Unravelling sustainable development at the sub-national scale in India

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Conceptualization: Nandini Garai, Ajishnu Roy; Methodology: Ajishnu Roy; Formal analysis and investigation: Nandini Garai, Ajishnu Roy; Writing: original draft preparation: Nandini Garai, Ajishnu Roy; Writing, review, and editing: Nandini Garai, Ajishnu Roy; Resources: Ajishnu Roy; Supervision: Kousik Pramanick;

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Abstract:

India's diverse socioeconomic landscape and environmental challenges make it a complex case for implementing the UN Sustainable Development Goals (SDGs). Despite India's federal structure, comprehensive research on subnational SDG progress is lacking. This study analysed progress, challenges, interlinkages, and spatial disparities in individual and grouped SDGs (environmental, social, and economic) across 37 Indian states and union territories (UTs). We employed a multi-method approach to analyse the SDGs across 112 indicators (2018-2020). Significant variations in SDG performance across India, with the southern and northern states generally outperforming the central and eastern states. Inequality showed decreasing trends in most SDG groups, indicating progress towards a more equitable distribution of SDG achievements. This study provides a comprehensive baseline for tracking the progress of the SDGs in India. Based on the results of this study, tailored context-specific suggestions for policymakers were proposed that integrate environmental, social, and economic priorities. Promoting inter-state collaboration, strengthening institutions, and data-driven decision-making are crucial for accelerating India's progress towards ambitious SDGs.

Keywords: sustainable development goals; subnational sustainability; regional inequalities; India;

Introduction:

India, a diverse subcontinental country, is comprised of 37 states and UTs in a complex union. India’s diverse landscape includes snow-capped peaks of the Himalayas in the north, lush tropical jungles and coastal regions in the south, dense hilly forests in the east, and the vibrant Thar Desert in the west. As the world's most populous democracy, India faces the dual challenges of rapid economic growth and environmental preservation. India has experienced a considerable increase in its ecological resource consumption due to the country's growing middle class and increased urbanisation. The country is struggling with poverty, inequality, and rural development at the same time. Owing to this particular combination of circumstances, sustainable growth requires a sophisticated strategy. India has a lot of potential, on the one hand: a wealth of renewable energy resources, a developing knowledge economy, and a cultural history that instils a tradition of environmental responsibility. On the other hand, it has significant challenges such as pervasive poverty, inadequate infrastructure, and the residue of unsustainable behaviours.

The UN's Sustainable Development Goals (SDGs) guide global efforts towards a sustainable future, with India playing a crucial role due to its population size. India's developmental difficulties and objectives, which aim to strike a balance between economic growth, social fairness, and environmental sustainability, are in line with SDGs. Through their integration of economic, social, and environmental aspects, they provide India with a path towards inclusive and sustainable development.

Literature review:

Over the years, subnational-scale SDG analyses have been conducted worldwide. For instance, Umar and Asghar (2018) developed an SDG scorecard and dashboard for Pakistan at the provincial level. Machado et al. (2020) evaluated 41 health-related indicators from the SDGs of 26 Brazilian states and federal districts between 1990 and 2017. Wang et al. (2020) analysed provincial-scale SDG analysis in China with an SDG dashboard. Xu et al. (2020) developed a systematic method to measure progress towards the 17 SDGs at the national and subnational levels in China. Andriati and Fahmi (2021) developed the Indonesian province SDGs' composite index. Gao et al. (2021) used 49 indicators of sustainable development for 2010, 2015, and 2018 in 31 provinces in China to understand SDGs using the best and worst value improved equal-weight TOPSIS method. Haghdoost et al. (2022) used different scenarios to project the likelihood of achieving the SDG 3.4 in Iran. Roy et al. (2022) have composed a global scale bibliometric analysis on water and sanitation goal (SDG 6). Zhang et al. (2022) analysed the spatial and temporal variation of SDG interactions based on a systematic classification framework (viz., 'Essential Needs', 'Objectives', and 'Governance'). Cao et al. (2023) used causal diagnosis and network analysis to construct 1302 directed networks for 31 provinces in China (2000-2020). Mangukiya and Sklarew (2023) analysed SDG progress at two sub-national scales within the USA (50 states and Washington DC; and 3142 localities) for 2010 and 2015. Recently, Işık et al. (2024) analysed SDG in the USA (1960–2022).

Several studies have been conducted on the SDGs in India over the past few years. Panda et al. (2018) evaluated the status of SDGs in India at the national level using a single indicator for each SDG. Panda and Mohanty (2019) assessed the sustainability of health in India using a composite health index. Roy and Pramanick (2019) evaluated the sustainability of the WaSH sector (i.e., SDG 6) at the national level using an ecologically safe and socioeconomically just operating space framework. Bhanja and Roychowdhury (2020) assessed progress towards SDGs by 2030 using the 2011 census and 2015-16 NFHS data for Indian states. Jatav (2021) analysed the sustainability of Indian regions. Biswas et al. (2022) analysed Indian areas' achievements towards SDG 6. Dwivedi and Sharma (2022) used the Shannon Entropy and COCOSO techniques in the MCDM model to assess the performance of the SDGs of Indian UTs. Roy et al. (2023) evaluated the sustainability of 56 prominent cities in India using 14 SDGs (from 77 indicators) for 2020-2021. Garai et al. (2023) composed a global-scale bibliometric review of the SDGs, MDGs, and the Anthropocene. 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.

Nine years after the initiation of the UN-SDG proposal and six years remaining to achieve the target of 2030, a comprehensive analysis on the subnational scale in India has not been conducted. Based on the gaps identified in the literature and the objectives of this study, we addressed the following research questions (RQs):

RQ 1: What are the progress and challenges in achieving SDGs across Indian areas?

RQ 2: How do the SDGs interrelate at the goal and indicator levels for Indian areas, and what are the implications of these relationships?

RQ 3: How can Indian areas be clustered based on their SDG profiles?

RQ 4: What is the relative efficiency of Indian areas in converting environmental inputs into socioeconomic outputs within the SDG framework?

RQ 5: How has inequality in SDG achievements evolved across Indian areas over time?

RQ 6: What insights can be gained from analysing the evenness and mean index scores of SDG achievements across Indian states and union territories?

RQ 7: How do Indian areas compare their SDG performance with national and global benchmarks?

These research questions guide our multimethod approach and provide a structured framework for our analysis. This study aimed to establish a comprehensive baseline for monitoring India's subnational SDG progress, emphasising the need to address regional disparities in the national development strategy. The conclusions and suggestions of this research will support focused and successful policies for sustainable development in India's heterogeneous state framework.

Methodology:

The data for SDG goals and indicators for the 37 Indian states and UTs were collected from National Data and Analytics Platform (NDAP) of NITI Aayog (2023), encompassing 112 indicators. SDGs 14 and 17 were excluded because of data unavailability.

Pearson's correlation examined SDG interrelationships (RQ2), quantifying how progress in one SDG relates to others, and revealed potential synergies and trade-offs. Understanding these relationships is crucial for developing integrated policies that can effectively address the multiple SDGs simultaneously. We used the 'pheatmap' package (v1.0.12) in R (v4.1.5). Network analysis was also applied to interpret the interconnections among SDG goals and indicators. We used the 'igraph' package (v2.0.3) in R (v4.1.5).

Hierarchical Clustering Analysis (HCA) grouped states and UTs based on SDG performance similarities to address RQ3. HCA identifies regional disparities and potential interventions by revealing clusters of states with similar sustainable development profiles, enabling policymakers to develop tailored strategies and facilitate knowledge sharing. Ward’s method (1963) was used for the area ordering. HCA was performed using SciPy's 'linkage' and 'fcluster' functions, with heatmaps created using ‘seaborn’ in Python (3.12.6).

For RQ4, using the 'deaR' package (v1.4.1) in R, we used a variable return to scale (VRS)-based input-oriented DEA with a slack-based model (SBM) (Tone, 2001) to evaluate the efficiency of Indian states and UTs in converting environmental resources into socioeconomic outcomes (Wang et al., 2020; Gao et al., 2021). DEA aids in identifying benchmark states that achieve optimal SDG outcomes, offering valuable insights for resource optimisation and policy design, and identifying best practices and improvement areas. The analysis utilised 12 soc- and econ-SDG outputs and four env-SDG inputs, which complied with the requirement for adequate discriminating power by having at least twice the sum of inputs and outputs (Banker et al., 1989). The returns to scale for each DMU were determined using the lambda value sums (Seiford and Zhu, 1999).

We used the Theil index (Theil, 1967) to quantitatively display trend variations in spatial variance for individual and grouped SDGs across India, addressing RQ5. This study utilises a decomposable inequality measure to analyse the evolution of disparities in SDG performance across states and UTs, revealing equitably achieved progress or regions left behind. Population-weighted indices were not computed because of the lack of official population statistics in some areas (2018–2020). This package uses Stoermann's (2009) formulation, because there are numerous metrics of Theil inequality. The Atkinson and Gini indices were also calculated using the Doersam (2004) and Portnov and Felsenstein (2010) formulations, respectively. The 'REAT' (v3.0.3) package in 'R' was utilised for this investigation.

