spatial divide between relatively better-served urban populations and rural communities with limited access to modern energy services. More recent evidence indicates that urban areas have gained electricity access considerably faster than rural areas, while substantial regional disparities remain (Frontiers, 2026).

Thus, Nigeria's energy-security problem must be understood spatially: climate change influences livelihoods and mobility; mobility redistributes population; redistribution changes energy demand; and unequal infrastructure determines who receives reliable energy.

2. Rural–Urban Redistribution and Energy Insecurity

Rural–urban migration has important implications for Nigeria's energy system. Climate variability, declining agricultural productivity, desertification, and flooding can undermine

rural livelihoods and encourage households to seek alternative economic opportunities in urban areas. Recent literature indicates that environmental pressures in northern Nigeria have contributed to migration and increased pressure on infrastructure and services in receiving communities (Abubakar et al., 2025).

The energy implications are two-sided. In rural areas, population out-migration may reduce immediate household demand but can leave behind communities with weak infrastructure and limited investment. Rural populations already experience significant energy deprivation, particularly in electricity and clean cooking. Ugwoke et al. (2020) identify rural electrification as one of the central unresolved challenges in Nigeria's energy-access system. In urban areas, however, population growth creates additional demand for electricity and fuel. Migrants often settle in informal or peri-urban communities where electricity infrastructure is inadequate. Consequently, migration does not automatically lead to improved energy access. Instead, it can reproduce energy insecurity in new geographical locations.

Recent research on Nigerian urban energy systems observes that rural-to-urban migration is likely to increase pressure on urban energy systems, while unreliable grid electricity encourages households and businesses to depend on petrol and diesel generators (Bridging Nigeria's Urban Energy Gap, 2026). The result is a spatial redistribution of energy demand without a corresponding redistribution of infrastructure. This is particularly problematic because electricity access does not necessarily mean reliable electricity. Rural and peri-urban households continue to experience frequent outages and expensive alternative energy sources (Electricity Supply Quality Study, 2023).

3. Climate Change and Changing Energy Demand

Climate change influences Nigerian energy demand both directly and indirectly. Rising temperatures increase the need for cooling, particularly in urban areas, while changing rainfall patterns and extreme weather can disrupt energy infrastructure and livelihoods. Climate change can therefore simultaneously increase energy demand and threaten energy supply.

Urbanisation intensifies this relationship. As populations concentrate in cities, households increasingly use appliances such as air conditioners, refrigerators, fans, and electronic devices. Recent modelling indicates that urban households consume substantially more electricity for cooling and electronics than rural households (Adeoye et al., 2026). This suggests that climate change and urbanisation may create a reinforcing cycle. Higher temperatures increase cooling demand; growing urban populations increase the number of consumers; and increasing electricity demand places additional pressure on an already constrained power system.

At the same time, climate change threatens rural livelihoods, particularly agriculture. When agricultural productivity declines, households may migrate, changing the geographical distribution of energy demand. Climate-induced migration can therefore become an indirect driver of energy insecurity by moving vulnerable populations toward areas where energy infrastructure is already under pressure.

Nigeria's household energy system also remains dependent on biomass. Millions of households rely on wood for cooking, creating environmental and health pressures while reinforcing energy poverty (Electricity Supply Quality Study, 2023). Research further indicates that rural households can experience a "reverse energy transition," shifting toward cheaper but less clean fuels when household income and energy affordability deteriorate (Urban and Rural Household Energy Transition, 2022). Therefore, climate change does not simply increase the amount of energy Nigeria needs. It changes when, where, and how energy is consumed, making conventional energy planning increasingly inadequate.

4. Unequal Access and Energy Insecurity

The consequences of these changes are unevenly distributed. Energy insecurity is particularly severe among rural households, low-income urban residents, and communities affected by climate-related displacement. Nigeria's electricity access rate has improved over time, but major spatial inequalities remain.

Evidence shows that rural and peri-urban populations experience unreliable and expensive electricity, while businesses suffer economic losses from frequent outages (Electricity Supply Quality Study, 2023). The electricity-access gap is also regional: satellite-based research found substantially stronger access improvements in southern than northern Nigeria and

reported that urban areas gained access at approximately twice the rate of rural areas (Frontiers, 2026).

Renewable energy provides an important response to these inequalities. Solar home systems and mini-grids can supply communities that are geographically distant from the national grid. Salihu et al. (2020) demonstrate the potential of photovoltaic microgrids for rural electrification, while research on Nigerian hybrid mini-grids indicates their potential to provide reliable electricity for households and small businesses. However, renewable energy itself can reproduce inequality if poorer households cannot afford solar systems, batteries, and other technologies. The energy transition must therefore be accompanied by appropriate financing, infrastructure, and institutional support. The challenge is not simply to increase renewable-energy capacity but to ensure that vulnerable populations can actually use and benefit from it.

