Charting uneven progress of sustainability: A multi-dimensional assessment of the SDGs in Northeast India

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Abstract

Sustainable Development Goals (SDGs) are used to assess progress in the fields of the environment, economy, and society. Although assessments conducted at national and international levels are popular, subnational research, especially on India, is less common. Using 84 accessible indicators (2021–2022), a comprehensive study of 15 SDGs was conducted across 103 districts in eight states in the northeastern region (NER) of India. Pearson's correlation, hierarchical clustering, network analysis, input-oriented data envelopment analysis (DEA), inequality (using the Theil and Atkinson indices), and relative SDG scoring were performed using 'R'. Four SDG groupings (environmental, social, economic, and socioeconomic) and individual SDGs at the overall, district, and state levels were analysed. The results showed that the SDGs were asynchronous and had significant inequalities among the NER districts, with SDG 13 showing the highest disparity and SDG 2 the lowest. Many districts performed worse socioeconomically, even when they had higher environmental scores. This study provided the first comprehensive multi-dimensional assessment of SDG progress across Northeast India at the district level, revealing critical disparities and complex interactions between environmental and socioeconomic goals. Finally, limitations in mitigating the drawbacks of the NER SDG framework were discussed, coupled with policy suggestions for environmental, societal, and economic aspects. The findings offered valuable insights for policymakers in designing targeted interventions, promoting balanced development, and addressing regional inequalities to achieve sustainable development in this ecologically sensitive and socioeconomically diverse region.

Keywords: sustainable development goals; clustering; regional inequality; evenness; subnational; India;

Introduction

Sustainability is a complex concept that extends beyond resource management. This requires a careful balance that promotes economic growth, social equality, and environmental preservation for both current and future generations. The United Nations' SDGs, which provide a roadmap for achieving sustainability, tackle global challenges such as poverty, health, education, and climate change through 17 interconnected goals (2015-2030).

The global pursuit of the SDGs faces numerous challenges, including uneven progress across regions, resource constraints, and the complex interplay between economic development and environmental preservation. These challenges are particularly pronounced in developing regions with diverse socio-economic and ecological landscapes. Northeast India exemplifies these complexities, with its rich biodiversity, varied topography, and unique cultural tapestry, presenting both opportunities and obstacles for sustainable development. The region's remoteness, historical underdevelopment, and vulnerability to climate change make it a critical case study for understanding the nuanced challenges of implementing SDGs in ecologically sensitive and economically diverse areas. As such, examining the progress of SDGs in Northeast India not only addresses local development needs, but also contributes to a broader understanding of sustainable development challenges in similar contexts globally.

Nestled amidst the Himalayas, Northeast India boasts a tapestry of eight states: Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, and Tripura. They house 3.77% of India's population and constitute 7.98% of the country's land area. The land is rich in natural resources, ranging from rivers and fertile plains to mineral deposits and bamboo forests. These NER states are bordered by five neighbouring countries: Tibet (north), Bangladesh (southwest), Nepal (west), and Bhutan (northwest).

Achieving the SDGs in Northeast India faces several unique roadblocks. Limited connectivity restricts access to markets, healthcare, and education, thus hindering economic growth and social progress (SDG 1, 8, and 10). Unsustainable practices, such as slash-and-burn agriculture, threaten biodiversity (SDG 13, 15). Shifting cultivation, a traditional practice, is under pressure owing to population growth and deforestation. Job creation and income generation remain challenges, leading to poverty and migration (SDG 1, 8). Ethnic tensions and insurgency movements have hampered development efforts. Empowering women and ensuring inclusive growth for all sections of society remains a work in progress (SDG 5 and 16).

Despite these hurdles, there has been a growing movement towards sustainable solutions. From promoting organic farming and bamboo-based industries to developing

ecotourism and utilising renewable energy, there is a collective will to chart a greener path. By addressing the specific needs of the region and harnessing its unique strengths, Northeast India can unlock its true potential and emerge as a model for sustainable development. This article examines the intricate connection between sustainability in Northeast India and SDGs. This study aims to inform policies, practices, and future research on sustainable development in the region.

Literature review

There have been a handful of studies on the sustainability of northeast India over the last few years. To date, some studies have focused on the SDGs in the Indian context (subnational or national). Mitra (1998) studied the environmental sustainability of Arunachal Pradesh. Chaudhuri and Roy (2017) analysed spatial inequality in WaSH (Water-Sanitation-Hygiene) facilities using 2011 census data. None of the NER states are seriously lacking in rural-urban equality. Bora and Saikia (2018) analysed neonatal mortality rate, NNMR and under-5 mortality rate, U5MR (SDG 3) in Indian districts based on data from the National Family Health Survey (NFHS 2015-16). Most districts of NER India are unlikely to achieve NMR-Male by 2030; however, they are likely to achieve U5MR-Male by 2030. Singh (2018) conducted a study on regional disparities in sustainable development in the NER States of India. Roy & Pramanick (2019) assessed SDG 6 on a national scale, in the context of an ecologically safe and socioeconomically just operating space framework. Chhetri (2020) analysed the SDG for Sikkim. Tiwari and Krishna (2020) analysed the social, economic, and environmental performance of 641 districts of India using a composite sustainability index based on comparatively old data (2011 census). Chaudhary et al. (2022) composed a subnational scale assessment of threats to Indian biodiversity via application of the species threat abatement and restoration (STAR) metric for amphibians, birds, and terrestrial mammals. Arunachal Pradesh, Assam, and Meghalaya are among the top nine states contributing 80% of the national STAR score. Ghosh et al. (2022) have analysed WaSH poverty in India at district level. Drinking water poverty is relatively more prevalent in NER than sanitation and hygiene poverty. Anand et al. (2023) published a few studies on food security, land degradation, gender equality, health, etc., focusing on NER India in their book. Ghosh et al. (2023) have analysed spatial clustering of diarrhoea among children (<5 years) in 707 districts of India. The prevalence of NER is mixed. Roy et al. (2023) have assessed urban sustainability of 56 prominent cities of India using 14 SDGs (from 77 indicators) for 2020–2021. Subramanian et al. (2023) performed an SDG progress assessment of 707 Indian districts

based on 33 indicators (covering nine out of 17 UN-SDGs) sourced from the NFHS (2016, 2021). They concluded that four SDGs (viz., SDG 1-3, 5) require urgent attention. Studies that have focused on the SDG of NER India is very less. When a search was conducted on the Web of Science for original articles published from 01-01-2015 to 30-04-2024 with NER India-related terms (see Supplementary file), only 35 results were found. This proves that even after nine years of the commencement of the UN-SDG proposal and six years to accomplish (2024-2030), very little research has been conducted focusing on this region. This study examines the intricate connection between sustainability in Northeast India and SDGs. Specifically, this study addressed the following research questions (RQs):

RQ 1: What are the achievements and shortfalls in NER districts regarding SDG performance?
RQ 2: What are the interrelationships among NER district features in terms of SDG progress?
RQ 3: How can NER districts be grouped according to their environmental, social, and economic characteristics?
RQ 4: What are the efficiencies in utilising environmental scores (env-SDGs) towards socio-economic achievements (socio-econ-SDGs)?
RQ 5: What is the extent of spatial inequality among NER districts in terms of SDG performance?
RQ 6: How do Evenness and Mean Index Scores reveal disparities and guide equitable SDG progress across the NER districts?
RQ 7: What is the relative performance of NER districts compared with state, national, and global benchmarks?

By addressing these research questions, this study aims to inform policies, practices, and future research on sustainable development in the region, provide a comprehensive assessment of SDG progress in Northeast India, and offer insights for targeted interventions to achieve balanced and sustainable development.

Methodology

The SDG scores (2021-22) of 120 districts (from eight Indian states) in Northeast India were collected from the NITI Aayog (NITI Aayog, 2024). Two SDGs (viz., SDGs 14 and 17) were not included because their overall scoring was not available in the dataset. Owing to the unavailability of data, only 103 districts were considered. The sample of 103 districts represented 85.83% of the total districts in the NER, providing a comprehensive dataset for our analyses. The sample size exceeded the minimum requirements for our statistical methods, thus

ensuring statistically significant results. The 84 indicators included in this study covered various topics related to local sustainability. The dataset used in this study has significant coverage of the official districts of the eight NER states. Share (%) of official districts included in study were Tripura (100%), Meghalaya (91%), Arunachal Pradesh (89%), Assam (77%), Mizoram (72%), Nagaland (68%), Sikkim (66%), and Manipur (56%) (Figure S.1 in the Supplementary File 1). The state-wise distribution of 103 study districts were Assam (26%), Arunachal Pradesh (24%), Meghalaya (10%), Nagaland (11%), Manipur (9%), Tripura (8%), Mizoram (8%), and Sikkim (4%) (Figure S.2).

Pearson's correlation coefficient was selected to investigate the interrelationships between SDGs owing to its capacity to quantify the strength and direction of linear associations between continuous variables, which is appropriate for SDG score data. It addressed our RQ2. Our use of Pearson's correlation aligns with recent SDG studies, such as Pradhan et al. (2017), who employed this technique to analyse synergies and trade-offs between SDGs on a global scale. For the assembly of correlation between various SDG scores for all of the 8 states included in this study, using the 'metan' (v1.18.0) package with 'R' (4.1.5).

To uncover more complex, non-linear relationships and provide a more comprehensive perspective of SDG interactions in NER, network analysis was employed at both the goal and indicator levels. This supplemented RQ2. Our network analysis approach builds on the work of Le Blanc (2015), who used network analysis to map the interactions between SDGs at a global level. This methodology is particularly advantageous in this context, as it facilitates the elucidation of complex, non-linear relationships that might not be discernible through correlation analysis alone, thus providing a more comprehensive perspective of SDG interactions in the Northeast region. 'igraph' (v2.0.3) package in 'R' has been used for this. In this network analysis, absolute correlation values and the Fruchterman-Reingold algorithm (suitable for undirected graphs) were used.

The application of Hierarchical Clustering Analysis (HCA) in this study is particularly valuable, as it enables the identification of patterns and similarities among districts without pre-defining the number of clusters, which is crucial given the heterogeneous nature of NER districts. This clustering approach allows the discovery of groups of districts with similar SDG performance profiles, potentially informing targeted policy interventions and resource allocation strategies tailored to the specific needs and challenges of each cluster. We employed HCA to group districts based on their environmental and socioeconomic SDG features. The application of HCA in our study was similar to the approach used by others (Wang et al. 2020; Wu et al., 2022), who used clustering to group Chinese provinces based on their SDG

performance. It addressed our RQ3. This analytical technique is appropriate for our study because it enables the identification of patterns and similarities among districts without pre-defining the number of clusters, which is crucial given the heterogeneous nature of NER districts. The within-cluster sum of squared (WSS) method was used to find cluster numbers via the silhouette method through the Euclidean distance using a single linkage. The silhouette method determines how well each point fits into its cluster and measures clustering quality. The length of a line segment connecting two locations in Euclidean space is called the Euclidean distance. The 'cluster' (v2.1.6), 'dendextend' (v1.17.1), and 'factoextra' (v1.0.7) packages with 'R' have been used.

We applied Data Envelopment Analysis, specifically an input-oriented DEA with a slack-based model (Tone, 2001) and variable return to scale assumption, to ascertain the relative efficiency of districts in converting environmental SDG inputs into socioeconomic SDG outputs. It addressed our RQ4. The use of DEA in our study is comparable to that of Guo et al. (2024), who employed DEA to evaluate the efficiency of SDGs in Organisation for Economic Co-operation and Development (OECD) countries. This methodology is particularly appropriate for our study, as it facilitates the simultaneous comparison of multiple inputs and outputs, which is essential given the multi-dimensional nature of SDGs. The efficiency of a district can be assessed by comparing three environmental SDG inputs (SDG 6, 13, and 15) and 12 socioeconomic SDG outputs (SDG 1-5, 7-12, 16). Moreover, if lambda sum = 1, DMU is in the CRS subzone; if lambda sum > 1, DMU is in the DRS subzone; and if lambda sum < 1, DMU is in the IRS subzone (Seiford and Zhu, 1999). The number of DMUs should be ≥2 times the sum of the inputs and outputs to achieve a sufficient discriminating power (Banker et al. 1989). Another stipulation is that the number of DMUs ≥ the sum of the input and output variables. There are three input variables and the output variables are twelve in this study, and 103 DMUs meet both criteria, culminating in a model with sufficient discriminating power. For these analyses, the 'deaR' (v1.4.1) package in 'R' was used.