To address RQ6, this study uses EIS and MIS indices to measure SDG achievement and disparities, aiding policymakers in identifying underperforming sectors and promoting inclusive growth in line with the 2030 agenda. EIS and MIS were calculated at the district, state, and SDG levels using methods described in recent studies (Liu et al. 2021, 2024; Qi et al. 2024), using the 'dplyr' package (v1.1.4) in R.

To address RQ7, we constructed a comparative index to evaluate the relative SDG performance of the Indian areas, enabling intra- and international comparisons. We calculated the comparative SDG performance as the percentage ratio of an area's score to another's score, implementing this across all Indian areas. We have presented all the major aspects of the methodology in this study (Figure 1).

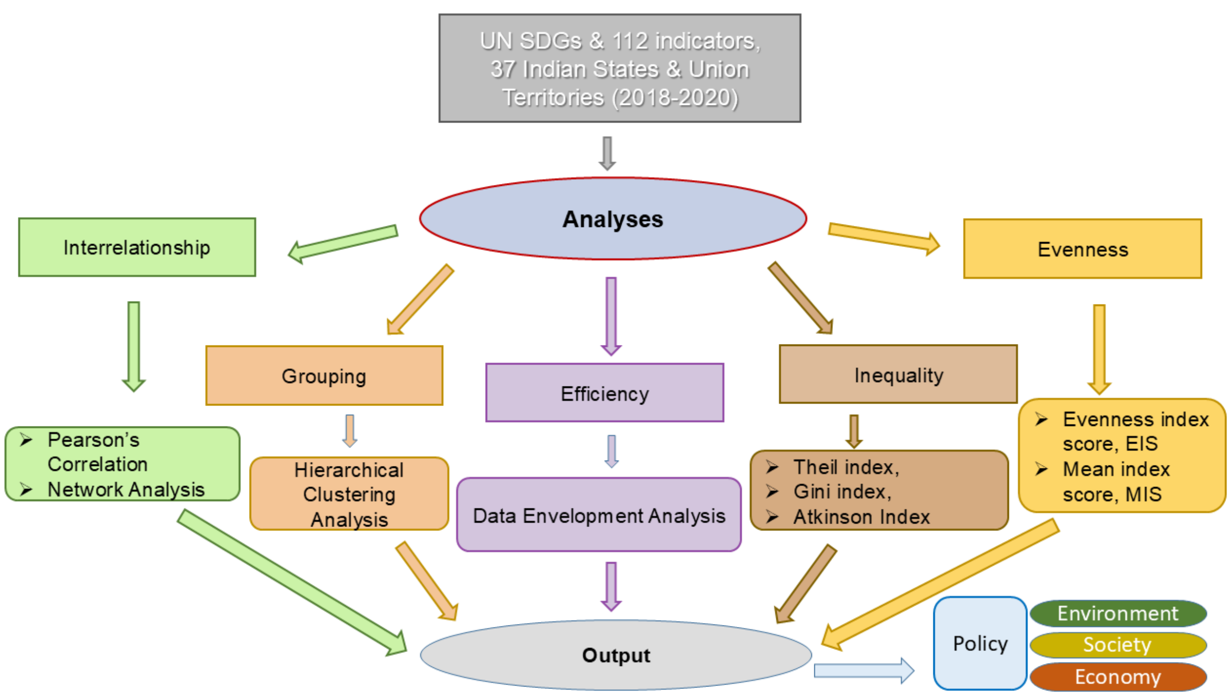


Figure 1. Schematic representation of methodology.

The limited three-year (2018-2020) SDG dataset (2021 and 2022 data identical to 2020) precludes the most sophisticated analytical techniques such as regression and forecasting.

Results:

We now present our findings, beginning with an overview of the SDG achievements and shortcomings across the country. This was followed by detailed results from each analytical method, providing insights into the complex landscape of sustainable development at the subnational level in India.

Achievements and shortcomings:

Addressing RQ1, the results revealed significant variations in India's SDGs performance over a three-year period, with several states crossing the 70% mark by 2020. However, states like Bihar, Uttar Pradesh, and Madhya Pradesh still lag behind urbanised and developed states, such as Kerala, Himachal Pradesh, and Tamil Nadu. Some states, such as Kerala and Goa, have performed well, while others struggle with high poverty (SDG 1) and malnutrition (SDG 2) levels. The southern and northern regions generally outperform the central and eastern states in terms of healthcare (SDG 3) and education goals (SDG 4). States like Chhattisgarh and Himachal Pradesh have shown improvement in gender equality (SDG 5), while Goa, Gujarat, and Himachal Pradesh have consistently high scores. States such as Goa, Maharashtra, and Kerala have shown better progress in SDG 11 (sustainable cities and communities), while states such as Bihar, Jharkhand, and Arunachal Pradesh have lagged behind. In SDG 14, Odisha and Andhra Pradesh are leading, whereas West Bengal and Tamil Nadu lag behind.

Indian UTs have shown mixed performance in achieving their SDGs, with some like Chandigarh and Lakshadweep performing better than others like Dadra and Nagar Haveli and Daman and Diu. Chandigarh and Lakshadweep consistently outperformed other UTs in healthcare (SDG 3) and education (SDG 4), while Jammu, Kashmir, and Ladakh showed room for improvement. Most UTs achieved near-perfect or perfect scores in SDG 6 (water and sanitation), with Chandigarh and Lakshadweep leading the way. Lakshadweep, with its extensive coastline and marine ecosystems, consistently had high scores on SDG 14 (life below water).

In 2020, Odisha, Andhra Pradesh, and Sikkim had the highest env-SDG scores (Figure 2a) among Indian states, while Rajasthan, Punjab, and Tamil Nadu had the lowest. Kerala, Tamil Nadu, and Goa had the highest soc-SDG (Figure 2b) scores, while Bihar, Assam, and Jharkhand had the lowest. Himapchal Pradesh, Tamil Nadu and Karnataka had the highest econ-SDG scores, while Bihar, Jharkhand, and Nagaland had the lowest scores (Figure 2c). Tamil Nadu, Himachal Pradesh and Kerala had the highest socioecon-SDG scores, while Bihar, Jharkhand, and Assam had the lowest scores. Chandigarh and the Andaman and Nicobar Islands had the highest env-SDG and soc-SDG scores, respectively.

The results revealed mixed performance across Indian UTs, with some showing significant improvements in SDGs and others experiencing a decline, particularly in environmental aspects (Figure 2d). Jammu and Kashmir and Chandigarh showed the highest overall improvement in the composite SDG, while Dadra and Nagar Haveli and Lakshadweep showed the highest improvement in the soc-SDG and econ-SDG. Puducherry, Jammu, and Kashmir showed the greatest improvements in the env-SDG.

The Indian states of Uttar Pradesh, Sikkim, Arunachal Pradesh, Haryana, Nagaland, and Odisha showed significant improvements in the various SDGs (Figure 2e). However, Chhattisgarh, Goa, Himachal Pradesh, and Maharashtra experienced notable declines in the env-SDG. Uttar Pradesh, Haryana, and Meghalaya showed the highest improvements in soc-SDG. The results reveal a diverse performance pattern across Indian states.