5. Renewable Energy and the Changing Energy Consumption Pattern

Nigeria's renewable-energy transition represents a significant change from the earlier pattern of centralized electricity supplemented by petrol and diesel generators. The Nigeria Electrification Programme (NEP) has promoted solar mini-grids and standalone systems for unserved and underserved communities. Renewable energy is particularly relevant to the rural–urban and climate-energy relationship because decentralized systems can be deployed closer to where demand emerges. This makes them potentially valuable for rural communities experiencing energy deprivation as well as rapidly expanding peri-urban settlements.

However, renewable energy has not yet replaced conventional energy nationally. Gas remains essential to electricity generation and grid stability, while hydropower remains the major renewable contributor. Recent modelling similarly concludes that natural gas is likely to remain important for grid reliability during Nigeria's transition (Adeoye et al., 2026).

The appropriate interpretation is therefore that renewable energy is supplementing and selectively replacing conventional energy, particularly generator use and traditional household fuels, rather than completely transforming Nigeria's national energy mix.

6. Prediction, Monitoring, and Resource Management

The increasingly complex relationship between climate risk, population distribution, and energy demand creates a strong need for improved systems of prediction, monitoring, and resource management. Traditional energy planning based mainly on historical electricity consumption is becoming less adequate because future demand will depend on migration, urbanisation, climate change, income, technology, and changing household behaviour. Recent research therefore recommends demand-driven energy-system modelling that integrates population growth, economic development and sectoral energy consumption (Adeoye et al., 2026).

Emerging technologies can strengthen this capacity. Satellite imagery and nighttime-light data can identify spatial patterns of electricity access, while GIS can combine information on population, climate vulnerability, infrastructure, and energy resources. Recent Nigerian research has already used satellite-based nighttime luminosity and population data to measure electricity access across all 774 Local Government Areas, demonstrating the potential of spatial technologies for energy planning (Frontiers, 2026).

Similarly, climate-risk mapping can identify areas where environmental pressures are likely to encourage future migration. Research integrating climate, socioeconomic, and population data has demonstrated the potential to identify areas of Nigeria with higher future migration risks (Frontiers, 2025).

The significance of these technologies is that they can connect where climate vulnerability is occurring, where people are moving, and where energy infrastructure is inadequate. Such integration can support more anticipatory rather than reactive energy planning.

7. Conclusion: The Future of Energy Security in Nigeria

Energy insecurity in Nigeria is increasingly an interconnected problem involving climate change, rural–urban redistribution, changing consumption and unequal infrastructure. Climate pressures can undermine rural livelihoods and encourage migration; migration can increase urban and peri-urban energy demand; inadequate infrastructure can then reproduce energy insecurity among both migrants and existing populations.

Renewable energy offers an important opportunity to break this cycle through decentralised electricity generation. Solar mini-grids and standalone systems can extend energy services beyond the limits of the conventional grid, particularly in rural and underserved communities. Nevertheless, affordability and unequal access remain significant challenges. The future of Nigerian energy security therefore requires an integrated approach. Energy planning should combine climate projections, migration patterns, population data, electricity demand and renewable-resource assessments. GIS, remote sensing, satellite-based monitoring, AI-supported forecasting and other digital technologies can contribute to this process.

Ultimately, Nigeria's energy transition should not be judged solely by how much renewable capacity is installed. Its success should be measured by whether vulnerable rural, peri-urban and urban populations receive reliable, affordable and sustainable energy. The central challenge is consequently to transform energy planning from a reactive system focused on electricity supply into an integrated system capable of anticipating where people will live, how climate change will affect them and how their energy needs will change.

Comparative Analysis

The juxtaposition of the cases of energy insecurity in India and Nigeria suggests an accord in terms of population migration, rural-urban divide and proposed policy interventions across expansion of renewable energy sources and the social vulnerability contention that comes with it.