To quantify the geographical variance in SDG performance across NER districts, multiple inequality indices were employed: the Theil, Atkinson, and Gini indices. It addressed our RQ5. Our application of inequality indices aligns with the approach of Chaudhuri and Roy (2017), who employed inequality measures to study spatial disparities in water and sanitation facilities (WaSH; SDG 6). The use of multiple indices provides a more robust assessment of inequality. The Theil index was particularly valuable because of its decomposability property, enabling the examination of inequality both within and between districts. Population-weighted indices could not be calculated because of the unavailability of official annual population data

(2020-2021). For this analysis, the 'REAT' (v3.0.3) package in 'R' was used. Given the existence of many Theil inequality measures, this study employs Stoermann's (2009) formulation. For the Atkinson and Gini indices, the formulations of Portnov and Felsenstein (2010) and Doersam (2004) were used, respectively.

Using the Evenness (EIS) and Mean Index Score (MIS) is essential for gaining a comprehensive understanding of development. MIS provides a clear measure of overall SDG performance, while EIS highlights imbalances across different goals, ensuring that progress is not only effective, but also equitable. Together, these indices guide policymakers in identifying underperforming areas, enabling targeted interventions to achieve holistic and inclusive growth aligned with the SDG 2030 Agenda. It addressed our RQ6. The methodology of the EIS and MIS calculations was derived from recent SDG studies (Liu et al. 2021, 2024; Qi et al. 2024). EIS and MIS were calculated at the individual district, state, and SDG levels. All the calculations have been made using 'dplyr' package (v1.1.4) in 'R'.

To address RQ7, we developed a comparative index for the relative SDG performance of the NER districts. This approach facilitates both intranational and extranational comparisons and provides a comprehensive assessment of how these districts perform relative to their state, national, and global counterparts. This methodology is crucial in our context as it enables the identification of areas where NER is excelling or lagging in SDG progress. The relative performance of any district in the NER on the SDGs was calculated by dividing the score by the score of another district. This ratio can also be multiplied by 100 to convert the performance scale to a %. This procedure was performed for all 103 NER districts.

Because of the nature of the available district SDG dataset (single point, single year) of Northeast India, most of the usual advanced analyses, such as different types of regressions and future projections, could not be applied in this study.

Results

Achievements and shortcomings

The SDGs in 103 NER districts were organised into three categories based on the 'wedding cake' framework (Folke et al. 2016). The first category comprised econ-SDGs (8-10 and 12) embedded within soc-SDGs (1-5, 7, 11, and 16). The second category depends on env-SDGs (6, 13, and 15).

The most environmentally prosperous districts in NER (e.g. Karimganj, W-Jaintia Hills [here, W = West], E-Garo Hills [here, E= East], Mamits, and Chirang) have led to the

implementation of environmental sustainability measures, including effective waste management, conservation efforts, and climate action initiatives. Conversely, the worst performing districts were Barpeta, Mon, SW-Garo Hills [SW = Southwest], Darrang, and Tawang. Among the NER districts, 50.5% (n = 52) were below the regional (district) average (70.14). The achievement gap (28.3) between the best (82.6, Karimganj of Assam) and worst (54.3, Barpeta of Assam) performing districts in the env-SDGs suggests that, while some districts have made significant progress, others are significantly lagging behind. Only 22% (n=23) of the NER districts performed below the Indian national (state-level) average (66.03) on the env-SDGs. This suggests that most NER districts are performing at or above the national average in terms of environmental sustainability.

Socially best-performing districts in NER (e.g. Champhai, E-Sikkim, Aizawl, Serchhip, and W-Tripura) have excelled in achieving social equity, quality education, and good health and wellbeing. However, districts with the poorest social performance (e.g. N-Garo Hills [here, N=North], S-Garo Hills [here, S=South], W-Jaintia Hills, Tuensang, and E-Garo Hills) may face challenges, such as a lack of resources, infrastructure, or awareness that hinders their social development efforts. Nearly half (49.5%, n=51) of the NER districts were below the regional (district) average (64.05). The difference (26.12) in soc-SDG performance between the top- (75.87, Champhai in Mizoram) and the lowest-performing districts (49.75, N-Garo Hills in Meghalaya) suggests that while some districts have made significant progress, others are significantly lagging behind. 61% (n=63) of the NER districts performed below the Indian national (state-level) average (66.35) in the soc-SDGs. This suggests that a significant number of NER districts need to improve their social development efforts to match the national average.

The most economically prosperous NER districts were Unakoti, Gomati, S-Tripura, W-Tripura, and N-Tripura. On the other hand, the economically weakest districts were Shi Yomi, Zunheboto, Kiphire, Leparada, and Kamle. 43% (n=45) of the NER districts performed below the regional (district) average (67.84), suggesting uneven progress within the region. The disparity between the best (86.25, Unakoti of Tripura) and worst (39.5, Shi Yomi of Arunachal Pradesh) performing districts in the econ-SDGs was 46.75. Only 29% (n=30) of the NER districts scored below the Indian national (state-level) average (62.34).

The most affluent districts, as indicated by the composite SDG, (e.g. E-Sikkim, Gomati, N-Tripura, W-Tripura, and Serchhip) have excelled in achieving balanced development across all SDGs. Conversely, the districts with the poorest composite SDG performance are Kiphire, Zunheboto, Kra Daadi, Tuensang, and Mon. The achievement gap between the top-performing district (75.87, E-Sikkim in Sikkim) and the lowest-performing district (53, Kiphire in

Nagaland) was 22.87. 45% (n=47) of the NER districts performed below the regional (district) average (66.28) in the composite SDG. The order of districts with lower performance across the individual SDGs was as follows: SDG 13 > 7 > 4 > 8 > 9 > 3 > 6 > 11 > 16 > 10 > 12 > 15 > 5 > 1 > 2. This suggests that the greatest disparities exist in SDG 13 (Climate Action), and the least in SDG 2 (Zero Hunger). The disparity between the top and bottom performing districts in the individual SDGs was as follows: SDG 7>13>12>11>10>9>15>5>1>16>6>4>2>3>8> composite SDG. This indicates that the disparities are more pronounced in specific SDGs than in overall development.

The relationship between societal and economic development is well-established and can be combined to achieve socioeconomic development. In the NER districts, W-Tripura, Gomati, S-Tripura, E-Sikkim, and N-Tripura are among the most socioeconomically prosperous. On the other hand, Zunheboto, Kiphire, Shi Yomi, Tuensang, and Kamle are the worst performing districts in terms of socioecon-SDGs. 53% (n=55) of NER districts performed below the regional (district) average (65.94) of the socioecon-SDGs. The performance gap between the best (79.37, W-Tripura) and worst performing districts (49.87, Zunheboto) in the socioecon-SDGs was 29.5. Only 35.9% (n=37) of the NER districts performed lower than the Indian national (state-level) average (64.34).

Based on the overall scores (Figure. 1), Tripura, Sikkim, and Mizoram were the top performing states, whereas Meghalaya, Arunachal Pradesh, and Nagaland had the lowest performances. In terms of env-SDGs, Tripura outperformed Mizoram and Sikkim, which in turn surpassed Assam, Meghalaya, the average of the NER states, Arunachal Pradesh, Nagaland, and Manipur. In terms of soc-SDGs, Sikkim, Mizoram, Tripura, Manipur, Arunachal Pradesh, the average of the NER states, Assam, Nagaland, and Meghalaya were ranked accordingly. For the econ-SDGs, Tripura, Sikkim, Assam, Meghalaya, the average of the NER states, Manipur, Mizoram, Arunachal Pradesh, and Nagaland were ranked in that order. Lastly, in terms of socioecon-SDGs, Tripura, Sikkim, Mizoram, Assam, Manipur, the average of the NER states, Meghalaya, Arunachal Pradesh, and Nagaland were ranked in that order.

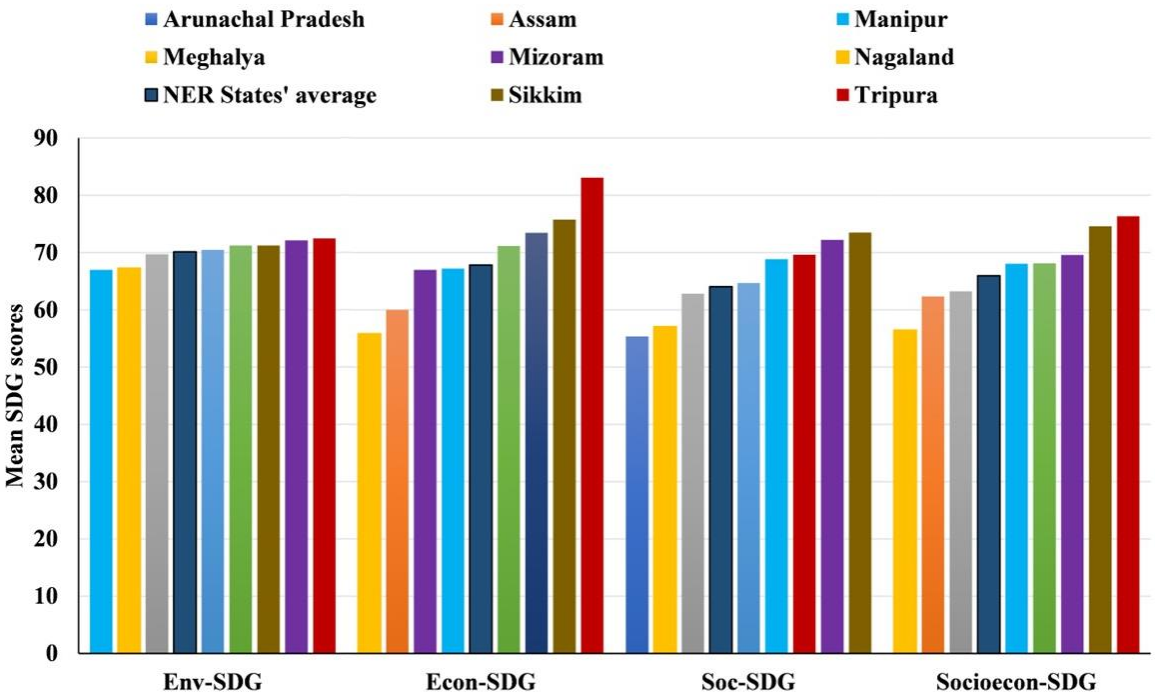

Figure 1. Achieving four types of SDGs for 103 districts (aggregated into 8 respective states) of Northeast India. The SDG groups are environmental (Env-SDG), economic (Econ-SDG), social (Soc-SDG), and Socioeconomic SDGs (Socioecon-SDG).

When considering the proportion of underperforming districts compared with the average performance for each state, the order of environmental underachievement was as follows: Meghalaya> Mizoram> Tripura> Assam> Arunachal Pradesh> Manipur> Nagaland> Sikkim. The order of societal underachievement was Tripura, Nagaland, Assam, Meghalaya, Arunachal Pradesh, Sikkim, Manipur, and Mizoram. The order of economic underachievement was Meghalaya, Manipur, Nagaland, Tripura, Arunachal Pradesh, Mizoram, Assam, and Sikkim. The order of socioeconomic underachievement is Manipur> Nagaland> Arunachal Pradesh> Tripura> Mizoram> Assam> Meghalaya> Sikkim. The order of overall underachievement was Manipur, Meghalaya, Tripura, Mizoram, Nagaland, Assam, Arunachal Pradesh, and Sikkim. Descriptive statistics based on individual SDGs and indicator data were also calculated (Tables S1 and S2, respectively, Supplementary File 1).

Interrelationships

The interrelationships between individuals and SDG groups were inferred using Pearson's correlation. After analysing the individual SDG scores of the NER districts (Figure.