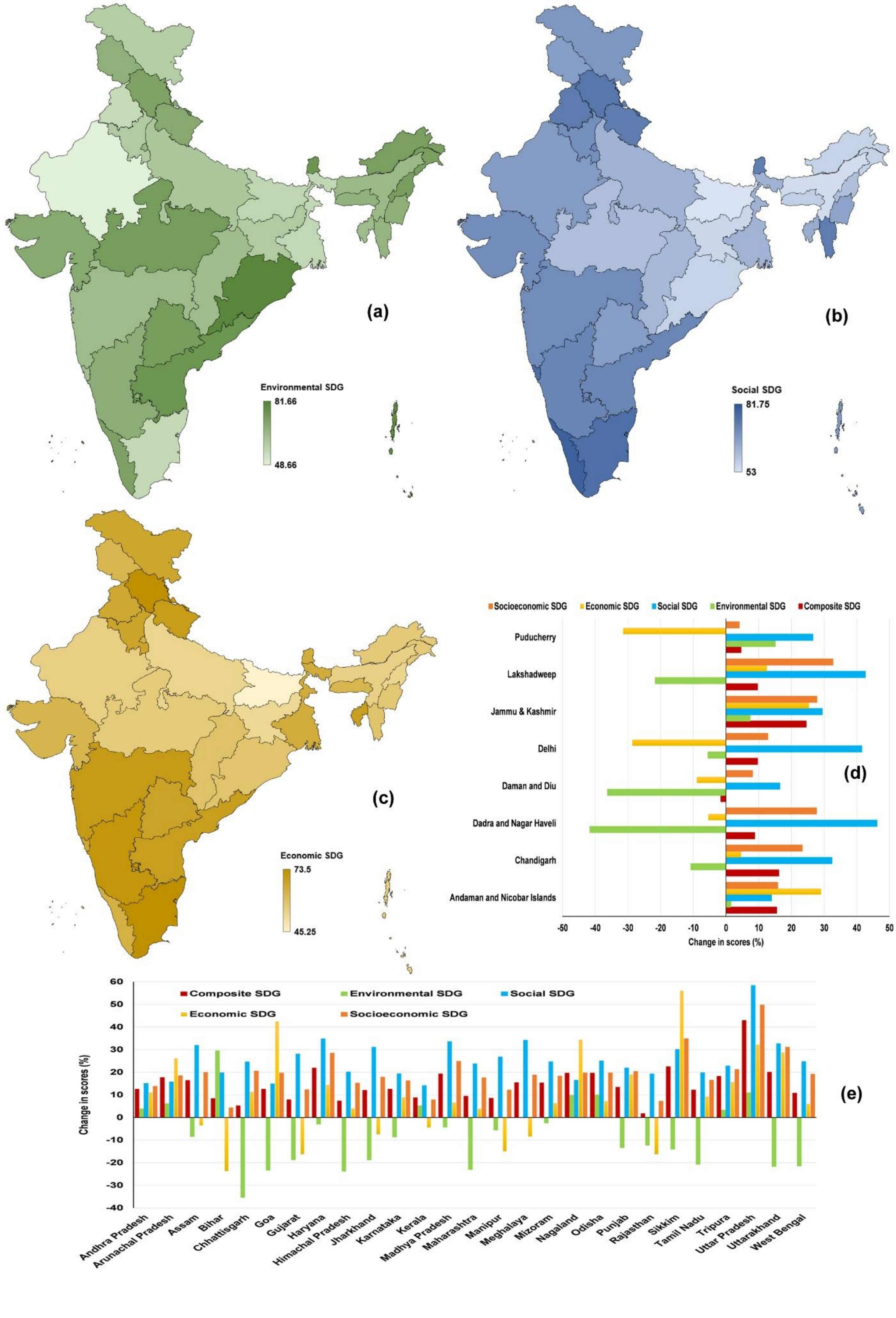

(a)
Environmental SDG
81.66
48.66
(b)
Social SDG
81.75
53
(c)
Economic SDG
73.5
45.25
(d)
Socioeconomic SDG
Economic SDG
Social SDG
Environmental SDG
Composite SDG
Puducherry
Lakshadweep
Jammu & Kashmir
Delhi
Daman and Diu
Dadra and Nagar Haveli
Chandigarh
Andaman and Nicobar Islands
-50
-40
-30
-20
-10
0
10
20
30
40
50
Change in scores (%)
(e)
Composite SDG
Environmental SDG
Social SDG
Economic SDG
Socioeconomic SDG
Change in scores (%)
60
50
40
30
20
10
0
-10
-20
-30
-40
Andhra Pradesh
Arunachal Pradesh
Assam
Bihar
Chhattisgarh
Goa
Gujarat
Haryana
Himachal Pradesh
Jharkhand
Karnataka
Kerala
Madhya Pradesh
Maharashtra
Manipur
Meghalaya
Mizoram
Nagaland
Odisha
Punjab
Rajasthan
Sikkim
Tamil Nadu
Tripura
Uttar Pradesh
Uttarakhand
West Bengal

Figure 2. Distribution of (a) environmental, (b) social, and (c) economic SDG scores in Indian states & UTs. This shows a varied progress across India in environmental SDG (range: 48→81), social (range: 53→81), and economic SDG scores (range: 45→73). Overall changes (%) of grouped SDGs for (d) Indian UTs, and (e) states. Most cumulative negative changes occurred in economic & environmental SDG scores, for both Indian states & UTs.

***Interrelationships*:**

To answer our RQ 2 on how the SDGs interrelate at the goal and indicator levels, we conducted Pearson's correlation analyses. The results revealed complex relationships between different SDGs, with both synergies and trade-offs observed. For the individual SDGs in the Indian States (Figure 3a), a positive correlation (0.47) was observed between SDG 1 and 2. This suggests that policies addressing both issues can be mutually reinforcing. A moderate positive correlation exists between SDG 4 and SDGs 3, 5, and 6, possibly due to increased awareness and access to healthcare information. A weak negative correlation (-0.07) suggested that SDG 9 might create challenges for clean water and sanitation (SDG 6). SDG 7 was positively correlated with several SDGs, including SDG 3, 8, and 9. This signifies the importance of clean energy for overall development. SDG 9 can create jobs and reduce inequality (SDG 10) but also lead to income disparity if not managed effectively. The high correlation (0.451) indicates that promoting responsible consumption patterns (SDG 12) can significantly contribute to combating climate change (SDG 13). The correlation (0.47) suggests that actions to address climate change (SDG 13) can also benefit below-water life (SDG 14). The weak negative correlation (-0.07) might indicate that issues such as deforestation or poaching (SDG 15) could be linked to conflict or a lack of strong institutions (SDG 16). The significant positive correlations between individual SDGs and the composite score (range: 0.33→0.76) reinforced the interconnectedness of the SDGs. These trends can be explained by various factors: (a) many SDGs are inherently linked, e.g., better education (SDG 4) can lead to improved health outcomes (SDG 3), which can contribute to poverty reduction (SDG 1) and gender equality (SDG 5); and (b) well-designed policies can address multiple SDGs simultaneously. For instance, promoting renewable energy (SDG 7) can improve air quality (SDG 3) and reduce greenhouse gas emissions (SDG 13); and (c) some SDGs might have trade-offs. For example, rapid industrialisation (SDG 8) may result in environmental degradation (SDG 12). For Indian States (with SDG 14 in the individual SDGs), the negative correlation (-0.54) indicates that unsustainable consumption practices (SDG 12) can significantly harm life below water (SDG 14). The negative correlations (range: -0.26→-0.67) suggest that many developmental activities have adverse impacts on marine ecosystems (SDG 14).

For Indian UTs in individual SDGs (Figure 3b), the correlation (0.17) between SDG 1 and 2 was weaker, suggesting that poverty reduction efforts might require a stronger focus on hunger eradication strategies. There was a strong positive correlation between the SDG 3 and 4. The surprising negative correlation (-0.17) between SDG 4 and 5 indicated specific challenges in promoting girls' education. The moderate positive correlations between SDG 7 and other SDGs such as SDG 3, 8, and 12 highlight the potential benefits of adopting clean energy. There was a negative correlation (-0.36) between SDG 8 and 12, suggesting that industrial activities might lead to unsustainable consumption patterns. There are strong negative correlations between SDG 14 and most other SDG (range: -0.28→-0.57) are a cause for concern. Development activities in UTs might be harming marine ecosystems. There are positive correlations between Sustainable Cities and Communities (11), and most of the other SDGs. The correlations (range: 0.05→0.61) suggest that developing sustainable cities can contribute to the progress of the multiple SDGs. There was a weak correlation between Life on Land (SDG 15) and Climate Action (SDG 13). The weak correlation (0.02) might indicate that UT-specific environmental challenges related to SDG 15 must be addressed independently of climate action (SDG 13). Factors such as smaller UTs and economies concentrated in specific sectors may influence the correlations between SDGs related to those sectors and others.

For Indian States in the grouped SDGs (Figure 3c), there was a moderate positive correlation (0.24) between the composite SDG and env-SDG scores. The weaker correlation compared to social and economic aspects suggests that environmental considerations might need to be more integrated into development strategies. There was a weak negative correlation (-0.03) between env- and soc-SDG. This surprising trend, although weak, might indicate potential conflicts between social development and environmental sustainability. The weak correlation (0.10) between the econ- and env-SDG scores suggests that economic growth may not necessarily lead to environmental improvements. There was a strong positive correlation (0.97) between the socioecon-SDG and the composite SDG. Socioeconomic development contributes significantly to achieving all SDGs, necessitating policy measures that promote economic and social growth while safeguarding the environment.

For Indian UTs in grouped SDGs (Figure 3d), there was a moderate positive correlation (0.85) between the composite SDG and socioecon-SDGs. This finding suggests that socioeconomic development is important for UTs. There was a negative correlation (-0.5) between the socioecon-SDG and the env-SDG. This is even stronger than the social-environment correlation (-0.42), suggesting that economic growth might come at the cost of environmental degradation, and environmental considerations might lag behind social development efforts. There was a negative correlation between env-SDG and both soc- and econ-SDGs. This emphasises the need to prioritise environmental sustainability along with economic and social development.