Dimension	India	Nigeria	Analytical Finding
Climate-migration relationship	80% of the population at risk from climate-induced disasters; ranks 9th globally in the	Rural–urban redistribution driven by declining agricultural productivity,	How climate redistributes population: in India, climate migration is

Comparative Analysis

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	Climate Risk Index; migration to cities is demand-intensive, with new urban centres emerging	desertification, and flooding; northern Nigeria identified as particularly vulnerable; migrants move to <i>existing</i> cities, with new urban centres rarely emerging	demand-creating — it builds new urban centres and intensifies energy demand; in Nigeria, it is redistributive — it shifts population within existing infrastructure. In both cases migration can relocate, rather than resolve, insecurity
Energy Vulnerability	Diversification-focused: reducing dependence on conventional sources to ensure availability and lower carbon footprint; peak demand rose from 148 GW to ~250 GW;	Access-focused: over one-fifth of Nigerians in extreme energy poverty; residential sector ≈42% of final energy consumption; heavy biomass dependence;	Access vs reliability vs affordability: India's vulnerability concerns availability and the distribution of transition costs; Nigeria's concerns basic access, supply, and affordability.

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	coal-dependent eastern communities face job and revenue losses	unreliable grid pushes households to diesel and petrol generators	Both are spatially concentrated — in India's eastern coal belt, in Nigeria's rural and northern regions
Governance Model	Target-driven and state-directed: national missions such as the Green Hydrogen Mission; 288.6 GW renewable capacity by 2026 with 50% non-fossil capacity reached ahead of target; climate approached as a policy objective embedded in law, strategy, and practice	No integrated, multidisciplinary planning presently exists; renewable responses are small-scale and decentralised (solar mini-grids, off-grid PV microgrids) aimed at reforming weak centralised infrastructure rather than transforming it; the need for a structured, inclusive approach is	Centralised vs decentralised responses: India's centralised, target-driven model delivers scale but risks leaving transition losers behind; Nigeria's decentralised patchwork addresses access but lacks integration. Neither suffices without a public-centered, bottom-up

Comparative Analysis

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		acknowledged	framework combining migration, urban planning, disaster management, energy security, and technological governance
Technology/ Adaptation Capacity	GIS and remote sensing most operationally mature for migration mapping; digital twins and AI most promising but least implemented; constrained by data gaps (delayed 2021 Census), digital and institutional inequities, and an unresolved	Satellite-based nighttime luminosity and population data already used to measure electricity access across all 774 Local Government Areas; climate-risk mapping identifies areas with higher future migration risk; GIS integrates population, climate vulnerability,	Where predictive/integrated tools matter: Nigeria demonstrates that spatial technologies can be operational for access mapping even under infrastructure constraints; India shows mature predictive tools whose impact is

Comparative Analysis

The juxtaposition of the cases of energy insecurity in India and Nigeria suggests an accord in terms of population migration, rural-urban divide and proposed policy interventions across expansion of renewable energy sources and the social vulnerability contention that comes with it.

	planning-to-implement gap	infrastructure, and energy resources	gated by institutions and data. In both, the value of technology depends on its embedding within functioning institutions
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The preceding analysis therefore reveals a planning problem that cannot be addressed through infrastructure expansion alone. If climate change alters where populations are located, where energy is demanded, and which communities are most vulnerable to supply disruptions, adaptation requires the capacity to anticipate these changes spatially and temporally. Conventional datasets and administrative planning mechanisms are often fragmented across these domains. Emerging technologies consequently become relevant not as independent solutions to climate change, but as tools capable of integrating climate, demographic, spatial and infrastructural information to support anticipatory decision-making.

Emerging technologies

1. Introduction

Climate-induced migration, the movement of people driven wholly or partly by the slow-onset and sudden-onset effects of a changing climate, has become one of the most pressing dimensions of global climate mobility. Rising sea levels, cyclones, droughts,

heatwaves, landslides, and coastal erosion are compounding pre-existing socio-economic vulnerabilities and are projected to displace tens of millions of people internally in South Asia alone by 2050 (Rigaud et al., 2018). In India, this pressure is especially acute: cumulative climate-induced internal displacement between 2008 and 2023 has been estimated at over 56 million individuals, positioning the country as a global climate-migration hotspot (Mohanty & Wadhawan, 2021). Within this context, emerging technologies artificial intelligence (AI), Geographic Information Systems (GIS), remote sensing, digital twins, and the Internet of Things (IoT) are increasingly framed as tools that can help predict, monitor, map, and manage migration pressures before, during, and after climate disasters. Similar policy interventions are studied for and suggested to tackle climate vulnerability on energy security and migration in the case of Nigeria as well. This section critically examines whether such technologies can move India's migration governance from reactive disaster response toward proactive, spatially informed adaptation.