2a), a strong positive correlation (0.7) was observed between SDG 1 and 8. This finding suggests that economic growth is accompanied by a reduction in poverty. Similarly, a strong positive correlation (0.63) exists between SDG 3 and 4, indicating that improved education levels are associated with better health outcomes in the region. Additionally, SDG 6 and 7 exhibited a strong positive correlation (0.61), suggesting that access to clean water and sanitation goes hand in hand with access to affordable and clean energy. Several SDGs exhibit moderate positive correlations, indicating that improvements in one area tend to accompany improvements in another. These include: SDG 1 and 10 (0.57), SDG 3 and 5 (0.57), SDG 4 and 5 (0.56), SDG 11 and 6 (0.51), and SDG 11 and 7 (0.5). Weaker positive correlations were found between other SDGs, indicating a weaker relationship between improvements in one SDG and the other. These include: SDG 1 and 13 (0.35), SDG 2 and 3 (0.28), and SDG 9 and 10 (0.23). Furthermore, a weak negative correlation was observed between SDG 13 and 8 (-0.12), suggesting that economic growth in NER may occur at the expense of environmental degradation. Pearson's correlation for individual SDG performance in NER districts grouped by state (Figure. S.3) was also analysed.

The analysis of the grouped SDG scores for the NER districts (Figure. 2b) showed that the strongest positive correlation (0.87) existed between the socioecon-SDGs and econ-SDGs. This indicates that economic development is strongly linked to improvements in social indicators, such as education, health, and gender equality. A strong positive correlation (0.7) was observed between env- and soc-SDGs. This suggests that environmental well-being goes hand in hand with social progress in the region. Districts that perform well in terms of environmental sustainability also tend to score better on social indicators. A moderate positive correlation (0.63) was observed between the socioecon-SDGs and the composite SDG. This suggests that progress in socioeconomic goals contributes significantly to the overall SDG achievement in the region. There was a moderate positive correlation (0.59) between econ- and composite SDG. The env-SDGs had a moderate positive correlation (0.51) with the composite SDG. There was a weak positive correlation (0.31) between soc-econ and env-SDGs. This finding suggests a less clear link between socioeconomic development and environmental well-being in this region. No negative correlations were observed between the SDG groups. Pearson's correlation of the grouped SDG performance of NER districts grouped by state (Figure. S.4) was also analysed.

Pearson's correlation of indicator level data for NER districts (after removing the data gaps) have been composed. An analysis of the 13 indicators of the env-SDGs in the NER districts (Figure. S.5) showed that the strongest positive correlation (0.72) existed between

forest cover (%) and change in forest cover. This suggests that districts with a higher % of forest cover experienced an increase in forest cover, indicating successful afforestation in these regions. A positive correlation (0.57) was observed between the % of area under forest cover and number of forest fires. Although this may seem counterintuitive, it could be due to several reasons, such as districts with larger forest cover having more forest areas and some forest fires being controlled for forest management purposes. A moderate positive correlation (0.55) was found between the % of forest cover and stage of forest growth, indicating that districts with a higher % of forest cover also had forests in a more mature stage of growth. A moderate positive correlation (0.5) was observed between the % of area under forest cover and availability of toilets with toilet facilities. However, a weak positive correlation (0.18) existed between forest cover and the % of households using LPG as cooking fuel, suggesting a weak link between forest conservation efforts and the adoption of clean cooking fuels in the region. A negative correlation (-0.57) was observed between the % of forest cover and the stage of forest degradation, which is a positive finding as it indicates that districts with a higher % of forest cover tend to have lower levels of forest degradation. Finally, a weak negative correlation (-0.21) was found between the % area under forest cover and the availability of clean cooking fuel.

After analysing 55 indicators of soc-SDGs in the NER districts (Figure. S.6), a strong negative correlation (-0.71) was observed between the head count ratio, as per the multi-dimensional poverty index (MPI), and the number of hospital beds empanelled under PMJAY (per 10,000 eligible population). This indicates that, as the poverty index decreases, the number of hospital beds increases, which is a positive outcome. Additionally, a positive correlation (0.29) was observed between hospital beds empaneled under PMJAY and the % of affordable houses completed against sanctions (rural and urban) under PMJAY. This finding suggests that areas with more hospital beds tended to have a higher % of affordable housing. Finally, a strong negative correlation (-0.78) was observed between beneficiaries covered under the National Food Security Act (NFSA) (%) and hospital beds empanelled under the PMJAY. This suggests that areas with more hospital beds tend to have fewer beneficiaries covered under the NFSA.

Analysis of the 16 econ-SDG indicators in the NER districts (Figure. S.7) shows that the strongest positive correlation (0.74) exists between the surface area, presumably of roads, and the % of workers engaged in agriculture. This suggests that districts with a higher % of agricultural workers tend to have more developed road networks. This could be due to the fact that agriculture often relies on efficient transportation to bring its products to market. A strong positive correlation (0.7) was found between the number of informal micro-, small-, and

medium-sized enterprises (MSMEs) and the % of workers in the primary sector. While this may seem counterintuitive at first, it could be because many rural areas with a high number of primary-sector workers also have a significant number of small informal businesses that cater to the needs of the local population. A moderate positive correlation (0.56) was observed between the surface area and annual rainfall, indicating that areas with higher rainfall may prioritise the construction of roads owing to transportation challenges during monsoons. A moderate positive correlation (0.53) was found between the number of informal MSMEs and Gross State Domestic Product (GSDP) per capita, suggesting that districts with a higher number of informal businesses tend to have a higher GDP per capita, potentially reflecting greater economic activity. Additionally, a moderately positive correlation (0.52) is observed between the % of agricultural workers and the % of households with bank accounts. This could be due to various reasons, including government initiatives that promote financial inclusion in rural areas. However, a weak positive correlation (0.22) was found between annual rainfall and the GSDP per capita, and a weak positive correlation (0.19) was observed between the % of workers in agriculture and the per capita availability of power. Pearson's correlation for each individual SDGs at the indicator level for the NER districts was also calculated (Figure. S.8-9).

Networks

Network analysis of individual SDGs and composite SDG (n=16) (Figure. S.10), with the highest degree (5), the composite SDG appeared to be the most connected in the network, suggesting its relevance as an overall measure of sustainable development in the region. SDG 1 and 4 both had a degree of 3, indicating significant connectivity within the network. SDGs 3, 9, 13, 6, and 2 have a moderate degree of 2, suggesting some level of interconnectedness. SDGs 8, 7, and 16, with a degree of 1, appear to be the least connected in the network. Some of the strongest positive correlations are found between Composite SDG and 1 (0.804), Composite SDG and 9 (0.704), SDG 4 & 6 (0.632). Some of the strongest negative correlations were found between SDG 13 and 2 (-0.542) and SDG 13 and 6 (-0.592). This suggests potential trade-offs between climate initiatives and goals related to food security and water management in the region. SDG 1 shows strong positive correlations with the composite SDG (0.804), 9 (0.579), and 3 (0.577). This suggests that poverty reduction is central to sustainable development in the northeastern states. SDG 4 demonstrates positive correlations with SDG 6 (0.632), 2 (0.565), and 8 (0.501). This highlights the potential role of SDG 4 as a catalyst for progress in other areas, particularly in water and sanitation (SDG 6) and economic growth

(SDG 8). The low connectivity of SDGs 7, 8, and 16 may indicate areas that require more integrated approaches.

Network analysis of individual SDG indicators (n=84; Figure. 2c), most indicators in the top tier (degree ≥ 60) were social. This suggests that social factors play a crucial role in the sustainable development of the NER districts. The highest-degree indicator (80) is related to education: "Percentage of trained teachers at the secondary level (Class 9-10)". Women's empowerment features prominently, with "Exclusive women SHGs in bank-linked SHGs" having the second-highest degree (74). Food security and agriculture are also significant, as evidenced by "Productivity of fruits and vegetables (kg/ha)" (degree 70) and "Percentage of Fair Price Shops (FPS) covered under online transaction system for PDS in the district" (degree 66). Economic indicators generally have lower degrees than social indicators do. The highest-ranking economic indicators (degree 64) are related to employment and micro-, small-, and medium-sized enterprises (MSMEs). Environmental indicators appear less frequently, and typically have lower degrees. The highest-ranking environmental indicator is "Forest cover as a percentage of the total geographical area" (degree 52). Indicators with the lowest degrees (2-4) include a mix of social, economic, and environmental factors. Notably, some critical indicators, such as "Infant Mortality Rate" and "Sex ratio at birth" had very low degrees (2 and 4, respectively). Health-related indicators formed a significant cluster of varying degrees (14-58). Education-related indicators also featured prominently, with degrees ranging from 18 to 80. Gender-related indicators appear across various SDGs, highlighting the crosscutting nature of gender issues. Indicators related to infrastructure and technology (e.g. Internet connectivity and mobile network coverage) had moderate degrees (38-52), suggesting their growing importance in sustainable development.

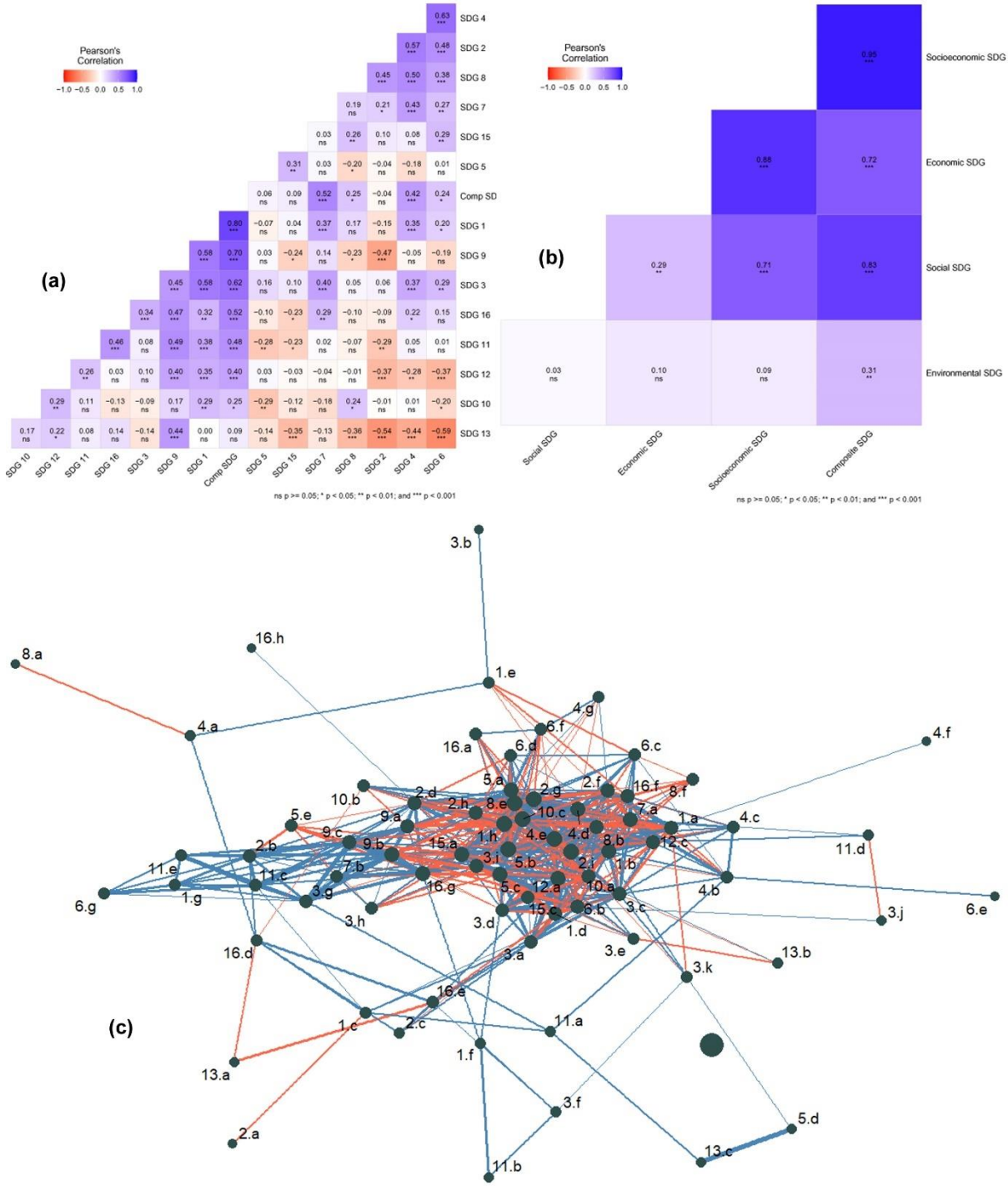

Figure 2. Interrelationships among SDGs for NER districts in India. (a) Pearson's correlation of individual SDGs; (b) Pearson's correlation of composite, env-, soc-, econ-, and socioecon-SDGs; (c) Network analysis of SDG indicators (n=84). Node points were shown in dark slate grey, and edges were shown in steel blue & tomato colour.