Network analysis of the 110 SDG indicators (Figure 3e, Table S.2-S.3) showed high centrality for environmental and health indicators. The highest degree (degree 100) was for DALY attributable to air pollution (SDG 13b), highlighting the environmental-public health nexus in India's sustainable development. The indicators of multidimensional poverty (96, SDG 1a), and under-5 mortality rate (92, SDG 3j) demonstrated high centrality, highlighting persistent challenges in addressing basic human development needs. ATM density was ranked high (92, SDG 8b), suggesting improved access to financial services. Households covered by bank accounts under Pradhan Mantri Jan Dhan Yojana (%) showed remarkably low centrality (4, SDG 8f), indicating potential disparities in financial inclusion. The high centrality of mobile connections (86, SDG 9d) and Internet subscriptions (72, SDG 9c) per capita underscores the growing importance of digital infrastructure in India's developmental trajectory. Indicators focusing on women's political representation (58, SDG 5d), labour force participation (52, SDG 5h), and gender-based violence (28, SDG 5f) showed moderate to low centrality, suggesting a complex landscape for gender equality efforts. Basic literacy rates showed relatively high centrality (76; SDG 4f), and indicators related to higher education enrolment (56, SDG 4d) and teacher training (54, SDG 4j) displayed lower centrality, indicating potential areas for focused intervention in the education sector. The differential centrality of the indicators related to housing quality in urban areas (58, SDG 11e) vs. overall (86, SDG 1b) contexts hints at enduring urban-rural divides in terms of living standards. Indicators spanning forest cover (76; SDG 15a), desertification (44; SDG 15c), and renewable energy adoption (34; SDG 13e) showed varying degrees of centrality, reflecting the complex nature of environmental sustainability efforts in India.

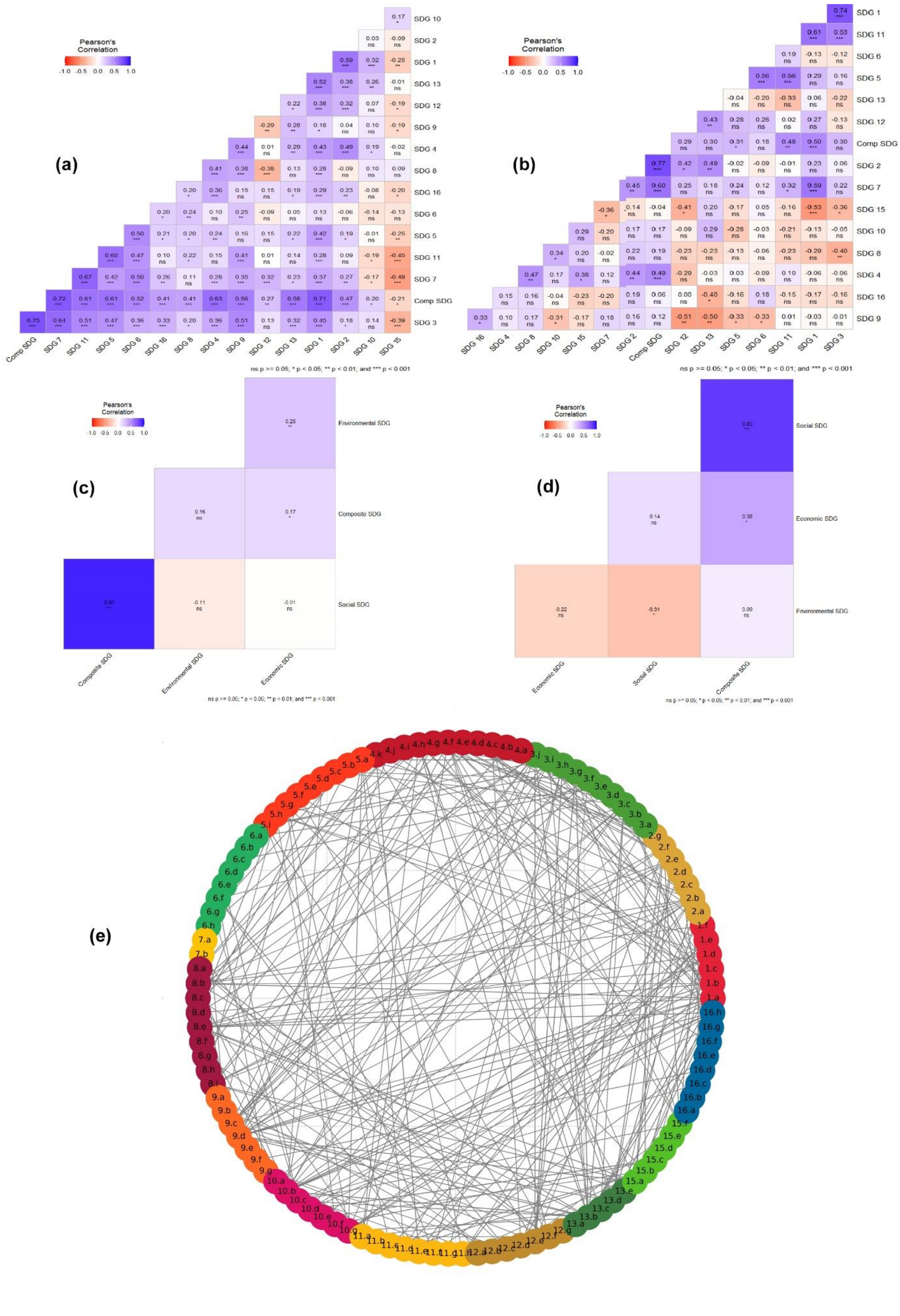

(a)
Pearson's Correlation
-1.0 -0.5 0.0 0.5 1.0
SDG 10
SDG 2
SDG 1
SDG 13
SDG 12
SDG 9
SDG 4
SDG 8
SDG 16
SDG 6
SDG 5
SDG 11
SDG 7
Comp SDG
SDG 3
Comp SDG SDG 7 SDG 11 SDG 5 SDG 6 SDG 16 SDG 8 SDG 4 SDG 9 SDG 12 SDG 13 SDG 1 SDG 2 SDG 10 SDG 15
ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001
(b)
Pearson's Correlation
-1.0 -0.5 0.0 0.5 1.0
SDG 1
SDG 11
SDG 6
SDG 5
SDG 13
SDG 12
Comp SDG
SDG 2
SDG 7
SDG 15
SDG 10
SDG 8
SDG 4
SDG 16
SDG 9
SDG 16 SDG 4 SDG 8 SDG 10 SDG 15 SDG 7 SDG 2 Comp SDG SDG 12 SDG 13 SDG 5 SDG 6 SDG 11 SDG 1 SDG 3
ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001
(c)
Pearson's Correlation
-1.0 -0.5 0.0 0.5 1.0
Environmental SDG
Composite SDG
Social SDG
Composite SDG Environmental SDG Economic SDG
ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001
(d)
Pearson's Correlation
-1.0 -0.5 0.0 0.5 1.0
Social SDG
Economic SDG
Environmental SDG
Economic SDG Social SDG Composite SDG
ns p >= 0.05; * p < 0.05; ** p < 0.01; and *** p < 0.001
(e)

Figure 3. Interrelationships, via Pearson's correlation & network analysis among Indian States & UTs (2018-2020). Pearson's correlation among individual SDGs for (a) Indian states, and (b) UTs. For Indian states, it shows most of the positive correlations existed among SDGs 7, 3, 11, 5, 6, 9, 8 & composite SDG. Negative correlations existed among SDGs 12, 10, 13, 1, 12, 16, 2 & 4. Pearson's correlation among grouped SDGs for (c) Indian states, and (d) UTs. (e) Network analysis of SDG indicators among Indian states & UTs. Here SDG indicators were organised in chronologically (1.a, 1.b, 1.c etc.) anti-clockwise.