2. Contemporary Emerging Technologies for Climate Mobility

A growing body of scholarship maps the technological toolkit available for climate-resilience and mobility governance. Vinuesa et al. (2020) provide the most widely cited quantitative assessment of AI's dual potential, finding through expert elicitation that AI could enable action on 134 of the 169 UN Sustainable Development Goal targets including climate action while inhibiting 59, several of which concern equity and resource access. This tension between AI's predictive power and its distributive risks recurs throughout the literature and is directly relevant to migration forecasting, where algorithmic risk models can both anticipate displacement hotspots and, if poorly governed, reproduce existing inequities.

GIS and remote sensing remain the most operationally mature technologies in this space. Balaganesh et al. (2020) demonstrate how GIS, combined with the Analytic Hierarchy Process, can overlay rainfall, temperature, and land-use layers to produce district-level drought vulnerability maps a method later scaled nationally by Mohanty and Wadhawan (2021) at the Council on Energy, Environment and Water (CEEW) to identify the roughly 40 percent of Indian districts facing compounding hazard risk. A 2024–25 systematic mapping study of the global technology literature similarly concludes that GIS, early-warning systems, and smart-energy systems are the most-studied climate-resilience technologies worldwide,

while AI and digital twins remain fast-emerging but comparatively under-represented (Systematic Literature Review and Mapping Study, 2024–25).

Digital twin technology dynamic virtual replicas of physical urban systems continuously updated by real-time sensor data is positioned as the next frontier for simulating flooding, sea-level rise, and displacement scenarios before they occur (Riaz, McAfee, & Gharbia, 2023). Therias and Rafiee (2023), reviewing six European case cities, find that City Digital Twin practice remains concentrated on data and technology architecture rather than on demonstrated resilience outcomes, calling for more practical, resilience-specific applications. A parallel bibliometric review of digital twins in the built environment reaches a comparable conclusion: research emphasises technical performance monitoring, while policy-relevant implementation studies, the kind needed to link digital twins to migration and resettlement planning remain scarce (Sustainability, 2024).

3. GIS and Digital Twin Applications in India

India's spatial-technology base for climate mobility is anchored by GIS-based composite vulnerability indices. Balaganesh et al. 's (2020) Drought Vulnerability Assessment for Tamil Nadu showing 62 percent of Namakkal district under mild drought conditions illustrates GIS overlay as a low-cost, replicable planning tool for state governments. At the national scale, Mohanty and Wadhawan (2021) integrate hydro-meteorological hazard layers with socio-economic exposure indicators into a single composite Climate Vulnerability Index, enabling disaster-management authorities to prioritise districts for intervention. These GIS applications, while not designed explicitly as migration-prediction tools, generate the district-level exposure and sensitivity data that migration models increasingly draw upon (Climate-Induced Internal Migration in India, 2026).

Digital twin adoption in India remains at an earlier, largely conceptual stage relative to GIS. The broader digital-twin literature (Riaz, McAfee, & Gharbia, 2023; Therias & Rafiee, 2023) proposes integrated digital-twin-plus-early-warning frameworks for hazard-responsive cities a model with clear relevance to India's flood-prone river basins, Himalayan landslide zones, and coastal cities such as Chennai and Kolkata, but one for which India-specific empirical

deployments and resettlement-simulation case studies are not yet well documented in peer-reviewed literature.

4. Technology in Practice - Institutional Response and Constraints

Institutionally, ISRO's geospatial platforms, the National Disaster Management Authority (NDMA), the India Meteorological Department (IMD), and the National Disaster Management Information System underpin India's early-warning and geospatial decision-support infrastructure, feeding the AI-enabled and GIS-based systems reviewed above. Yet the literature repeatedly cautions that technology availability does not by itself guarantee adoption or impact. Agrawal (2010) argues that adaptive capacity depends more on institutional access to resources than on the existence of technology, a finding empirically reinforced by a case study of mango farmers in India, where credit-access and extension-service gaps not the absence of climate-resilient technology were the binding constraint on adoption (Socio-Economic and Institutional Barriers to Climate-Technology Adoption, 2023). This institutional lens is directly relevant to emerging technologies for migration management: an AI-driven early-warning system or GIS vulnerability map has limited value for at-risk communities unless it is embedded within functioning institutions capable of acting on its outputs.