Clusters

Hierarchical clustering analysis (HCA) was used for the two sets of data. First, the econ- and soc-SDGs were used as outputs, whereas the env-SDGs were used as inputs (Figure. S.11). Second, a similar methodology was applied, with the individual SDG scores of the env-SDGs serving as inputs and those of the econ- and soc-SDGs serving as outputs (Figure. 3). The author concluded that the five clusters were ideal in both situations via an analysis of optimal clusters. Here, as we moved up the ladder, the scores improved on both sides. As per the env-SDGs, the five clusters were composed of two (blue), 11 (red), 51 (green), 24 (orange), and 15 (violet) districts. This means that, from the perspective of env-SDGs, NER districts fall into various categories with varying numbers of members. The five clusters on the right side are composed of 14 (blue), 10 (red), 57 (green), 6 (orange), and 16 (violet) districts. This also shows that socio-economically, NER districts fall into various categories with varying numbers of members. When individual SDGs are considered rather than the average grouping scores (i.e. the second HCA), a similar situation is observed in the second technique. These results indicate three types of occurrences. For only a few of them, an almost equal status is achieved for env-SDGs, soc-, and econ-SDGs. This means that districts such as Dibrugarh and Phek showed similar performance on both sides. For the remaining districts which are the most numerous, two types can be seen. Those with higher env-SDG performance did not reflect better performance in the econ- and soc-SDGs. These districts are Nalbari, Udalguri, Leparada, Zunheboto, Kiphire etc. Conversely, districts with better performance in the econ- and soc-SDGs did not reflect their env-SDGs. These districts are Kohima, Dimapur, Serchhip, W-Khasi Hills, SW Khasi Hills, and others. These findings suggest that improved performance in the econ- and soc-SDGs in NER districts is not always correlated with improved performance in env-SDGs. Similarly, districts that performed better in the econ- and soc-SDGs may not have attained the same level of success in the env-SDGs. A similar picture emerged for the other HCA, where individual SDGs were considered.

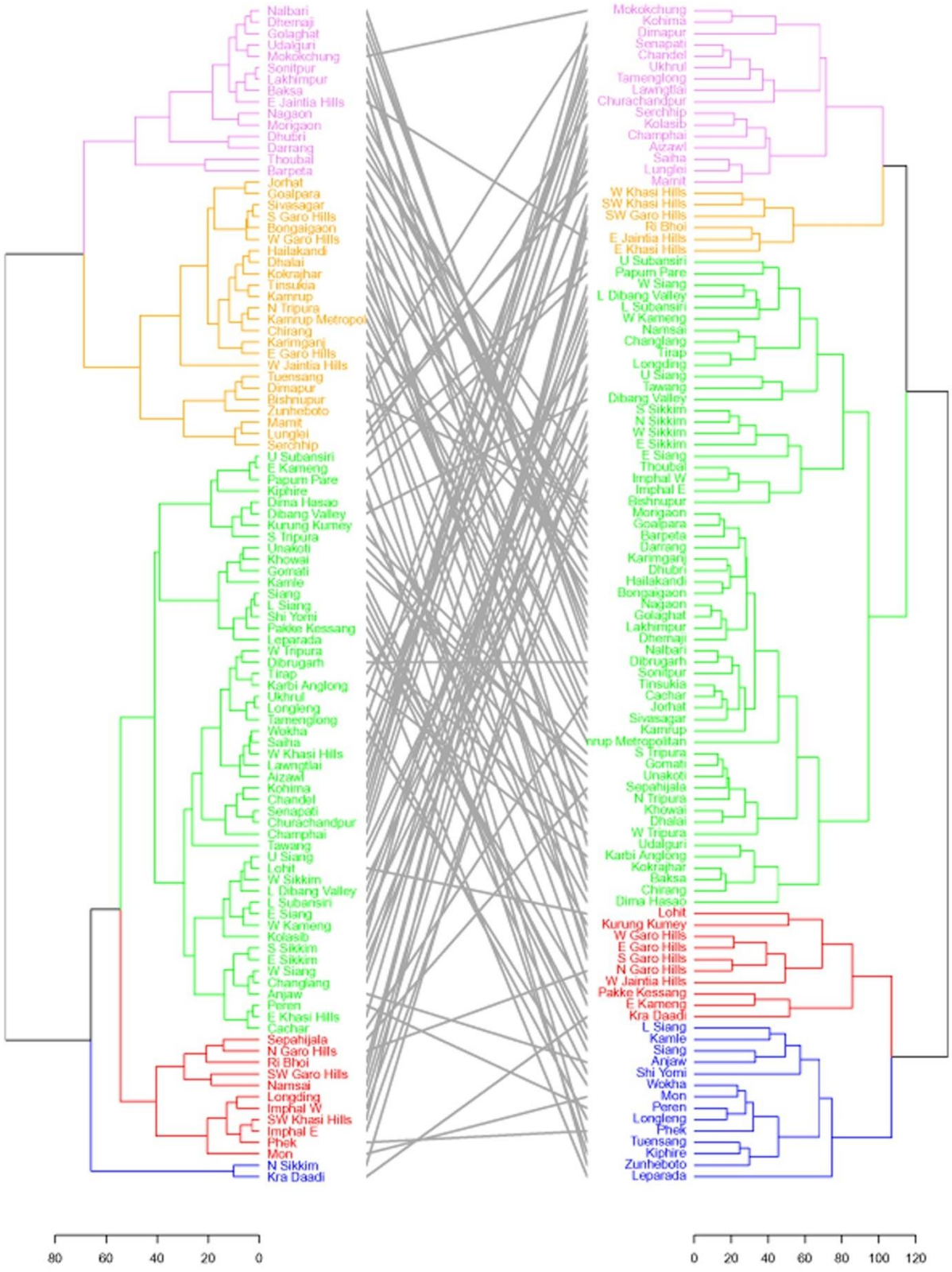

Figure 3. Bundling among SDGs for NER districts in India. Hierarchical clustering analysis, using individual SDG scores of SDG 6, 13 and 15 (left) and SDG 1–5, 7–12, and 16 (right).

Efficiency

Next, data envelopment analysis (DEA) is used to evaluate the efficiency of the 103 NER districts (Figure. 4). This technique for measuring performance was employed to evaluate the comparative effectiveness of decision-making units (DMUs). The goal of this investigation was to determine how well NER districts translate improved environmental characteristics into socioeconomic opportunities.

There were 26 non-efficient districts (25.24%) in the NER (See Supplementary File 2). The distribution of non-efficient districts for each NER state was 12% (Arunachal Pradesh), 40% (Assam), 11% (Manipur), 27% (Meghalaya), 12% (Mizoram), and 63% (Nagaland). None of the districts in Sikkim and Tripura were inefficient.

To create improvement targets, a set of indicator values for comparable districts was combined in a linear fashion. Improvement objectives indicate the changes that need to be made to increase the efficiency of inefficient DMU's. Since reference districts are seen to adhere to best practices, inefficient districts should make every effort to model their subsequent actions. Only a handful (n = 18; 17.47%) of the NER districts acted as peers ≥ 3 times. Top ten them, along with the times of appearance as references, were Tawang and N-Sikkim (14, both), Barpeta (13), W- and S-Tripura (11, both), SW-Garo Hills and Morigaon (8, both), Papum Pare (5), Namsai (5), and Mon (5).

DEA divides effective DMUs into three separate zones based on the returns to scale (RTS) concept. DMUs can raise their outputs (in this case, soc- and econ-SDGs) at a faster pace than their inputs (in this case, env-SDG) in the increasing returns to scale (IRS) zone; that is, a greater increase in socioecon-SDG can be achieved with a relatively smaller increase in env-SDG. The input: output ratio (in this case, the env-SDG/soc- and econ-SDG ratio) of DMUs is continuously maintained in a constant return to scale (CRS) zone. Greater reductions in DMUs' inputs (here, the env-SDG) occur with somewhat smaller shrinkages in their outputs (here, the soc- & econ-SDGs) in the decreasing returns to scale (DRS) zone. Only five districts (4.85%) belong to the IRS subzone. These districts are Karimganj (Assam), Baksa (Assam), Tamenglong (Manipur), Ri Bhoi (Meghalaya), and Dimapur (Nagaland). Only six districts (5.82%) belong to the DRS subzone. These districts are Kamle (Arunachal Pradesh), Kokrajhar (Assam), Golaghat (Assam), Cachar (Assam), Lawngtlai (Mizoram), and Peren (Nagaland). All the remaining districts (n=92 or 89.32%) belonged to the CRS subzone.

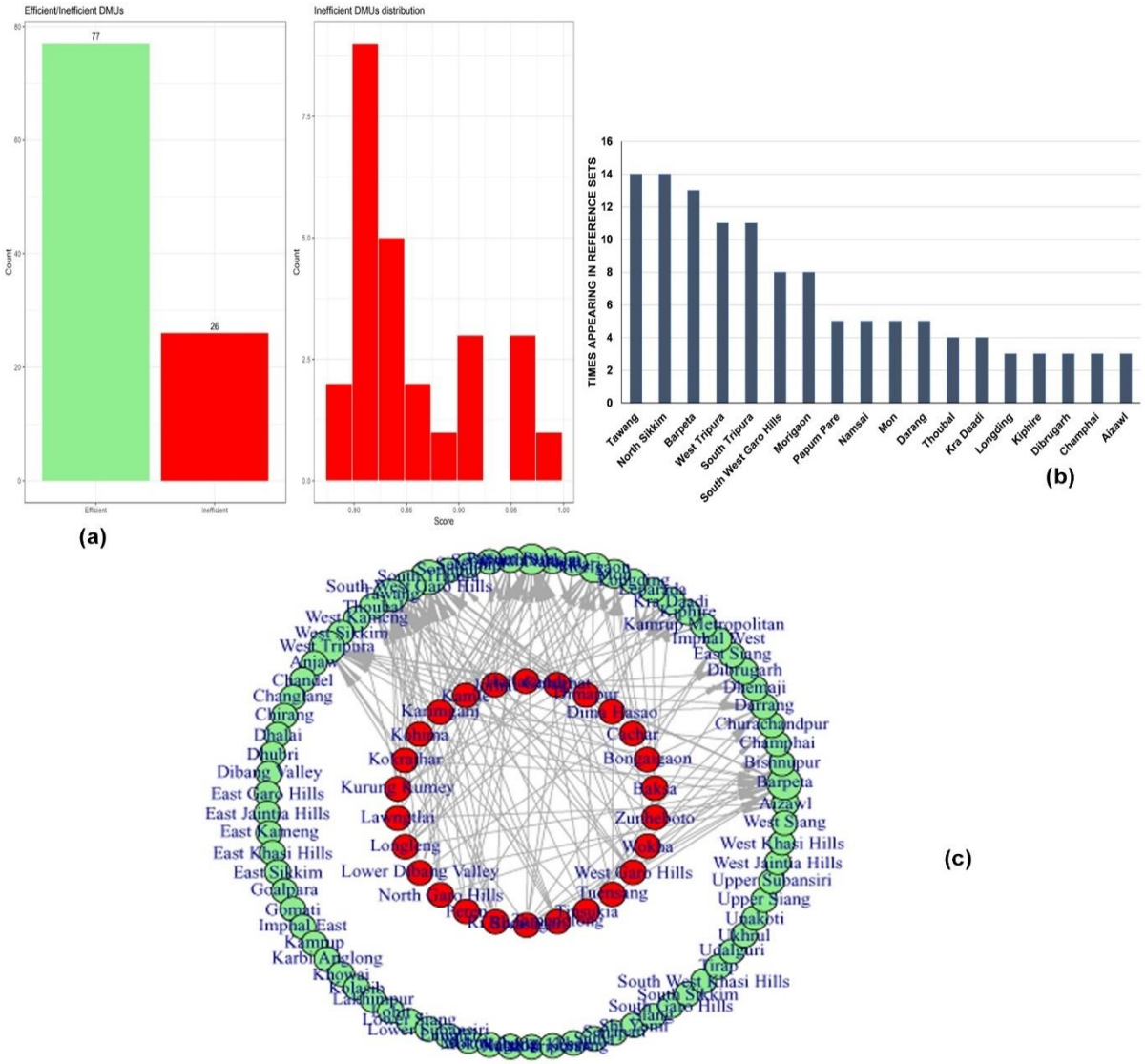

Figure 4. The efficiency of converting environmental SDGs into socioeconomic SDGs for NER districts in India. (a) Grouping of efficient and non-efficient DMUs (NER districts, n = 103); and Distribution of efficiency score for non-efficient DMUs (n=26 NER districts). (b) Ranking of efficient DMUs (NER districts) acting as peers (≥ 2 times) in reference sets, (c) non-efficient DMUs (26 NER districts, red, inner circle) and their respective reference efficient DMUs (77 NER districts, green, outer circle).