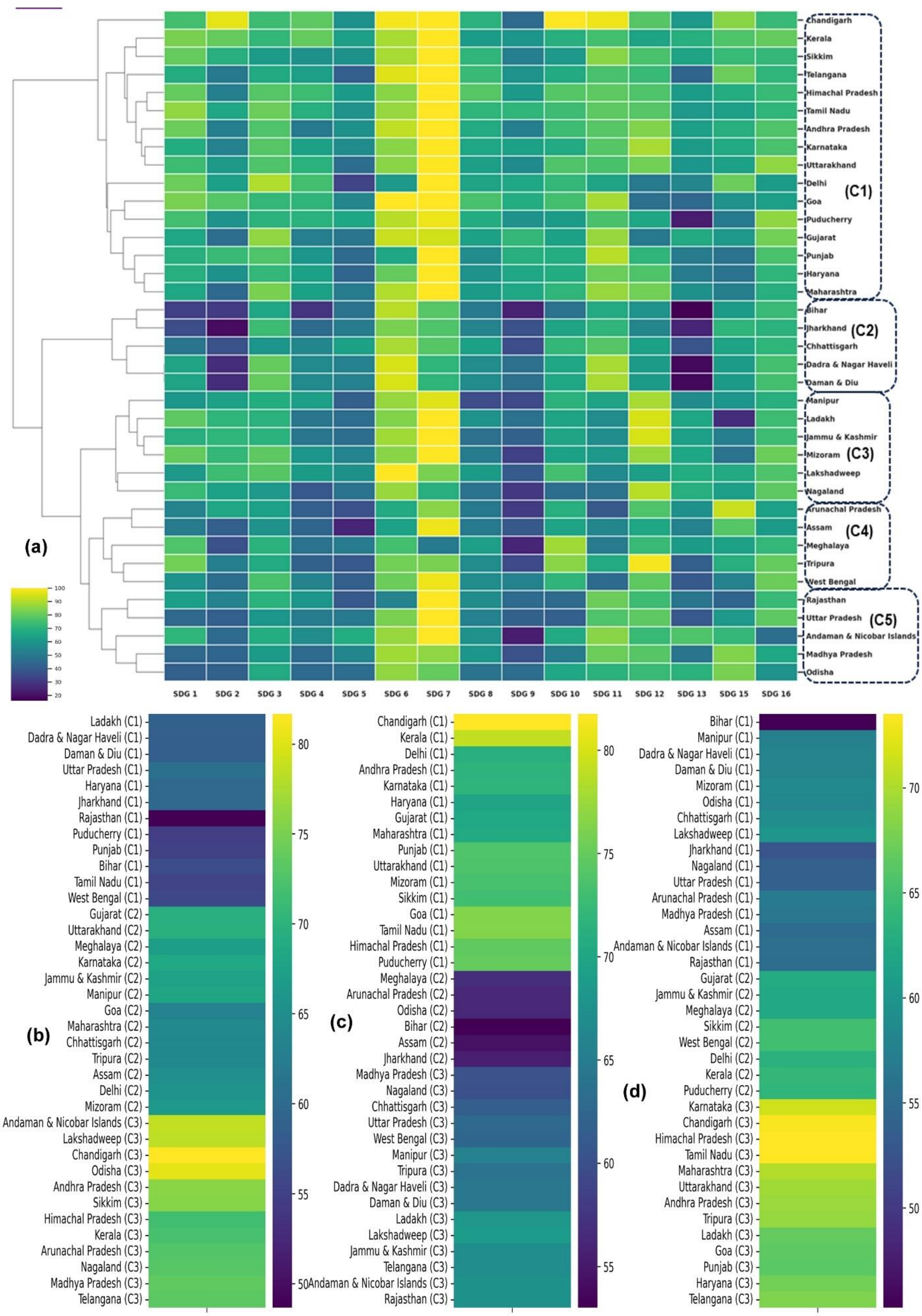
Clustering:

In response to RQ 3 on how Indian states and UTs can be clustered based on their SDG profiles, we employed HCA. This analysis (see Supplementary File 2) revealed distinct regional patterns in SDG achievement, offering insights into targeted policy intervention. The HCA of individual SDGs revealed five distinct clusters (Figure 4a), indicating heterogeneity and regional disparities. Cluster 1 (C1, high performers, n=16) includes economically advanced areas like Kerala, Maharashtra, Tamil Nadu, and Chandigarh. This group consistently achieved high scores across most SDGs, particularly SDG 6 and 7. However, even these leading states struggled with SDG 5. Cluster 2 (C2) consisted of developing states (n=5), primarily from eastern and central India, including Bihar, Jharkhand, and Chhattisgarh. These states face significant challenges, particularly in SDG 1 and 2, while showing moderate progress in basic infrastructure-related goals, such as SDG 6 and 7. Cluster 3 (C3) predominantly comprises northeastern states and island territories (n=6), including Manipur, Mizoram, Nagaland, and Lakshadweep. This group demonstrates mixed performance across SDGs, with strengths in SDG 7 and 12, but challenges in economic and infrastructure-related goals (SDG 8 and 9). Clustering of these geographically distinct areas suggests shared challenges and opportunities related to their unique locations. Cluster 4 (C4), consisting mainly of eastern and northeastern states (n=5) such as Assam, Meghalaya, and West Bengal, exhibits variable performance across SDGs. These states show relative strength in SDG 7 and 10, but face significant challenges in SDG 5 and 9. The diverse SDG scores within this cluster indicated a complex development landscape in the region. Cluster 5 (C5) includes a mix of large central states and coastal regions (n=5) such as Madhya Pradesh, Odisha, Rajasthan, and Uttar Pradesh. This group demonstrated moderate performance across most SDGs, with notable strength in SDG 7, but persistent challenges in SDG 1 and 2. This cluster highlights India's diverse development needs, emphasising the need to tackle poverty and hunger alongside other areas of progress.

The HCA of the grouped SDGs (Figure 4b-d) revealed three clusters for each group. For the env-SDGs (Figure 4b), cluster 1 (n=12, low performers, average: 56) included Bihar, Haryana, and Jharkhand. The presence of both industrialised states (e.g. Tamil Nadu) and agrarian states (e.g. Punjab) in this cluster suggests that environmental challenges cut across different economic structures. States in cluster 2 (n=13, moderate performers, average: 67), including Assam, Chhattisgarh, Delhi, Goa, Gujarat, Jammu and Kashmir, Karnataka, Maharashtra, Manipur, Meghalaya, Mizoram, and Uttarakhand, demonstrated moderate performance in environmental SDGs. Cluster 3 (n=12, high performers, average: 75) comprises areas like Andaman & Nicobar Islands, Andhra Pradesh, Chandigarh, Himachal Pradesh, Kerala, Lakshadweep, Madhya Pradesh, Nagaland, Odisha, Sikkim, and Telangana. The presence of both hilly states (e.g. Himachal Pradesh and Sikkim) and coastal regions (e.g. Kerala, Andaman, and Nicobar Islands) in this cluster suggests that geographical diversity can contribute to strong environmental performance.

Among the soc-SDG clusters (Figure 4c), Cluster 1 (n=16, high performers, average 74) included areas such as Andhra Pradesh, Chandigarh, and Delhi. The states in Cluster 2 (n=6, low performers, average: 55) included Arunachal Pradesh, Assam, Bihar, Jharkhand, Meghalaya, and Odisha. These states, predominantly from the northeastern and eastern regions of India, may face challenges such as poverty reduction, healthcare access, and educational attainment. Cluster 3 (n=15, moderate performers, average: 65) comprises areas like Chhattisgarh, Dadra & Nagar Haveli, Daman & Diu, Jammu & Kashmir, Ladakh, Lakshadweep, Madhya Pradesh, Manipur, Nagaland, Rajasthan, Telangana, Tripura, Uttar Pradesh, and West Bengal. The diverse composition of this cluster indicates widespread social development challenges that require ongoing attention across different regions of India.

Among the econ-SDG clusters (Figure 4d), Cluster 1 (n=16, low performers, average: 56) included areas such as the Andaman and Nicobar Islands, the Arunachal Pradesh, and Assam. Many of these states are from the northeastern, central, and eastern regions of India, highlighting the persistent regional economic disparities. The states in Cluster 2 (n=8, moderate performers, average: 64) include Delhi, Gujarat, Jammu and Kashmir, Kerala, Meghalaya, Puducherry, Sikkim, and West Bengal. Cluster 3 (n=13, high performers, average: 69) comprises areas like Andhra Pradesh, Chandigarh, Goa, Haryana, Himachal Pradesh, Karnataka, Ladakh, Maharashtra, Punjab, Tamil Nadu, Telangana, Tripura, and Uttarakhand. The presence of both traditionally industrialised states (e.g. Maharashtra, Tamil Nadu), and emerging economic powerhouses (e.g. Telangana) in this cluster suggest diverse pathways for economic sustainability.