5. Challenges and Future Opportunities

Three limitations recur across the reviewed literature. First, data gaps and interoperability remain unresolved: India's delayed 2021 Census constrains accurate national migration estimation, prompting statistical workarounds in recent modelling work (Climate-Induced Internal Migration in India, 2026). Second, digital and institutional inequities risk being reproduced rather than resolved by new technology Vinuesa et al. (2020) note AI's capacity to inhibit as well as enable equitable outcomes, while household-level vulnerability research shows that district averages can mask substantial within-district disparities that purely top-down geospatial tools may overlook (Balaganesh et al., 2024). Third, and most fundamentally, no source in the current literature connects emerging-technology capability directly to the documented adaptation planning-to-implementation gap in Indian climate governance (Berrang-Ford et al., 2019; Sethi et al., 2021), leaving open whether AI, GIS, and digital twins can genuinely bridge that gap or will fail for the same institutional reasons that

non-technological adaptation has (Agrawal, 2010). Opportunities going forward include participatory and community-based GIS mapping, tighter integration of digital twins with resettlement and shelter-location planning, and predictive migration-governance frameworks that explicitly link vulnerability data to destination-area planning for housing, labour markets, and energy demand.

6. Conclusion

Emerging technologies offer substantial, empirically demonstrated capability for predicting, monitoring, and mapping climate-induced migration pressures in India, with GIS and remote sensing the most operationally mature and digital twins and AI the most promising but least implemented. Realising this potential for proactive, rather than reactive, migration governance will depend less on further technical development and more on resolving the institutional, data, and equity gaps that the literature consistently identifies as the true bottleneck to climate-resilient adaptation in India.

The potential of these technologies, however, depends not only on their capacity to generate or integrate information but also on their ability to translate that information into timely and context-sensitive decisions. GIS and remote sensing can identify where risks are concentrated, while digital twins can model how systems may respond to changing conditions. Artificial intelligence extends this analytical capacity by processing large and complex datasets to identify patterns, generate predictions and support decision-making at a scale that conventional administrative systems may struggle to manage. Yet this expanded capacity also raises a new governance question: when increasingly consequential adaptation decisions are informed by algorithmic systems, how can their accuracy, accountability and equity be ensured?

Integrating AI into Governance

1. Introduction

Algorithms are dominating every sphere of our lives, and it seems that governance is no exception. Governments worldwide are swiftly moving towards “Digital Governance”, not only due to global competition, but also due to its efficiency. Aside from a wide range of emerging technologies, Artificial Intelligence models are being increasingly incorporated into the climate action plans of various governments. AI models can take on diverse roles in protection and rehabilitation of vulnerable communities, enhancing the efficiency of emerging technologies.

With AI being strung together into the governance fabric, issues of staggering scale and complexity can be solved at unprecedented speed. However, debates regarding its negative impacts often shadow discussions of its potential. The potential of AI in governance is widely acknowledged, but the apprehensions regarding the issues it brings are also widely discussed and debated. Can it be used for the betterment of vulnerable communities by filling the potholes in current structures or will it lead to further proliferation of existing hierarchies? What place does AI occupy in the process of reducing climate vulnerability?

Even though use of AI in governance raises considerable, well-founded apprehensions, its potential is boundless and cannot be ignored. It has diverse applications across sectors and its utility needs to be weighed against its shortcomings to make a fair evaluation of its contribution to governance.

2. AI Applications Across Critical Sectors

In countries like India where approximately 46% of the workforce is dependent on agriculture and allied sectors (*Periodic Labour Force Survey (PLFS) Annual Report, 2025*), or Nepal where approximately 66% workforce is dependent on agriculture (*FAO, n.d*), AI can be incorporated in various dimensions to help streamline the process. Though considerable improvement has been made in irrigation and securing livelihoods of farmers beyond temporal consideration, AI algorithms are increasingly used to predict floods, droughts and

famine, as such critical information, if received timely, can save the farmers from heavy losses. The ability of AI models to synthesise massive data sets and simultaneously process various types of data will not only help the farmers determine the best kind of inputs, but will also help them find these locally and at cheaper prices. However, the effectiveness of such systems ultimately depends on whether the information reaches vulnerable communities and whether corresponding institutional and financial support is available.

A lot of countries face a similar problem, where its soils produce enough food to sustain the entire nation yet certain communities and regions are faced with severe food insecurity. Improving technology on its own is not enough; the distribution system needs to be automatised in a way that reduces opportunities for corruption and improves transparency., which can be done by firstly ensuring unskewed data sets. Self-learning models need to be trained to include social, cultural and environmental contexts and nuances before it proceeds with a decision. These algorithms can be involved in food distribution systems, which would lead to their optimisation and will enable them to secure vulnerable communities and ensure food security at every level. (*Omotayo et al., 2025*)