Inequality

A high inequality index indicates significant inequality in how different districts within the NER are progressing towards the SDGs. This means that some districts are far ahead of others, creating an uneven development landscape. The findings from the individual SDGs (Figure. 5a) of all NER districts (from the Theil index) indicate that the order of inequality is

SDG 13 > 7 > 9 > 11 > 12 > 10 > 5 > 1 > 4 > 2 > 15 > 6 > 3 > 16 > 8 > composite SDG. SDG 13, 7, 9, and 11 showed the most significant inequalities among districts. This suggests uneven progress in tackling climate change, energy access, infrastructure development, and sustainable urbanisation across the NER. SDG 13 (0.095663) had the highest Theil index among all SDGs. NER is rich in biodiversity and is ecologically sensitive. Uneven progress in climate-change mitigation and adaptation strategies across districts could explain this high inequality. The range of inequality in SDG 11 (range: 0.063253–0.155033) is significant. This suggests that urban areas in some districts might be much farther ahead in terms of sustainable development than others. There is considerable variation in the Theil index across districts for SDG 7 (range: 0.008896–0.020231). This could be due to factors such as differing levels of access to renewable energy sources or hydropower potentials.

SDGs 1, 4, and 2 showed a lower degree of inequality. This might indicate a more balanced effort across the districts in these areas. However, this does not necessarily mean that all districts are doing well, just that the gaps are smaller. The range of Theil index values in SDG 1 (range: 0.001465–0.026989) was relatively low compared with other SDGs. This might indicate a more even distribution of progress in poverty reduction across districts, possibly due to government initiatives or the region's agricultural potential. The NER is generally well-watered. This low range of Theil index values in SDG 6 (range: 0.006706–0.012716) suggests more equitable access to clean water and sanitation facilities across most districts.

In terms of grouped SDGs (Figure. 5b), the degree of inequality was in the order econ-SDG > soc-SDG > socioecon-SDG > env-SDG. Districts in the NER appear to have the most significant inequality in achieving the socioecon-SDG (0.004934). This could indicate a gap between progress in social development goals such as poverty reduction or education (SDG 1 and 4), and economic development goals such as decent work and industry (SDG 8). The Theil index for env-SDGs (0.003582) was lower than that for socioecon-SDGs, but higher than that for soc-SDGs (0.005206). This suggests moderate inequality in environmental progress across districts. There might be variations in how districts address climate change (SDG 13) or protect biodiversity (SDG 15). The Soc-SDGs (0.005206) appear to have a slightly lower level of inequality than the env-SDGs. This suggests that districts might be making more even progress on social development goals, such as poverty reduction, health (SDG 3), and gender equality (SDG 5). This suggests uneven economic development across districts, which could be linked to factors, such as access to markets, resources, and infrastructure. However, env-SDGs, which include goals such as Climate Action and Life on Land, show the least disparity, suggesting a more uniform response to environmental challenges across the districts.

When examining the disparities among individual SDGs at the intra-state level, it is evident that SDGs 13 and 15 in Arunachal Pradesh, SDGs 13 and 3 in Assam, SDGs 10 and 4 in Manipur, SDGs 11 and 8 in Meghalaya, SDGs 13 and 16 in Mizoram and Nagaland (both), SDGs 13 and 12 in Sikkim, and SDGs 13 and 11 in Tripura exhibited the highest and lowest inequalities, respectively. Arunachal Pradesh, Meghalaya, Mizoram, and Nagaland had Theil indices higher than the average for soc-SDGs. NER generally performed well on some social indicators, such as literacy rates. The high social inequality index in these states could be due to uneven progress across different social goals (health, education, and gender equality) or disparities between rural and urban areas. Assam, Sikkim and Tripura have a lower Theil index for socioecon-SDG compared to the average. This might indicate more balanced progress between social development (such as poverty reduction) and economic development (such as decent work) in these districts. Assam has historically faced insurgency challenges, so its lower socioeconomic inequality could be due to recent targeted initiatives.

Nonetheless, regarding the disparity in the SDGs grouped together, it is evident that the env-SDGs display the greatest disparity in Assam, Meghalaya, Mizoram, Sikkim, and Tripura. Conversely, the econ-SDGs exhibited the highest disparity in Arunachal Pradesh, Manipur, and Nagaland. The Atkinson and Gini indices for the individual and group SDGs were also calculated (Figure. S.12-13).

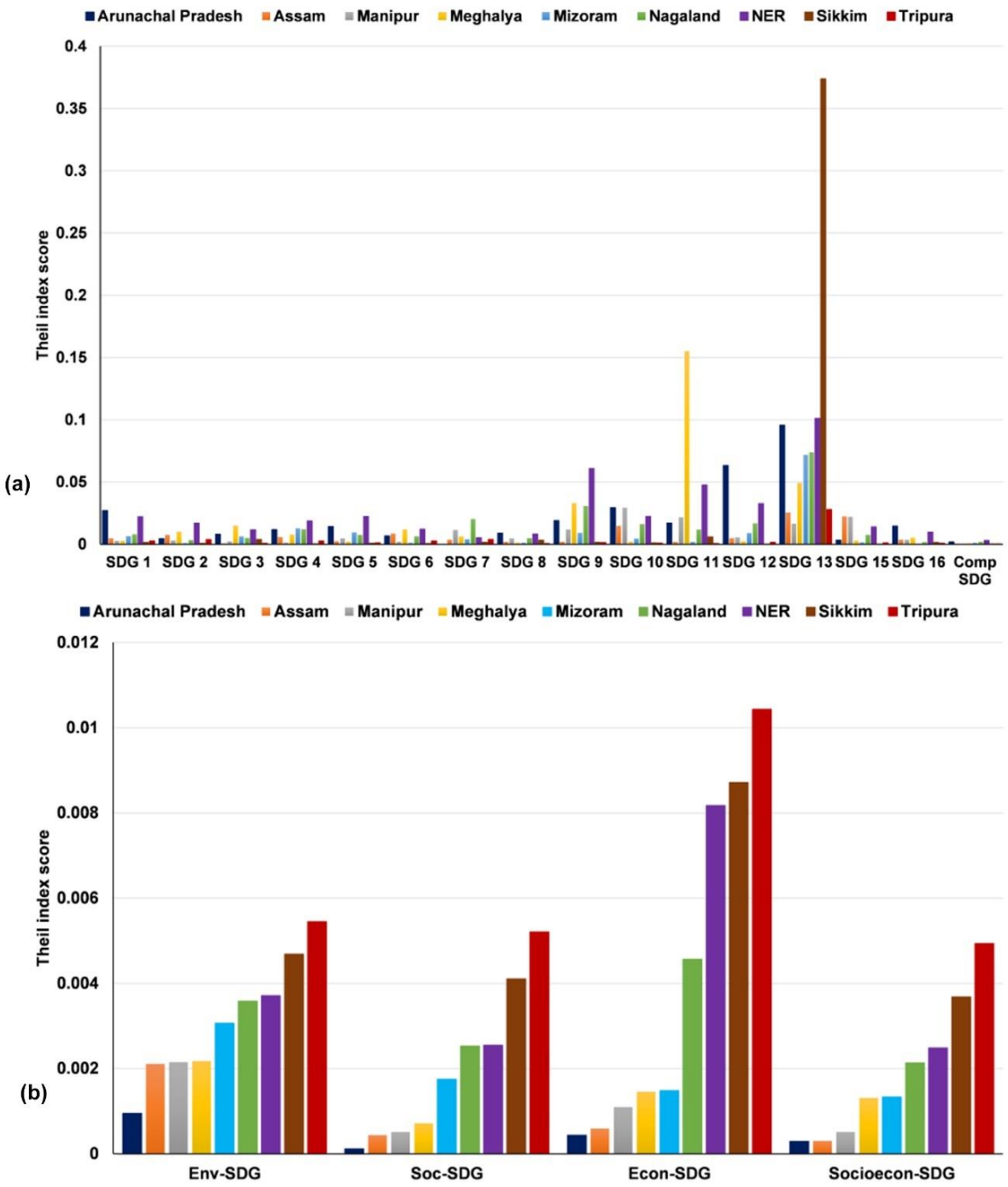

Figure 5. Distribution of scores of inequality analysis based on Theil index. Inequality in (a) individual and (b) grouped SDG score among NER districts of India.

Evenness

From the analysis of EIS and MIS at NER state level (Figure 6a), the EIS range from 58.78 in Nagaland to 73.77 in Tripura, indicating significant disparities in SDG achievement. The increasing order of EIS was: Nagaland < Meghalaya < Arunachal Pradesh < Assam <

Manipur < Mizoram < Sikkim < Tripura. This suggests that, while some states perform well in equitable resource distribution, others, particularly Nagaland, show less balance. Tripura and Mizoram have the highest EIS (73.77 and 70.79, respectively), indicating a more equitable distribution of resources. Tripura also had the highest MIS (78.23), reflecting both evenness and overall performance in the SDG metrics. Assam, Manipur, and Arunachal Pradesh exhibit moderate EIS (67.33 to 68.04), suggesting reasonable equity in SDG achievements, although they do not reach the higher benchmarks of Tripura and Mizoram. Nagaland and Meghalaya were the lower performers, with Nagaland scoring 58.78, indicating significant imbalances in SDG achievements. A lower MIS suggests challenges in meeting the SDGs effectively. The increasing order of MIS was: Arunachal Pradesh < Sikkim < Meghalaya < Nagaland < Assam < Manipur < Mizoram <Tripura. These findings highlight the need for targeted policy interventions in states like Nagaland and Meghalaya to improve equity and the overall SDG performance. Successful strategies by Tripura and Mizoram could serve as models for enhancing development outcomes in other states.

From the analysis of EIS and MIS at individual SDG levels (Figure 6b), SDG 15 had the highest MIS (86.18) and commendable EIS (66.07), indicating effective environmental sustainability. The increasing order of EIS for SDGs was: 13 < 3 < 1 < 4 < 2 < 11 < 10 < 9 < 16 < 12 < 8 < 7 < 5 < 6 < 15. SDG 5 and 6 also show high MIS (73.30 and 73.35%, respectively) but exhibit some disparities in resource distribution, as reflected in their EIS (64.18 and 67.12%, respectively). SDG 1 and 3 have a lower MIS (56.95 and 56.39) and indicate significant challenges in addressing these issues, necessitating targeted interventions. SDG 7 had the lowest EIS (51.11), whereas SDG 13 showed the lowest MIS (50.89) and EIS (46.71), highlighting the critical challenges in these areas. The increasing order of MIS for SDGs was: 13 < 7 < 12 < 11 < 10 < 1 < 9 < 16 < 5 < 3 < 4 < 2 < 15 < 6 < 8. Overall, although certain SDGs have been successful, significant disparities and challenges remain, particularly in poverty alleviation, health, clean energy, and climate action. The

From the analysis of EIS and MIS at the NER district level, Tripura and Sikkim showed strong MIS, with Tripura's districts scoring between 71.93 and 75.73, and Sikkim ranging from 71.87 to 75.87. The top five NER districts with the highest MIS were E-Sikkim, N-Tripura, Gomati, W-Tripura, and Serchhip. The NER districts with lowest MIS were Kiphire, Zunheboto, Kra Daadi, Tuensang, and Mon. Notably, Tripura's districts, such as Dhalai and Gomati, have an EIS exceeding 81, indicating an equitable resource distribution. Mizoram also performed well, with MIS values of 63.4 to 74.87. Lunglei stands out with an EIS of 85.9, reflecting a balanced approach to achieving the SDGs. Nagaland faces significant challenges,

particularly in districts like Kiphire (MIS of 53) and Zunheboto (EIS of 54.53), highlighting the need for targeted interventions. Arunachal Pradesh and Assam exhibited variability in performance, with some districts performing well, while others, such as Kra Daadi (MIS of 55.6), lagged significantly. This indicates a disparity in SDG achievements. The top five NER districts with the highest EIS were Lunglei, Mokokchung, Dhalai, Serchhip, and Gomati. The NER districts with lowest EIS were E-Kameng, Kra Daadi, Kiphire, Shi Yomi, and Pakke Kessang. Overall, while Tripura, Sikkim, and Mizoram demonstrate notable success in SDG achievement, Nagaland and certain districts in Arunachal Pradesh and Assam require focused efforts to improve performance and equity in resource distribution.