(a)
SDG 1
SDG 2
SDG 3
SDG 4
SDG 5
SDG 6
SDG 7
SDG 8
SDG 9
SDG 10
SDG 11
SDG 12
SDG 13
SDG 15
SDG 16
Chandigarh
Kerala
Sikkim
Telangana
Himachal Pradesh
Tamil Nadu
Andhra Pradesh
Karnataka
Uttarakhand
Delhi
Goa
Puducherry
Gujarat
Punjab
Haryana
Maharashtra
(C1)
Bihar
Jharkhand
Chhattisgarh
Dadra & Nagar Haveli
Daman & Diu
(C2)
Manipur
Ladakh
Jammu & Kashmir
Mizoram
Lakshadweep
Nagaland
(C3)
Arunachal Pradesh
Assam
Meghalaya
Tripura
West Bengal
(C4)
Rajasthan
Uttar Pradesh
Andaman & Nicobar Islands
Madhya Pradesh
Odisha
(C5)
(b)
Ladakh (C1)
Dadra & Nagar Haveli (C1)
Daman & Diu (C1)
Uttar Pradesh (C1)
Haryana (C1)
Jharkhand (C1)
Rajasthan (C1)
Puducherry (C1)
Punjab (C1)
Bihar (C1)
Tamil Nadu (C1)
West Bengal (C1)
Gujarat (C2)
Uttarakhand (C2)
Meghalaya (C2)
Karnataka (C2)
Jammu & Kashmir (C2)
Manipur (C2)
Goa (C2)
Maharashtra (C2)
Chhattisgarh (C2)
Tripura (C2)
Assam (C2)
Delhi (C2)
Mizoram (C2)
Andaman & Nicobar Islands (C3)
Lakshadweep (C3)
Chandigarh (C3)
Odisha (C3)
Andhra Pradesh (C3)
Sikkim (C3)
Himachal Pradesh (C3)
Kerala (C3)
Arunachal Pradesh (C3)
Nagaland (C3)
Madhya Pradesh (C3)
Telangana (C3)
80
75
70
65
60
55
50
(c)
Chandigarh (C1)
Kerala (C1)
Delhi (C1)
Andhra Pradesh (C1)
Karnataka (C1)
Haryana (C1)
Gujarat (C1)
Maharashtra (C1)
Punjab (C1)
Uttarakhand (C1)
Mizoram (C1)
Sikkim (C1)
Goa (C1)
Tamil Nadu (C1)
Himachal Pradesh (C1)
Puducherry (C1)
Meghalaya (C2)
Arunachal Pradesh (C2)
Odisha (C2)
Bihar (C2)
Assam (C2)
Jharkhand (C2)
Madhya Pradesh (C3)
Nagaland (C3)
Chhattisgarh (C3)
Uttar Pradesh (C3)
West Bengal (C3)
Manipur (C3)
Tripura (C3)
Dadra & Nagar Haveli (C3)
Daman & Diu (C3)
Ladakh (C3)
Lakshadweep (C3)
Jammu & Kashmir (C3)
Telangana (C3)
Andaman & Nicobar Islands (C3)
Rajasthan (C3)
80
75
70
65
60
55
(d)
Bihar (C1)
Manipur (C1)
Dadra & Nagar Haveli (C1)
Daman & Diu (C1)
Mizoram (C1)
Odisha (C1)
Chhattisgarh (C1)
Lakshadweep (C1)
Jharkhand (C1)
Nagaland (C1)
Uttar Pradesh (C1)
Arunachal Pradesh (C1)
Madhya Pradesh (C1)
Assam (C1)
Andaman & Nicobar Islands (C1)
Rajasthan (C1)
Gujarat (C2)
Jammu & Kashmir (C2)
Meghalaya (C2)
Sikkim (C2)
West Bengal (C2)
Delhi (C2)
Kerala (C2)
Puducherry (C2)
Karnataka (C3)
Chandigarh (C3)
Himachal Pradesh (C3)
Tamil Nadu (C3)
Maharashtra (C3)
Uttarakhand (C3)
Andhra Pradesh (C3)
Tripura (C3)
Ladakh (C3)
Goa (C3)
Punjab (C3)
Haryana (C3)
Telangana (C3)
70
65
60
55
50

Figure 4. Clustering (via Hierarchical clustering analysis, HCA) among Indian states & UTs, using (a) individual SDGs, and grouped SDGs: (b) Environmental, (c) Social and (d) Economic SDGs. Cluster identifications have been added in each heatmap (C1/2/3, with area name). It showed 6 clusters for individual SDGs, and 3 clusters for each of grouped SDGs.

***Efficiency*:**

Addressing RQ 4 on the relative efficiency of Indian areas in converting environmental inputs into socioeconomic outputs, we applied input-oriented DEA (see Supplementary File 3). The findings highlight the significant variations in efficiency across the country. In 2020, the efficiency scores for Indian states (Figure 5a) ranged from 1 (Rajasthan, perfectly efficient) to 0.6667 (Nagaland, least efficient), indicating how well states achieved their soc- and econ-SDG scores relative to their env-SDG score. This indicates significant variation in how states translate environmental resources into social and economic well-being. States such as Kerala (1) and Tamil Nadu (1) were considered efficient frontiers. Analysing strategies for social development could be valuable for other states.

Indian UTs (2018) represent the efficiency score for each union territory (DMU) on a scale of 0→1 (Figure 5b). A score of 1 indicates complete efficiency in converting environmental input (env-SDG) into social and economic output (soc- and econ-SDG). Puducherry and Chandigarh were perfectly efficient (1), whereas Dadra and Nagar Haveli were the least efficient (0.475). For the 'slacks' of both input and output measures, a non-zero slack value indicates inefficiency. For example, a value in env-SDG slack >0 implies that a DMU can also achieve the same output using fewer environmental resources. Similarly, slacks in the soc- and econ-SDG scores indicate potential improvements in these areas without changing environmental input. If a DMU has 'slack' in a specific output, the result provides 'targets' for that output measure. These targets represent the minimum improvements required to achieve efficiency in that dimension. For instance, the Andaman and Nicobar Islands require a 50-point improvement in their soc-SDG scores to become efficient. 'Lambdas' refers to the weights assigned to other DMUs when constructing a virtual reference unit on the efficient frontier for each DMU under evaluation.

The efficiency analysis of Indian states (2020) (Figure 5c) used 'targets' and 'slacks' to assess environmental performance. Non-zero slack values for inputs (env-SDG) and outputs (soc- and econ-SDG) indicate potential areas for improvement. Rajasthan achieved a perfect efficiency score (1), but with slack in all categories (env- and output SDGs). States such as Andhra Pradesh (0.71) and Odisha (0.62) have slack in the env-SDGs. They could potentially achieve similar social and economic outcomes with less environmental impacts. Although Kerala excels in social development (efficiency 1), it has slack in the econ-SDG category. This suggests that they might prioritise social development over economic growth, even though they have potential for both. This suggests a potential trade-off that they prioritised. Uttar Pradesh has a lower efficiency score (0.79), but is slack in both the env- and econ-SDGs. This means that higher econ-SDG scores can be achieved by using fewer environmental resources. The 'lambdas' show which states are used as benchmarks (reference points) for improvement by other states. Himachal Pradesh had a high efficiency score (0.95), but relied heavily on references (slack was 0 in most categories). This suggests that external factors may have contributed to their efficiency. States such as Haryana (0.89) and Punjab (0.97) can serve as benchmarks for efficient conversion of environmental resources into economic outcomes. Bihar shows high efficiency (0.86), but with slack in soc-SDGs. This might indicate efficient resource use, but potential shortcomings in social development outcomes. A value of one suggests variable returns to scale (VRS), where the optimal scale can vary. The returns to scale (RTS) indicate that some states have increasing returns to scale (IRS) (e.g. Karnataka), while others have decreasing returns to scale (DRS) (e.g. Madhya Pradesh). This suggests that the relationship between environmental input and social and economic outputs is not always linear.

A nonzero lambda value for a DMU (reference DMU) indicates that the inefficient DMU can learn from the reference DMU to improve its efficiency. For example, the Andaman and Nicobar Islands (Figure 5d) may consider the strategies of Puducherry (reference DMU) to enhance their soc- and econ-SDG scores. Based on the efficiency scores, Puducherry and Chandigarh are the most efficient (1), followed by Jammu and Kashmir (0.75), Delhi (0.68), Andaman and Nicobar Islands (0.61), Daman and Diu (0.51), Dadra and Nagar Haveli (0.475), and Lakshadweep (0.47). All except Puducherry and Chandigarh have room for improvement in their env- to soc- and econ-SDG score conversion.

The Malmquist index analysis (2018-2020) (Figure 5e) showed that Andhra Pradesh (1.039) and Kerala (1.004) had the highest productivity scores in 2019, indicating efficient resource use. Scores > 1 indicate an improvement over the reference technology. Several states showed an increase in their MI scores, including Arunachal Pradesh (1.005→1.12), Haryana

(1.06→1.21), and Mizoram (0.99→1.13). This indicates growth in productivity in these states. Some states, such as Odisha (1.14→0.95) and West Bengal (1.005→0.98), experienced a decrease in MI scores, suggesting potential inefficiencies or a lack of improvement in resource utilisation. Technological change (tc) reflects improvements due to technological advancements or innovation within a state. For instance, Goa (0.99→1.08) and Haryana (0.99→1.13) show significant positive changes in technological change, indicating potential technological progress. The 'pech' represents the change in efficiency due to catching-up to frontier technology. Positive values, such as those in Tripura (1.051→1.05) and Uttar Pradesh (1.309→1.02), suggest an improvement in catching up, whereas negative values may indicate a state of falling behind. The 'sech' shows changes in efficiency due to returns to scale (RTS). A score of 1 indicates constant returns (CRS), >1 indicates increasing returns (IRS), and <1 indicates decreasing returns (DRS). There is significant variation in productivity levels and changes across states. This highlights the need for state-specific policies to address productivity gaps.