A successful model from India can be used as an example of the extent of incorporation of algorithms in agriculture. Traditional agriculture advisory systems have failed to advise farmers properly about risks, potential yields, market prices etc, or produce inadequate or simple results. In a country where vibrant agriculture flourishes in every corner, empowering the primary sector is the key to economic growth. Recognising this, the Government of India introduced the Project Krushi Samriddhi, which provides the farmers with a platform to address their complaints and find solutions. The model is able to compute massive data sets and provide consistent, localised solutions that can easily be applied by the farmers. To make the model accessible, Natural Language Processing (NLP) is used along with generative AI. (*IndiaAI, 2026*)

Though data centres that support AI models contribute to emissions, it is important to note that their share in global emissions is reported to be 0.5% to 2% as per data released by International Energy Agency (IEA) in 2025 (*IEA, 2025*). Industries such as agriculture or commercial livestock are more polluting. Methane gas is one of the most lethal effluents into

the environment, whose leaks are often one of the greater causes of industrial pollution, and can be detected and prevented by predictive AI models and algorithms (*Gabbatiss, 2026*). These models can also flag if a particular industry is consuming excessive amounts of conventional energy or polluting beyond the emissions limit. Then, these industries can be held accountable and the government can take strict actions.

In the energy sector, R&D seems to be the most promisable application of AI models. Not only can it aid the search of new sources of energy but also identify and evaluate local and sustainable alternatives for previously energy intensive activities (*Gabbatiss, 2026*). It can regulate fair distribution among communities and plan the long-term use and reserve of scarce conventional energy resources.

AI used in industries is very different from ‘user-facing’ models that directly interact with humans. These models are fine-tuned to the needs of various industries. The incorporation of these algorithms is often considered as a part of the Fourth Industrial Revolution. The merit of these models lies in their capability to automatise processes and their ability to incorporate real-time data to speed up and optimise processes. Struggling small or artisanal industries can be protected and their functioning can be promised in a way that their products are able to compete in global markets, hence increasing India’s manufacturing sector as well as exports thereby increasing India’s competitive advantage. help produce world-class products, increasing India’s competitive advantage. (*Belcic & Smalley, 2026*)

3. Ethical AI

The boundless potential of AI in governance can only be harnessed if its use remains ethical. Otherwise, a risk of gross misuse arises. These models are called Ethical AI models. It needs to be ensured that every consideration and stage in the process should not be devoid of the spirit of environmental justice. An Ethical AI is not truly ethical if it pollutes the environment. It deviates from its original purpose of furthering mankind. (*Nordgren, 2022*)

The most fundamental caution that is to be taken when considering these models for purposes of administration is that the data set(s) the model is trained on are not skewed. Worldwide, reports of these models disseminating incorrect information or taking decisions that have dire

consequences have been brought to light. The COMPAS (Correctional Offender Management Profiling for Alternative Sanctions) software was extensively used by courts in the United States to profile criminals. It is a risk assessment algorithm that helps the court decide bail, sentencing and parole. (*Salo et al., 2012*) However, in 2016 it was found that the algorithm was prone to profile Black people as ‘potential offenders’ in a higher proportion to the white. It flagged Black defendants at “high risk” which influenced conviction rate, sometimes almost as high as twice as compared to individuals of other races. The racial bias that crept into the functioning of the system was found to be because of use of historical data sets that reproduced prejudice and stigma. (*Angwin et al., 2016*)

Another feature of Ethical AI is that it is non-invasive with respect to the privacy of the citizens. The data of the citizens must remain within the country, protected with stringent data protection laws. The data sets fed to these models are essentially raw data, but can nonetheless be extracted and misused. Levels of digital literacy of the population matter more than ever.

Similarly, the vulnerable communities need to be secured first. These algorithms must be judiciously used, but an increase in the number of these models would mean an increase in the number of data centres that support them thereby raising the computational footprint. However, the same research and data quoted above by the International Energy Agency, shows that this electricity demand can be met through the usage of clean and renewable energy, the usage of which is expected to rise from 40% to 60% (*IEA, 2025*). Regardless of this reassurance, the number of data centres must be kept limited, and their ownership and construction must be controlled. These limited data centres should be deployed for the aid of the vulnerable communities as a priority. AI models as tools of governance should be used to fill the existing gaps in the contemporary administrative structures. They should extend the reach of the government and possibly revolutionise it and the potential of AI algorithms can be cultivated ethically within the bounds of human oversight. In all its glorification, it is important to not forget that AI systems are just tools and should not supersede humans, especially in situations involving reconsideration or nuances. Therefore, the incorporation of AI should be halted the second it begins moving beyond human capacity for its regulation. Accountable AI is ethical AI. In case fatal erroneous decisions caused by AI systems, AI

models cannot be tried in court, who should be held accountable? Is it the consumer, the government, the company or the programmer? This is precisely why human oversight is imperative if AI is to be increasingly incorporated into critical sectors.