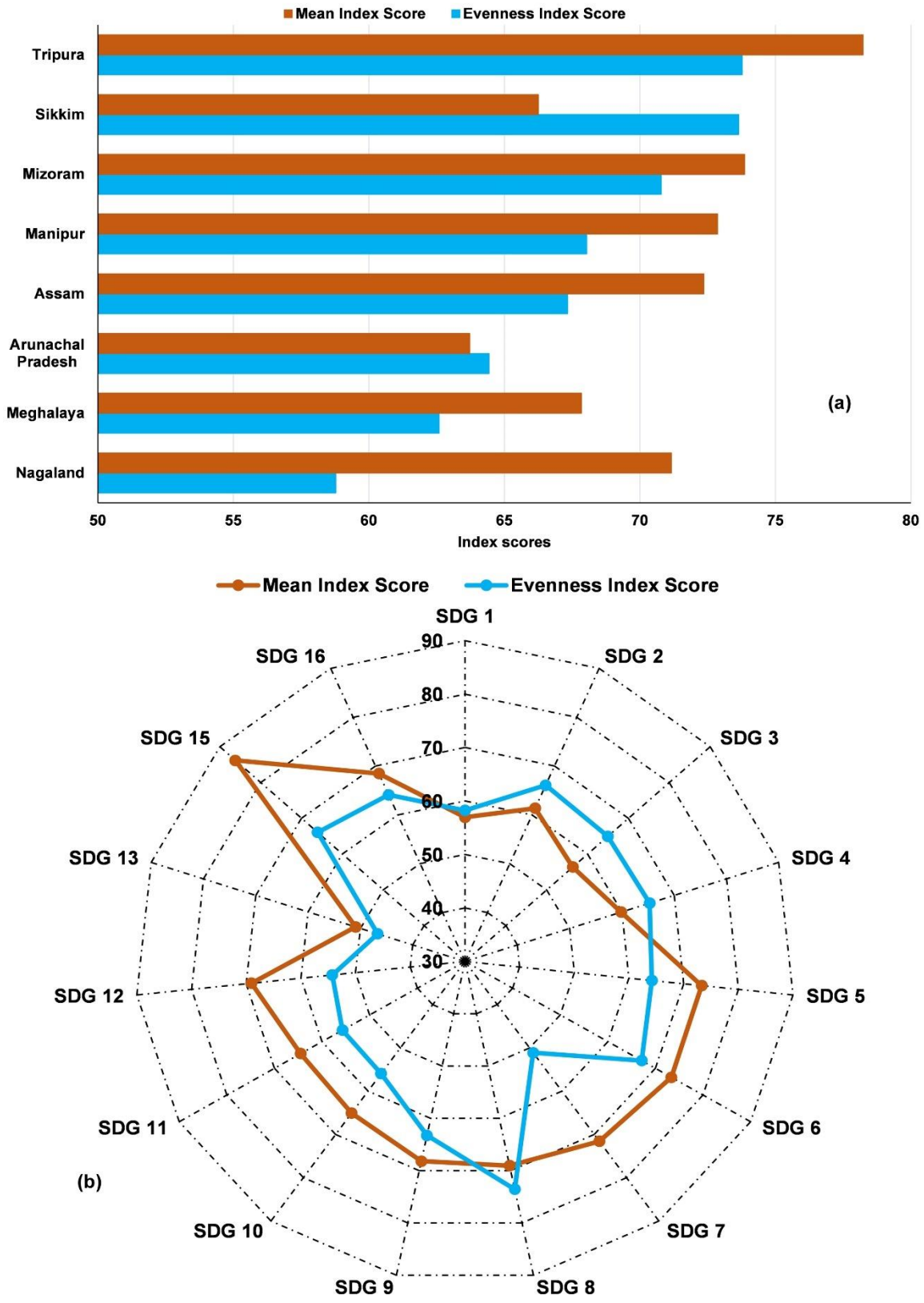

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Figure 6. Comparative performance of evenness index score (EIS) and mean index score (MIS) for (a) NER states (n=8) and (b) individual SDGs.

627 ***Relative scoring***

628 We must assess whether the performance of the districts in NER India with respect to
629 SDGs is superior or inferior to that of other comparable entities.

630

631 ***a) Intranational***

632 The relative performance of NER districts with their respective states and nations (i.e.
633 India) (Figure. 7a-7d, with the Tripura district as an example).

634 Districts that performed better in the composite SDG than their respective states were
635 28 (Assam), 16 (Arunachal Pradesh), and 3 (Manipur & Sikkim). This suggests uneven
636 progress across districts in these states. This means that > 50% of the districts perform equally
637 or better than their respective states' composite SDG. This is a positive sign, as it indicates that
638 a significant number of districts are not just keeping pace with their state's progress, but are
639 also potentially leading the way in sustainable development. The top districts that have
640 outperformed their states for each individual SDG are: Kamrup Metropolitan (SDG 1), W-Garo
641 Hills (SDG 2), E-Sikkim (SDG 3), Kohima (SDG 4), Karbi Anglong (SDG 5), L-Dibang
642 Valley (SDG 6) [here, L=Lower], W-Garo Hills (SDG 7), Imphal-W (SDG 8), Serchhip (SDG
643 9), Peren (SDG 10), SW-Khasi Hills (SDG 11), Udalguri (SDG 12), N-Tripura (SDG 13),
644 Kolasib (SDG 15), and Leparada (SDG 16). It is necessary to identify and address the needs of
645 those who lag behind their state average.

646 In terms of env-SDG scores, 56 NER districts performed better, and three performed
647 equally well (i.e. total >57%) with the state's score. The top three districts were Karimganj
648 (127%), N-Tripura (124%), and Mamit (123%). While >79% of the NER districts (n=82)
649 scored higher than their state's soc-SDG score, this is the lowest % compared to the econ- and
650 env-SDGs. The top three such districts were L-Subansiri (128%), Tawang (127%), and W-
651 Siang (125%). A staggering 99 districts (>96%) outperformed their state's econ-SDGs. The
652 top three such districts were Nalbari (140%), Udalguri (139%), and Dibrugarh (138%).

653 Only four NER districts (3.88%, viz. W-Tripura, Gomati, and N-Tripura in Tripura and
654 Serchhip in Mizoram) performed better than the national composite SDG. 71% of the NER
655 districts performed equally or better than the national env-SDG. This is a positive sign, and
656 shows that these districts are making good progress in terms of environmental sustainability.
657 The top three such districts were Karimganj (122%), W-Jaintia Hills (121.6%), and E-Garo
658 Hills (121.1%). While >43% of the districts (44 better and one equally performing) scored
659 higher than the national average on the soc-SDGs, this is a lower % compared than the env-
660 and econ-SDGs. The top three such districts were Champhai (115%), E-Sikkim (114%), and

Serchhip (113%). Approximately 67% of the NER districts performed better or equally well with the national econ-SDGs. The top three such districts were Unakoti (134%), Gomati (132%), and S-Tripura (131%). The relative intranational SDG performance for individual SDGs was calculated (for a comparison of NER districts with their respective states, see Figure. S.14. For India, see Figure. S.15). Intranational relative SDG performance for grouped SDGs was also calculated (for a comparison of NER districts with their respective states, see Figure. S.16 for a comparison of the NER districts with India (see Figure. S.17).

b) Extranational

For this purpose, the relative performances of NER districts with their respective regions (East and South Asia, ESA), income groups (lower-middle income, LMI), and global (world) scores were considered (Figure. 7e-7j, for the district of Tripura).

Better-performing NER districts had a higher score on the env-SDGs (78%) than on the soc- (19%) and econ-SDGs (59%). This suggests that these districts are doing relatively well in terms of environmental sustainability compared to their counterparts in the ESA. When compared to the LMI group score, the NER districts performed similarly in the env-SDGs and econ-SDGs (60%). However, they outperformed the LMI group in terms of soc-SDGs (68%). This indicates that these districts are making significant strides towards achieving social equity, quality education, and good health and well-being. The NER districts' performance in the env-SDGs (72%) is comparable to the global score, suggesting that these districts are on par with the global standards for environmental sustainability. However, the scores for the soc-SDGs (32%) and econ-SDGs (58%) were lower than the global scores, indicating the need for focused efforts in these areas to catch up with global progress. The relative extranational SDG performance for individual SDGs was calculated (for a comparison of the NER districts with the ESA: Figure. S.18, for the LMI group: Figure. S.19, the global score: Figure. S.20). The extranational relative SDG performance for grouped SDGs was also calculated (for comparison of NER districts with ESA: Figure. S.21, the LMI group: Figure. S.22, the global score: Figure. S.23).

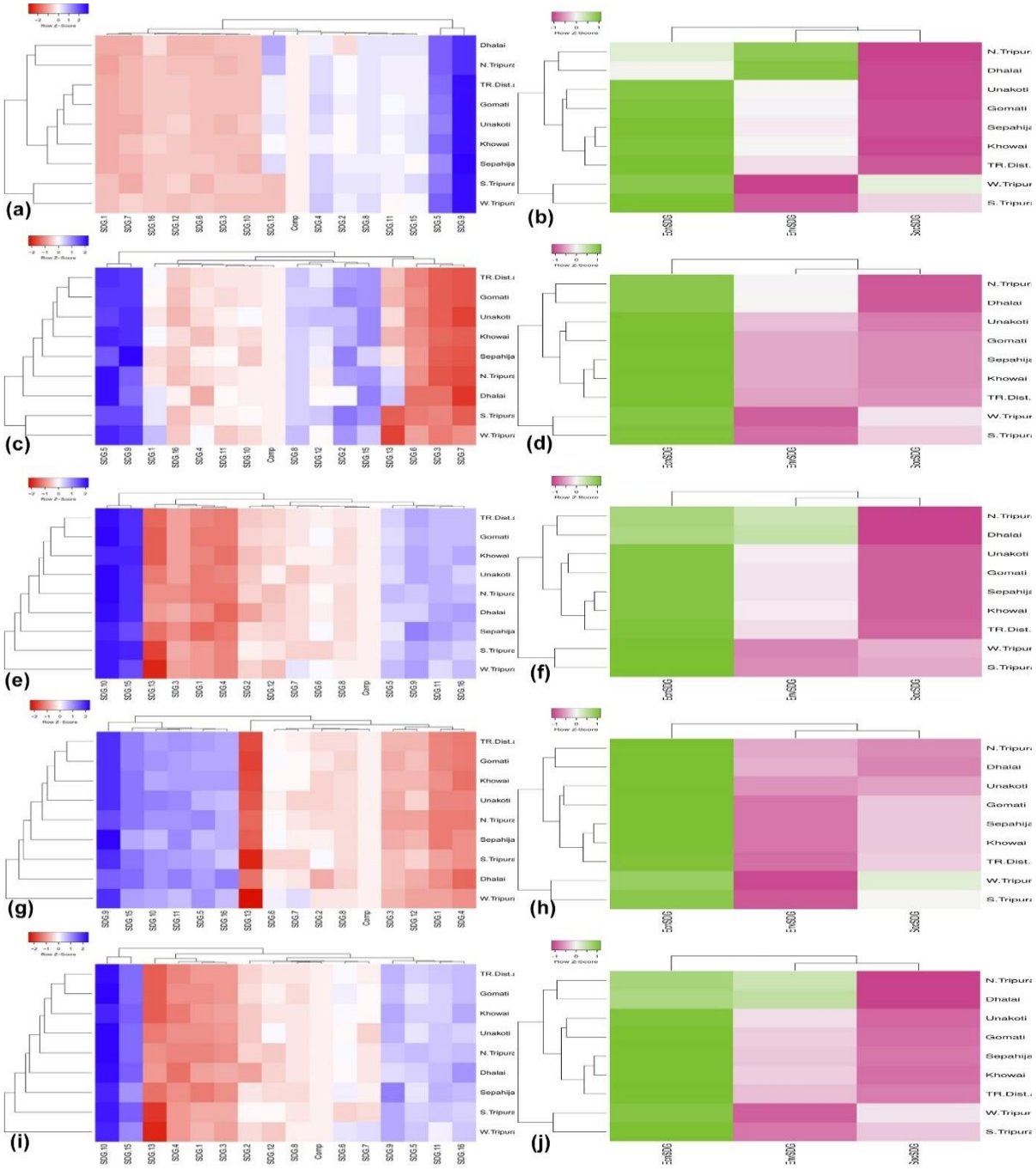

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Figure 7. Relative SDG performance of 8 districts of Tripura (TR). Left side: for individual SDGs, in comparison to (a) Tripura state, (c) India, (e) East and South Asia (ESA), (g) Lower middle-income (LMI) economies, and (i) Global score. Right side: for grouped SDGs, in comparison to (b) Tripura state, (d) India, (f) East and South Asia (ESA), (h) Lower middle-income (LMI) economies, and (j) Global score.