The Malmquist index analysis of Indian UTs (2018-2020) (Figure 5f) showed mixed results, with some territories improving and others regressing. MI scores near 1 suggest modest overall productivity growth. Examining individual UTs (e.g. Andaman and Nicobar Islands, Chandigarh), we can observe variations. Some UTs, such as Chandigarh, exhibited scores consistently close to 1, indicating efficient resource utilisation and minimal room for improvement. Others, such as Dadra and Nagar Haveli, show lower MI scores, suggesting the potential for enhancing productivity by either reducing the environmental impact for the same social and economic outcomes (pure efficiency change), or achieving better social and economic outcomes with the same environmental impact (technical change). The MI of the Andaman and Nicobar Islands increased (0.978→1.003), suggesting a slight increase in productivity.

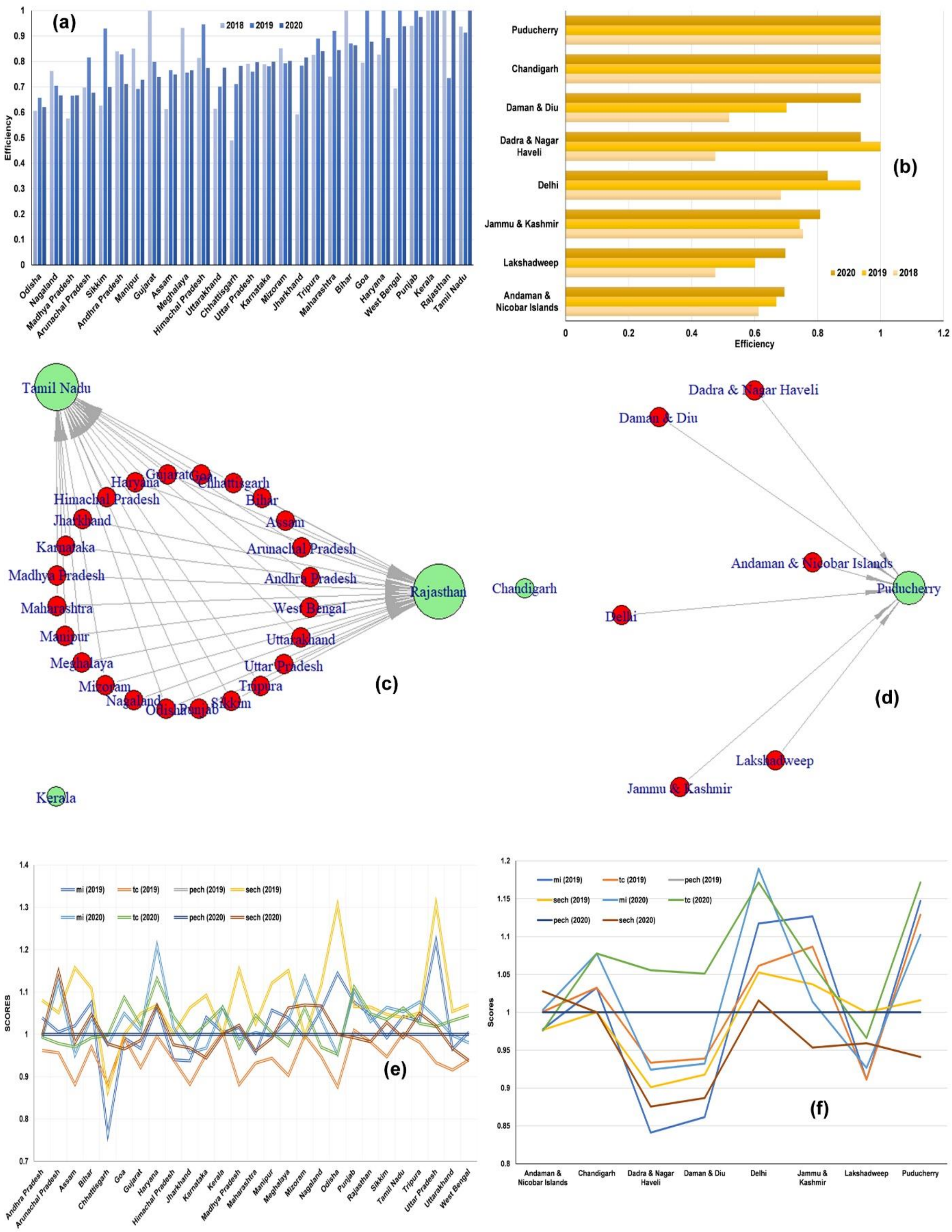

(a)
2018 2019 2020
Efficiency
(b)
Efficiency
2020 2019 2018
Puducherry
Chandigarh
Daman & Diu
Dadra & Nagar Haveli
Delhi
Jammu & Kashmir
Lakshadweep
Andaman & Nicobar Islands
(c)
Tamil Nadu
Rajasthan
Kerala
Chandigarh
(d)
(e)
SCORES
mi (2019) tc (2019) pech (2019) sech (2019)
mi (2020) tc (2020) pech (2020) sech (2020)
(f)
Scores

Figure 5. Efficiency analysis of Indian states and UTs. Trends of efficiency of (a) Indian states, and (b) UTs. It showed efficiencies for most of Indian areas have increased over time. DEA plots for (c) Indian states (2020), and (d) UTs (2018). These showed Tamil Nadu, Rajasthan and Puducherry were reference DMUs for Indian regions. Change in Malmquist index (mi), technical efficiency change (tc), pure efficiency change (pech) and scale efficiency change (sech) by (e) Indian states and (f) UTs (2018-2020).

***Inequality analysis*:**

We conducted a series of inequality analyses to answer RQ 5, which revealed changing patterns of disparity across different SDG dimensions (see Supplementary file 4). The Theil index analysis of individual SDGs in Indian states (2018-2020) showed increased inequality for the composite SDG score (0.02→0.004), suggesting increased overall SDG inequality (Figure 6a). The individual SDGs displayed fluctuations, indicating varying inequality patterns across specific SDGs. Inequality in SDG 3 showed a significant decrease by 2020. The inequality for both SDG 1 and SDG 2 increased during this period. This is surprising because poverty reduction and food security are national priorities in India. Inequality in SDG 6 sharply decreased by 2020. The inequality of SDG 7 remained high throughout. SDG 8 showed a decreasing trend, suggesting a decline in inequality in economic opportunities and decent work throughout India.

Theil index analysis of grouped SDGs (2018-2020) showed a downward trend in composite SDG scores, whereas individual groups fluctuated, indicating varying inequality patterns across the SDGs (Figure 6b). The inequality for the env-SDG remained relatively high throughout the study period, suggesting persistent inequality in environmental sustainability. Inequality for the soc-SDGs shows a decreasing trend, suggesting a decline in inequality regarding aspects of social development, such as education and healthcare. The inequality for the econ-SDGs showed a decreasing trend, suggesting a decline in inequality regarding economic opportunities and growth. Interestingly, inequality in the socioecon-SDG index (combining soc- and econ-SDG) was higher than that in both the individual soc- and econ-SDGs in 2018 and 2019. This suggests that when social and economic factors are considered together, inequality may initially be greater. In 2020, the socioecon-SDG approached the level of individual social and econ-SDG inequalities. This suggests potential convergence in how states address these combined aspects. The overall trend suggests a decrease across most of the SDG groups between 2018 and 2020, indicating progress towards a more equitable distribution of SDG achievements. Inequality in the composite SDG score increased slightly (0.007→0.004).

From the inequality analysis (using the Theil index) of the individual SDGs among Indian UTs (2018-2020) (Figure 6c), the Theil index for the composite SDG score showed a significant decline (0.059→0.002). The individual SDGs displayed mixed results. Some show an improvement (decrease), whereas others exhibit fluctuations. Inequality in SDG 1 sharply decreased by 2020. This indicates a substantial decline in inequality regarding poverty reduction efforts. The inequality in SDG 2 increased in 2019 before decreasing in 2020. Inequality in SDG 3 showed a decreasing trend, suggesting a decline in inequality regarding access to healthcare and outcomes. Inequality in SDG 4 shows a decreasing trend, indicating a decline in inequality regarding access to quality education. Inequality in SDG 5 shows a slight decrease, suggesting a decline in inequality regarding gender equality. Inequality in SDG 6 showed a decreasing trend, suggesting a decline in inequality in access to clean water and sanitation. Inequality in SDG 8 shows a decreasing trend, suggesting a decline in inequality in economic opportunities and decent work.