A successful example of regulation of AI models for ethical digital governance can be found in Singapore. The Singaporean government aimed to rapidly adopt Large Language Models (LLMs) to draft policies, handle citizen enquiries and summarise public feedback, risks regarding data privacy and cases of false information, known as “hallucinations” and algorithmic bias began to be highlighted. The Infocomm Media Development Authority (IMDA) of Singapore launched Project Moonshot. It is an open-source AI governance tool and testing model which was specially designed to evaluate safety and vulnerabilities in public-sector AI applications (IMDA, 2024). It is an automated tool that intentionally probes government LLMs for data leaks, outputs and other vulnerabilities. These corrective AI models can raise the levels of accountability of AI governance.

LLMs can be useful in government, but their outputs cannot simply be accepted at face value. They may leave out information that seems minor to the model but is crucial in a particular social or administrative context. Human oversight is therefore necessary to check whether AI-generated responses are accurate, relevant and sensitive to the needs of the people affected (Doshi-Velez & Glassman, 2025).

4. Conclusion

It cannot be stressed enough that if a model is adverse to long-term environmental goals, even if it meets the above mentioned parameters, it is still an unethical model. Every unit of water and energy consumed by data centres is one unit lesser for vulnerable communities that already face respective scarcities. The computational footprint can be reduced either by judicious use of these models or technological changes in the structure and code of these models.

5. POLICY RECOMMENDATIONS

Climate Change can no longer be treated as an ordinary environmental problem. It has gradually intersected with migration issues, energy security, geopolitics and technological development. Due to migration, some regions receive additional pressure regarding housing, energy demand and transport issues. Emerging technologies like Digital Twin & Artificial Intelligence help in combating these issues. New technologies often come with new problems like water & energy consumption and digital inequality. Climate change requires a framework which integrates all these problems instead of addressing them separately.

Thence, by means of this study, an attempt has been made to not compile a list of disconnected asks but as five interdependent policy pillars. Together they shall form a system:

- **Policy Pillar I:** Integrated Climate Vulnerability Mapping
- **Policy Pillar II:** Climate Mobility Planning
- **Policy Pillar III:** Climate–Energy Planning
- **Policy Pillar IV:** Technology for Anticipatory Governance
- **Policy Pillar V:** Equity and AI Governance

These pillars take into account, there are a few laid out policy requirements weaved together into integrated planning frameworks. These standalone policies include:

1. **Integrating GIS into climate planning**
2. **Climate Induced Migration Addressal**
3. **Integration of Energy Security**
4. **Expand decentralised renewable energy for vulnerable communities**
5. **Enabling AI enabled Early Warning Systems**
6. **Ethical & Equitable AI framework**
7. **Energy efficient AI system**

Policy Pillar I — Integrated Climate Vulnerability Mapping

The first pillar rests on a consequential premise, adaptation investment cannot be pre-positioned where it is needed, if the data needed to locate that need remains fragmented.

The study exhibits that India's vulnerability is spatially and socially uneven; 80% of its population lives with risk from climate-induced disasters, and the country ranks 9th globally in the Climate Risk Index. Yet the datasets that would identify the most expected and least protected households are scattered across departments that rarely speak to one another.

The remedy is an integrated vulnerability-mapping framework that overlays climate projections, census data, socioeconomic indicators, migration data, and infrastructure records, so that decision-makers can see precisely where climate exposure, special vulnerability, future population movement, and infrastructure deficits coincide. This overlap zone of all these indicators and data sets in question, is where adaptation needs to take place.

Operationally, this demonstrates an incorporation of GIS into State Action Plans and District Management Plans, using parameters such as housing conditions, health risks, and climate exposure to identify communities which are most likely to face displacement in the coming decades. These include setting of dataset standards, funding of effort, maintenance of integrated vulnerability databases, mapping and identification of vulnerable communities on the local level. None of these would work without the communities themselves. That makes participatory and community based GIS mapping a core-component.

Policy Pillar II — Climate Mobility Planning

The second pillar addresses the central migration finding of the study: *displacement is structural, unequal, and growing*. Cumulative climate induced internal displacement in India between 2008 and 2023 has been estimated at over 56 million people, and in 2024 alone roughly 2.5 million people were displaced in Assam. The lesson inferred therefore is, movement is no longer a consequence or a failure but rather needs to be looked at as *adaptation*. The guiding principle for this pillar is thus, migration should not be treated solely as a failure of adaptation; rather policy should focus on making both staying and moving safer and dignified.