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Discussions

This research offers a thorough examination of the UN SDGs across NER India's districts, uncovering significant variations in the area's advancement towards sustainability. The results highlight the intricate nature of sustainable development in NER, which is influenced by a distinctive combination of environmental, societal, and economic elements. Addressing RQ1, our analysis revealed significant disparities in SDG achievement across the NER districts. The Env-SDGs, particularly SDG 13, showed the highest variation, with a 28.3-point gap between the best- and worst-performing districts. This highlights the region's vulnerability to climate change and the uneven application of mitigation measures. The fluctuating performance across the SDGs emphasises the region's varied challenges and prospects, indicating that a uniform approach to sustainability is insufficient.

A notable finding of this research is the significant disparity in SDG achievement across NER districts. The environmental objectives, particularly SDG 13, exhibited the greatest variation, highlighting the area's susceptibility to climate change and unequal application of measures to mitigate its effects. This is consistent with previous studies (Yadav, 2013; Dikshit & Dikshit, 2014; Singha, 2018), indicating that the topography and ecological sensitivity of the NER amplify the impact of climate change, necessitating region-specific adaptation measures. Addressing RQ5, our inequality analysis using the Theil index revealed that the highest disparities were in SDG 7, 9, and 13. This spatial inequality underscores the need for targeted interventions in the lagging districts to ensure balanced regional development. The results indicate that, while certain areas have achieved notable improvements, others have fallen behind considerably, potentially widening regional inequalities if not tackled through focused interventions.

In response to RQ6, our analysis of the Evenness Index Scores (EIS) and Mean Index Scores (MIS) highlighted significant disparities among NER states and districts. For instance, Tripura showed both high EIS (73.77) and MIS (78.23), indicating balanced and strong overall performance, whereas Nagaland had the lowest EIS (58.78), suggesting significant imbalances in SDG achievements. The econ-SDGs showed considerable variation, with certain districts displaying strong economic outcomes, whereas others struggled financially. This unequal economic progress could be linked to various factors, including inadequate infrastructure, restricted access to markets, and disparate levels of industrial development across different districts. These findings align with the existing literature (Barua, 2020; De, 2021; Roy et al., 2022; Das and Dutta, 2024) that points to infrastructural and connectivity challenges as major

impediments to economic growth in the region. The findings of this research shed light on the complex interplay between the env- and econ-SDGs, underscoring the conflict between progress and ecological preservation. In response to RQ4, our data envelopment analysis showed that only 26 of 103 districts (25.24%) were non-efficient in converting environmental SDG inputs into socioeconomic SDG outputs. This suggests that while many districts are effectively balancing environmental and socioeconomic progress, there is room for improvement in approximately a quarter of the region's districts. In some regions, economic advancement may be achieved at the expense of environmental health, illustrating the ongoing challenge of balancing development and sustainability.

In response to RQ2, our correlation and network analyses revealed strong positive relationships between several SDGs, notably between SDG 1 and 8, SDG 3 and 4, and SDG 6 and 7. These findings indicate that advancements in social welfare are interrelated, with progress in one domain potentially catalysing improvements in others. The region exhibited a varied social landscape, with some areas demonstrating excellence in healthcare, educational attainment, and gender parity, while others lagged. The robust links noted between SDGs 1, 3, and 4 indicate that advancements in social welfare are interrelated, with progress in one domain potentially catalysing improvements in others. Nevertheless, the uneven distribution of soc-SDGs highlights the need for more encompassing policies tailored to meet the unique requirements of the most underprivileged districts. This is particularly vital for promoting gender equality (SDG 5), as certain areas continue to face considerable obstacles.

Addressing RQ3, our hierarchical clustering analysis revealed that districts with strong environmental performance did not always excel in econ- or soc-SDG indicators, and vice versa. This decoupling of environmental and socioeconomic progress suggests that policy interventions must be carefully calibrated to avoid trade-offs that may undermine long-term sustainability. The analysis of district groupings based on their SDG achievements showed that areas with strong environmental performance did not always excel in econ- or soc-SDG indicators; the reverse was also true. This decoupling of environmental and socioeconomic progress suggests that policy interventions must be carefully calibrated to avoid trade-offs that may undermine long-term sustainability (Barua, 2020; Kokho, 2021; Jain et al., 2022). Addressing RQ7, our relative performance analysis revealed that only four NER districts (3.88%) performed better than the national composite SDG score. However, 71% of the NER districts performed equally or better than the national environmental SDG score, indicating strong environmental sustainability efforts in the region.

Our findings suggest a need for targeted policy interventions that address the specific challenges of each district. These include capacity building for low-performing districts; establishing knowledge-sharing networks; implementing performance-based incentives; and developing tailored strategies for climate action, social development, and economic growth. This research underscores the critical importance of adopting a nuanced approach to sustainable development in NER, considering the distinct geographical, environmental, and socioeconomic characteristics of each district. It is imperative for policymakers to focus on targeted initiatives that address existing disparities in SDG achievement, particularly in underdeveloped areas. Additionally, promoting inter-district collaboration and information exchange could contribute to more balanced and sustainable growth across NER. Subsequent investigations should concentrate on gaining a more detailed understanding of the underlying causes of SDG inequalities and formulating strategies that combine the env-, econ-, and soc-SDGs to attain comprehensive and sustainable development in NER India.

This study had certain limitations. These limitations not only restrict a deeper understanding of the region's sustainability but also present opportunities for future research and policy improvements.

a) Data gaps and omissions: For each of the NER district's unique SDG indicators, the dataset is deficient in relevant and trustworthy data. Significantly, two complete SDGs are missing: Life Below Water (SDG 14) and Partnerships for the Goals (SDG 17). Although the authors contest their apparent insignificance (as deemed 'not relevant' by NITI Aayog), these objectives probably have important but indirect links to NER, particularly when considering consumption-based effects (such as supply networks). A thorough investigation of possible synergies, trade-offs, and feedback loops among all 17 goals is hampered by omitting these SDGs, which is essential for a thorough sustainability assessment. In addition, data are frequently absent at the indicator level, even for the selected 103 districts. The data custodian, NITI Aayog, has to fix these omissions and gaps in the data.

b) Limited indicator coverage: The NER dataset features fewer indicators for the four major goals (SDG 10, 5, 9, and 12) than other SDG datasets for India (e.g. The Indian City SDGs or state-UT SDGs) (Figure. S.24). In addition, it contains only two indicators for Clean and Affordable Energy (SDG 7). More indicators are typically required for thorough evaluation, as it would give a complete and more complex picture of the progress made, particularly for those with less coverage.

c) Absence of time-series data: There is only one snapshot of SDG performance available in the current dataset. It is impossible to forecast future trends or evaluate progress over time

because of the lack of time-series data. Evaluating India's chances of achieving the SDGs for NER by 2030 is difficult in the absence of this temporal factor.

d) Incomplete district coverage: For 17 districts spread throughout the eight NER states, SDG data are completely absent. Removing these districts diminishes the representativeness of the dataset and restricts our comprehension of the sustainability landscape of the region as a whole. To fully understand NER's progress towards the SDGs, data for every district must be included.

Our analysis has critical implications for sustainable development in Northeast India. Significant variations in SDG achievement across districts, particularly in environmental goals, underscore the need for tailored district-specific approaches. The decoupling of environmental and socioeconomic progress in many districts highlights the challenge of balancing development and ecological preservation, suggesting the need for green growth models. Strong positive correlations between certain SDGs indicate that integrated approaches to social and economic development could yield synergistic benefits. However, the high disparity in climate action performance underscores a region's vulnerability to climate change impacts, implying an urgent need for climate-resilient strategies. The varied social and economic landscapes across districts suggest that development initiatives need to be more context-specific, addressing unique local challenges. These implications collectively highlight the need for a nuanced, multi-dimensional approach to sustainable development in NER, balancing environmental conservation with socioeconomic progress, addressing regional disparities through targeted interventions, and fostering inclusive growth that leaves no district behind.

Policy suggestions

This study examined the performance, interrelationship, and efficiency of the SDGs in 103 districts of NER India. A few suggestions for policymakers can be categorised into three groups: environment, society, and economy (Figure 8). These policy recommendations provide a structured approach towards achieving balanced regional development while addressing the specific challenges identified through SDG performance analysis. The success of these interventions relies heavily on coordinated implementation and continuous monitoring of outcomes across all three dimensions of sustainability.

The environmental policy framework should encompass a comprehensive approach to capacity enhancement and sustainable practices. This includes establishing targeted capacity-building programs in environmentally vulnerable districts (e.g. Barpeta, and Mon) through systematic training in waste management and climate action strategies. A regional knowledge-sharing

network was proposed to facilitate the transfer of best practices from high-performing districts (e.g. Karimganj and West Jaintia Hills) for those requiring support. This framework advocates performance-based incentivisation systems with transparent metrics for tracking environmental SDG progress. Particular emphasis is placed on addressing climate action disparities in states such as Arunachal Pradesh, Mizoram, and Nagaland through region-specific interventions including renewable energy adoption and climate-smart agricultural practices.

Social development strategies should adopt an integrated approach to address the multidimensional challenges in underperforming districts. Priority interventions target districts exhibiting significant social inequalities, such as the North Garo Hills and South Garo Hills, through enhanced infrastructure and educational programs. The framework emphasises gender mainstreaming across all social indicators, particularly in districts that demonstrate high social SDG inequality. Community empowerment remains central to the strategy and advocates for increased local participation and governance capacity-building. Additionally, needs-based social development programs are proposed, exemplified by targeted educational initiatives in Manipur, where SDG 4 disparities are pronounced.

The economic policy framework should prioritise infrastructural development in economically disadvantaged districts such as Shi Yomi and Zunheboto, emphasising improved transportation networks and market connectivity. A comprehensive approach to economic development includes targeted skill enhancement and entrepreneurship programs tailored to the local context. This strategy promotes sustainable tourism practices as an economic driver, while preserving environmental integrity. Financial support mechanisms for micro, small, and medium-sized enterprises (MSMEs) are proposed through grants and fiscal incentives.
Furthermore, the framework addresses market access limitations in states exhibiting high economic SDG inequality, such as Arunachal Pradesh, Manipur, and Nagaland, through strategic investments in the transportation infrastructure and digital connectivity enhancement.

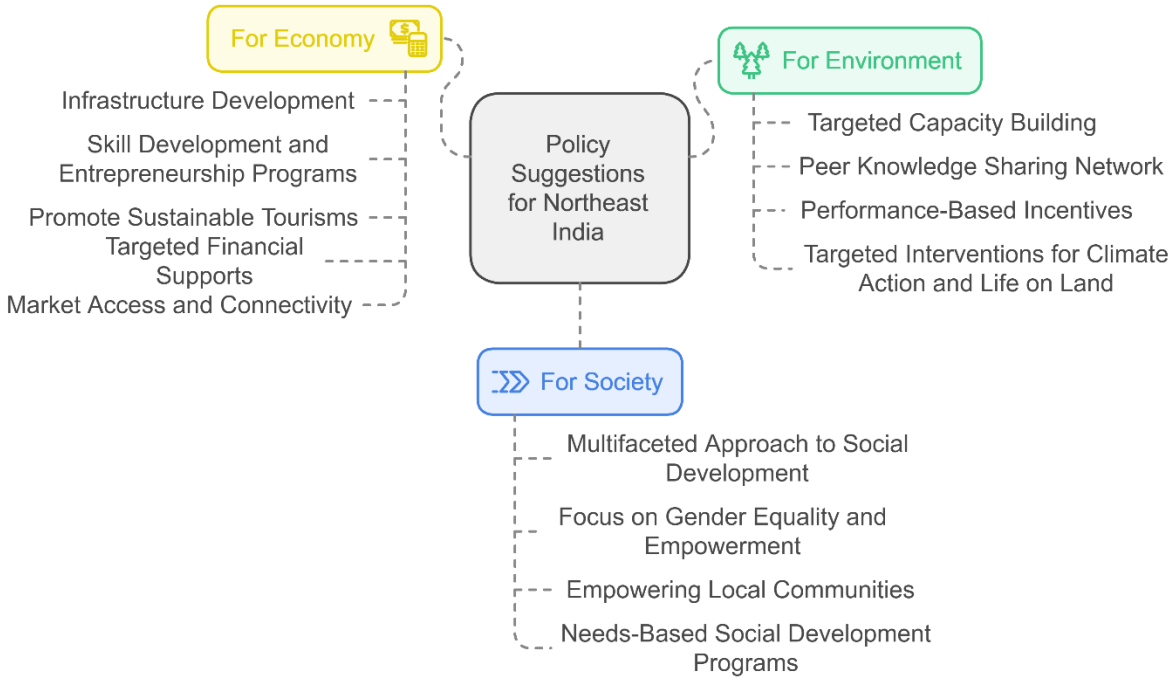

Figure 8. Policy suggestions for Northeast India.

Conclusion

This study provides a comprehensive multi-dimensional assessment of SDG progress across Northeast India's districts, revealing critical disparities and complex interactions between environmental and socioeconomic goals. Our findings underscore the need for targeted, district-specific interventions to address developmental inequalities and promote balanced sustainable development in this ecologically sensitive, socioeconomically diverse region.

Key recommendations for policymakers include implementing tailored climate action strategies for districts lagging SDG 13, developing integrated socioeconomic policies that capitalise on strong positive correlations between related SDGs, establishing inter-district knowledge-sharing networks to disseminate best practices, and prioritising green growth models that balance environmental conservation with socioeconomic development. These targeted interventions aim to address the specific challenges faced by different districts while promoting balanced and sustainable development across the Northeast Region.

Future research should address this study's limitations by conducting longitudinal studies to track SDG progress over time, investigate the causes of intra-district inequalities, explore cross-border influences on sustainable development, and develop more comprehensive

indicators for underrepresented SDGs, particularly SDG 7, 14, and 17. These efforts will provide a more nuanced understanding of the sustainable development challenges in Northeast India and inform more effective targeted interventions.

By addressing these research gaps and implementing targeted policies, Northeast India can make significant strides towards achieving the SDGs, potentially serving as a model for sustainable development in other ecologically sensitive and diverse regions globally.

References:

- Anand S, Das M, Bhattacharyya R, Singh RB. Eds., (2023). Sustainable Development Goals in Northeast India: Challenges and Achievements. ISBN: 978-981-19-6478-7. https://doi.org/10.1007/978-981-19-6478-7
- Atkinson AB. (1970). On the measurement of inequality. *Journal of Economic Theory*, 2 (3), 244-263. https://doi.org/10.1016/0022-0531(70)90039-6
- Banker RD, Charnes A, Cooper WW, Swarts J, & Thomas D. (1989). An introduction to data envelopment analysis with some of its models and their uses. *Research in Governmental and Nonprofit Accounting*, 5, 125–163.
- Barua, T. (2020). The Look East Policy/Act East Policy-driven development model in Northeast India. *Jadavpur Journal of International Relations*, 24 (1), 101–120. https://doi.org/10.1177/0973598420908844
- Bora JK, & Saikia N. (2018). Neonatal and under-five mortality rate in Indian districts with reference to Sustainable Development Goal 3: An analysis of the National Family Health Survey of India (NFHS), 2015–2016. *PloS One*, 13 (7), e0201125. https://doi.org/10.1371/journal.pone.0201125
- Chaudhary A, Mair L, Strassburg BB, Brooks TM, Menon V, & McGowan PJ. (2022). Subnational assessment of threats to Indian biodiversity and habitat restoration opportunities. *Environmental Research Letters*, 17 (5), 054022. https://doi.org/10.1088/1748-9326/ac5d99
- Chaudhuri S, & Roy M. (2017). Rural-urban spatial inequality in water and sanitation facilities in India: A cross-sectional study from household to national level. *Applied Geography*, 85, 27-38. https://doi.org/10.1016/j.apgeog.2017.05.003
- Chhetri DP. (2020). Sustainable Development Goals in the Landlocked Himalayan State of Sikkim, India: Five Years of Initiatives and Achievements. *Gedrag & Organisatie Review*, 33 (04). https://doi.org/10.37896/gor33.04/024

- Das, N., & Dutta, P. (2024). An exploration of the relationship between public infrastructure and economic growth in Northeast India: A panel data approach. *The Indian Economic Journal*. https://doi.org/10.1177/00194662241252968
- De, P. (2021). Connectivity and Northeast India - Challenges and ways forward. In *Northeast India and Japan* (pp. 77–99). Routledge India. https://doi.org/10.4324/9781003165026-7
- Dikshit, K. R., & Dikshit, J. K. (2014). North-East India: Land, People and Economy. Dordrecht: Springer Netherlands. https://doi.org/10.1007/978-94-007-7055-3
- Doersam P. (2004). Wirtschaftsstatistik anschaulich dargestellt. Heidenau: PD-Verlag.
- Folke C, Biggs R, Norström AV, Reyers B, & Rockström J. (2016). Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society*, 21 (3). https://doi.org/10.5751/es-08748-210341
- Ghosh K, Chakraborty AS, & SenGupta S. (2023). Identifying spatial clustering of diarrhoea among children under 5 years across 707 districts in India: a cross sectional study. *BMC Pediatrics*, 23 (1), 272. https://doi.org/10.1186/s12887-023-04073-3
- Ghosh P, Hossain M, & Alam A. (2022). Water, Sanitation, and Hygiene (WASH) poverty in India: A district-level geospatial assessment. *Regional Science Policy & Practice*, 14 (2), 396-416. https://doi.org/10.1111/rsp3.12468
- Guo, Y., Yu, M. M., & See, K. F. (2024). Developing a sustainable development goals index for OECD countries: An effectiveness-based hierarchical data envelopment analysis. *Environmental Science & Policy*, 160, 103836. https://doi.org/10.1016/j.envsci.2024.103836
- Jain, A., Tanu, S., & Madhaba Sheekha, N. (2022). Agricultural Sustainability in the North Eastern Region of India. *Ecology, Economy and Society–the INSEE Journal*, 5 (2). https://doi.org/10.37773/ees.v5i2.486
- Kokho, K. (2021). Economic and development policies in the northeastern region and the current conditions. In *Northeast India and Japan* (pp. 53–76). Routledge India. https://doi.org/10.4324/9781003165026-6
- Le Blanc, D. (2015). Towards integration at last? The sustainable development goals as a network of targets. *Sustainable Development*, 23 (3), 176-187. https://doi.org/10.1002/sd.1582
- Liu, Y., Du, J., Wang, Y., Cui, X., Dong, J., Gu, P., Hao, Y., Xue, K., Duan, H., Xia, A., Hu, Y., Dong, Z., Wu, B., Kropp, J., & Fu, B. (2024). Overlooked uneven progress

across sustainable development goals at the global scale: Challenges and opportunities. *The Innovation*, 5, (2), https://doi.org/10.1016/j.xinn.2024.100573

- Liu, Y., Du, J., Wang, Y., Cui, X., Dong, J., Hao, Y., Xue, K., Duan, H., Xia, A., Hu, Y., Dong, Z., Wu, B., Zhao, X., & Fu, B. (2021). Evenness is important in assessing progress towards sustainable development goals. *National Science Review*, 8(8), nwaa238. https://doi.org/10.1093/nsr/nwaa238
- Mitra A. (1998). Environment and sustainable development in the hilly regions of North-East India: A study in Arunachal Pradesh. *International Journal of Social Economics*, 25 (2/3/4), 196-206. https://doi.org/10.1108/03068299810193399
- NITI Aayog. North-eastern Region District SDG Index & Dashboard 2021–22. https://sdgindiaindex.niti.gov.in/NER/dashboard/#/ (Accessed 20th October 2024).
- Portnov BA, & Felsenstein D. (2010). On the suitability of income inequality measures for regional analysis: Some evidence from simulation analysis and bootstrapping tests. *Socio-Economic Planning Sciences*, 44 (4), 212-219. https://doi.org/10.1016/j.seps.2010.04.002
- Pradhan, P., Costa, L., Rybski, D., Lucht, W., & Kropp, J. P. (2017). A systematic study of sustainable development goal (SDG) interactions. *Earth's Future*, 5 (11), 1169-1179. https://doi.org/10.1002/2017EF000632
- Qi, Y., Shi, X., Chen, Y., & Shen, Y. (2024). Country-level evenness measure in assessing progress towards Sustainable Development Goals (SDGs). *Humanities and Social Sciences Communications*, 11 (1), 1-13. https://doi.org/10.1057/s41599-024-03572-7
- Roy A, & Pramanick K. 2019. Analysing progress of sustainable development goal 6 in India: Past, present, and future. *Journal of Environmental Management*, 232, 1049-1065. https://doi.org/10.1016/j.jenvman.2018.11.060
- Roy A, Garai N, & Biswas JK. (2023). Exploration of urban sustainability in India through the lens of sustainable development goals. *Discover Sustainability*, 4 (1), 41. https://doi.org/10.1007/s43621-023-00158-2
- Roy, S., Chaberek, G., Hore, S., & Mitra, S. (2022). Delineating regional differentiation on the development of the railway infrastructure in northeast India through an efficient synthetic indicator. *Transport Problems*, 17 (3), 165–178. https://doi.org/10.20858/tp.2022.17.3.13

- Seiford LM, Zhu J. (1999). An investigation of returns to scale in data envelopment analysis. *Omega*, 27, 1–11.
- Singh SN. (2018). Regional Disparity and Sustainable Development in North-eastern States of India: A Policy Perspective. *Socio Economic Challenges*, 2 (2), 41-48. https://doi.org/10.21272/sec.2(2).41-48.2018
- Singha, S. (2018). Assessing vulnerability and resilience in the face of climate change: A case study in northeast India. *European Journal of Sustainable Development*, 7 (3). https://doi.org/10.14207/ejsd.2018.v7n3p53
- Störmann W. (2009). Regionalökonomik: Theorie und Politik. In Regionalökonomik. Oldenbourg Wissenschaftsverlag. ISBN: 9783486851762.
- Subramanian SV, Ambade M, Kumar A, Chi H, Joe W, Rajpal S, & Kim R. (2023). Progress on Sustainable Development Goal indicators in 707 districts of India: a quantitative mid-line assessment using the National Family Health Surveys, 2016 and 2021. *The Lancet Regional Health- Southeast Asia*, 13. https://doi.org/10.1016/j.lansea.2023.100155
- Theil H. (1967). Economics and information theory. Amsterdam: North Holland Publishing Co.
- Tiwari P, & Krishna M. (2021)**.** An assessment of the performance of different districts towards Sustainable Development targets in India. *Ecological Questions*, 32 (1), 1-24. https://doi.org/10.12775/EQ.2021.002
- Tone K. (2001). A slacks-based measure of efficiency in data envelopment analysis. *European Journal of Operational Research*, 130, 498–509. https://doi.org/10.1016/S0377-2217(99)00407-5
- Wang, Y., Lu, Y., He, G., Wang, C., Yuan, J., & Cao, X. (2020). Spatial variability of sustainable development goals in China: A provincial level evaluation. *Environmental Development*, 35, 100483. https://doi.org/10.1016/j.envdev.2019.100483
- Wu, X., Liu, J., Fu, B., Wang, S., Wei, Y., & Li, Y. (2022). Bundling regions for promoting sustainable development goals. *Environmental Research Letters*, 17 (4), 044021. https://doi.org/10.1088/1748-9326/ac5c9d
- Yadav, P. (2013). Slash-and-burn Agriculture in Northeast India. *Expert Opinion on Environmental Biology*, *02* (01). https://doi.org/10.4172/2325-9655.1000102