To make stay viable, investments are required at the origin: livelihood diversification, resilient agriculture, local employment, and adaptation finance that reaches households before they are forced to choose between land and life. Attaining dignity at movement, requires deliberate planning at the destination, where receiving cities are able to absorb population

without adequate housing, transport, energy, water, or health infrastructure, and where the absence of planning produces informal settlements.

The instruments are however the same, GIS, census data, climate projections, and migration data used together to anticipate population redistribution and pre-position housing, energy and transport capacity. Institutionally, there exists a requirement to run resilience programmes, and planning for absorption and reduced forced displacement at source.

Policy Pillar III — Climate Energy Planning

The third pillar takes into account the India-Nigeria comparison and converts its analysis into a planning logic. It is based on the understanding that climate change does not merely increase how much energy a society needs; it also changes based on when, where and how energy is consumed. Conventional planning however overlooks this as it is based on the assumption of a static demand. India is at a transition problem: peak electricity demand rose from 148 GW in 2014 to approximately 250 GW in 2024, and the challenge is securing availability and affordability while managing the losers of decarbonisation; coal-dependent districts facing job and revenue losses even as decentralised solar benefits other rural communities.

The analytical finding thus is that "electricity access" alone is an insufficient metric to capture reliability, affordability or spatial redistribution of demand in the purview of climate change.

The policy therefore is based on demand driven energy planning: migration projections, demographic data, and climate projections feed energy demand projections. These in turn determine where distributed renewables, cooling infrastructure, energy efficient housing, and affordability mechanisms are deployed. Decentralised generation; building on programmes such as PM-KUSUM in India and solar-mini grid and off-grid PV microgrid in Nigeria, should be deliberately directed towards marginal farmers and underserved communities rather than large landowners. There is thus a need for the state to set standards and fund infrastructure, obligatory deployment of power by private developers to reach the underserved customers and energy efficient housing systems.

Policy Pillar IV — Technology for Anticipatory Governance

The fourth pillar discovers that technology is empirically capable but institutionally constrained. GIS and remote sensing are the most operationally mature tools available in the Indian context; digital twins and AI are the most promising but least implemented ones. This is so because they are held back by data gaps and by an unresolved gap between planning and implementation. The danger that thus unfolds is that an improvement in the monitoring systems merely increases the surveillance of the problem without actually solving it. This pillar thus focuses on the fact that technology must connect risk identification to resource allocation to institutional response.

In practice this implies the introduction of AI-enabled multi-hazard early warning systems that integrate satellite imagery, remote sensing, GIS, and IoT to improve forecasting, flood warnings, and mobile-based communication. These infer an important shift from reactive disaster management to anticipatory climate adaptation in which warnings automatically trigger district-level resource deployment and evacuation orders rather than waiting for administrative orders.

The Nigerian case demonstrates that even where infrastructure is weakest, spatial technologies can leapfrog conventional data collection: satellite-based nighttime luminosity and population data have already been used to measure electricity access across all 774 Local Government Areas, connecting where vulnerability is occurring with where people are moving and where energy infrastructure is inadequate. Institutionally, this pillar does the same, national early warning infrastructures are built and standardised, integrated into disaster management architecture. Communities are the end users and the monitors.

Policy Pillar V — Equity and AI Governance

The fifth pillar responds to governance risks pointed out in the paper's ethical AI analysis. AI systems carry skewed data, algorithmic bias, privacy violations and outputs that cannot be held accountable in the legal premises. The pillar therefore, mandates algorithmic audits, privacy protection, explainability, bias assessment, and accessibility and digital literacy programmes, so that the communities most affected by AI decisions can understand, use and contest them.

Institutionally, mandatory standards for an AI governance framework seem necessary. Privacy compliance, independent certification mechanism to verify fairness, non-discrimination, audibility, and accountability.

6. CONCLUSION

Climate change, rather than an environmental concern, is now a question of livelihood security and energy access. Vulnerable communities are hardest hit by the growing frequency of climate-related hazards. The approach of dealing should be changed towards an integrated climate adaptation framework. Use of emerging technologies like AI, digital twin, remote sensing, IoT and GIS will strengthen early-warning systems and will help in analysing risk assessment. The effectiveness of new technologies will depend on how they are adjusted into adaptation strategies and climate plans.

New technologies will come with challenges relating to privacy concerns, digital inequality, electricity consumption and water use demand. To combat these problems of technologies, India needs a framework related to these new technologies. Displacement due to climate factors requires a framework combining migration, urban planning, disaster management, energy security and technological governance. The country requires an approach centering around the public to put it in other words, a bottom-up approach rather than top-down approach.

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