From the inequality analysis (with the Theil index) among the grouped SDGs of Indian UTs (2018-2020) (Figure 6d), inequality for the composite SDG score displayed a significant decrease (0.003→0.002). This suggests a remarkable reduction in inequality concerning progress towards all SDGs combined. All the SDG groups (Env. Social, Economic, and Socioeconomic) exhibited decreasing inequality over time. Despite starting with the highest inequality in 2018, the env-SDG group showed a significant improvement, suggesting a decline in inequality regarding environmental efforts. The soc-SDG trend indicated a decrease in inequality in access to education, healthcare, and other aspects of social development. The econ-SDG also showed a decreasing trend, suggesting a decline in inequality regarding economic opportunities and growth. The socioecon-SDG remained consistently lower than the individual soc- and econ-SDG indices. This implies that when these aspects are considered together, inequality may be inherently lower compared to separate evaluations. Indian University (UT) has progressed towards SDGs and reduced inequality, showing a favourable trajectory between 2018 and 2020, indicating efforts to distribute SDG achievements more equitably. Although the env-SDG showed improvement over time, its inequality in 2018 was significantly higher than that of the other groups. Even though the env-SDG shows a decreasing trend, the inequality in 2020 (0.0103) remains higher than that of the other groups (social: 0.0026, economic: 0.0032). This suggests that, while progress is happening, addressing environmental inequality might require more targeted efforts. The UTs consistently showed lower inequality in the socioecon-SDGs. Inequality analysis using the Gini index (Figure S1 for states' individual SDGs; Figure S2 for UTs' individual SDGs; Figure S3 for states' grouped SDGs; and Figure S4 for UTs' grouped SDGs) and the Atkinson index (Figure S5 for states' individual SDGs; Figure S6 for UTs' individual SDGs; Figure S7 for states' grouped SDGs; and Figure S8 for UTs' grouped SDGs) were also assessed.

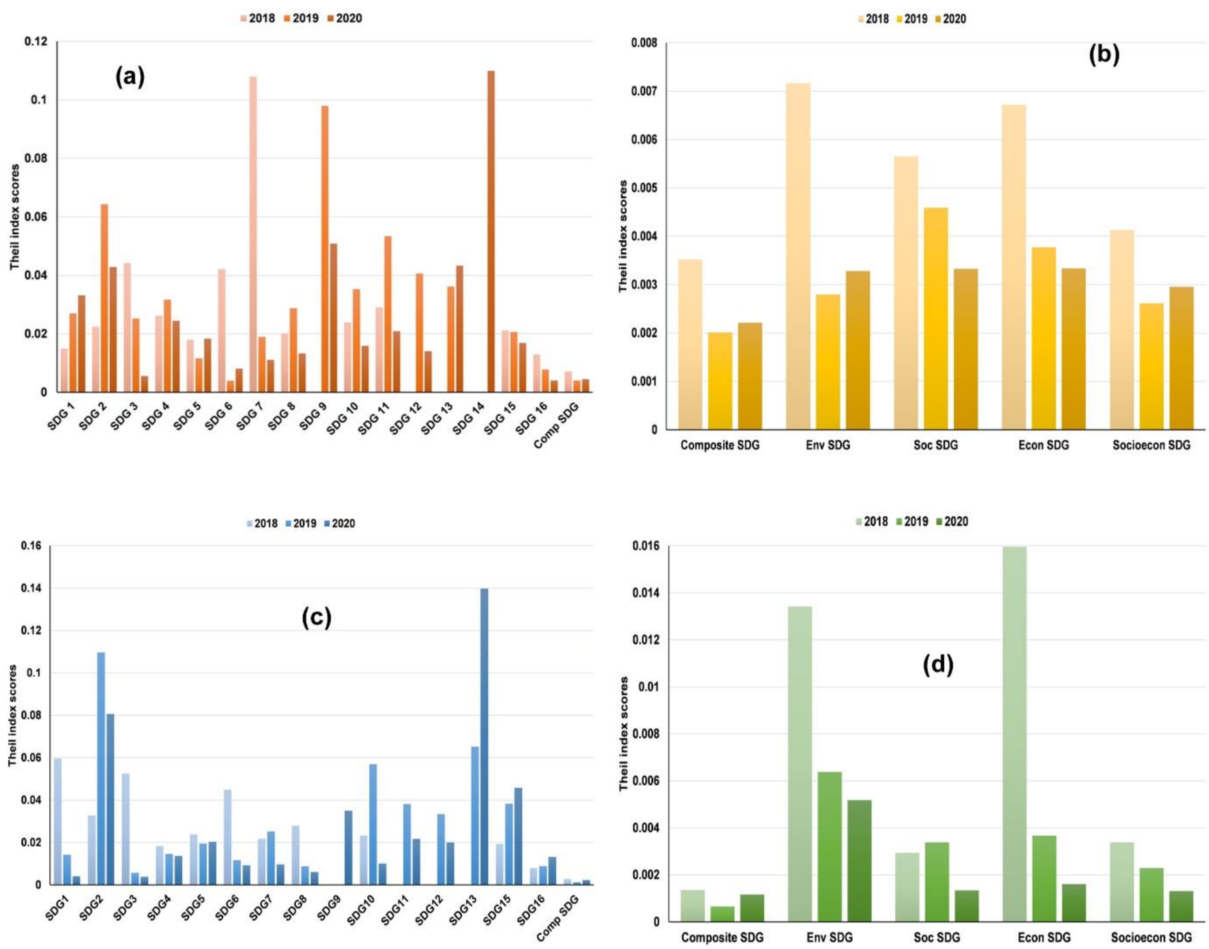


Figure 6. Inequality (with the Theil index) in Indian states and UTs for individual and grouped SDGs (viz. env-SDG, soc-SDG, econ-SDG, and socioecon-SDG. Indian states for (a) individual SDGs, (b) grouped SDGs, Indian UTs for (c) individual SDGs, and (d) grouped SDGs. All of

these showed mixed nature of change in inequalities (increase and decrease) for individual and grouped SDGs for Indian areas.

Evenness:

Area-wise, SDG-wise, and Indian region-wise (2018-2020) Evenness index scores (EIS) and mean index scores (MIS) were calculated (see Supplementary file 5). for Kerala consistently led Indian states with the highest EIS values (Figure 7a), improving from 94.65 to 121.49, indicating a balanced approach to SDGs. Gujarat's score increased (46.85→84.24), while Andhra Pradesh's rose (53.87→83.06). This suggests successful efforts to balance the various SDG indicators. Himachal Pradesh and Karnataka maintained high EIS scores across all three years. Himachal Pradesh improved (72.34→91.06), while Karnataka decreased (71.18→90.32). States, such as Assam and Meghalaya, show significant fluctuations in their EIS scores. Assam's score jumped (24.64→46.15), then dropped to 31.86 in 2020. This volatility might indicate challenges in maintaining consistent progress across all the SDGs. Despite improvements in its MIS (Figure 7b), the EIS of Uttar Pradesh remained comparatively low, increasing only slightly (63.57→47.91).

Among Indian UTs, Chandigarh nearly doubled its EIS (45.29→84.44), indicating balanced SDG progress (Figure 7c). Overall, the UTs showed steady EIS and MIS improvements (Figure 7d), with increasing EIS (29.92→37.88). Lakshadweep's EIS more than doubled (25.19→57.69), indicating substantial improvements in balancing SDG achievements. Delhi showed fluctuations in its EIS, first dropping (44.73→37.1) and then rising to 48.52 in 2020.

Analysis of evenness in individual SDGs (Figure 7e, left) showed a dramatic improvement in SDG 3 (2018-2020, EIS: 15.47→101.56), possibly due to increased health focus during Covid-19. SDG 7 showed consistent progress (EIS: 11→68.45). High performance was maintained, with MIS consistently improving to 84.84, suggesting a sustained focus on SDG 6. Regarding the downward trend in EIS (35.87→12.78), indicating increasing disparities in addressing SDG 2. Slow progress with consistently low EIS scores despite some improvement (5.7→23.8) suggests ongoing challenges in SDG 9. Relatively high and stable scores in both EIS and MIS (Figure 7e, right) across all three years indicate consistent efforts in SDG 16. The decline in EIS (47.85→22.62) suggest challenges in maintaining progress in SDG 15. Significant improvement in EIS increasing (8.26→34.41), indicating progress in SDG 11.

Analysis of the Indian regions (Figure 7f) showed remarkable improvement in the southern region, with EIS (Figure 7f, left) rising from 67.74→106.31, indicating success alongside steady MIS growth. The Northern region exhibits significant volatility in its EIS, peaking (105.11) before dropping (69.37). This variation shows that even with continuous improvements in the overall MIS (Figure 7f, right), it may be difficult to maintain steady, balanced development across the SDGs. The central region showed a dramatic improvement in EIS (45.54→74.13). The northeastern region demonstrated consistent improvement in both EIS and MIS over the three years, with an increase in EIS rising (44.35→68.44). This steady progress indicates sustained efforts to improve the various SDGs in this historically underdeveloped region. The Western region shows an interesting pattern in its EIS, first rising (73.27) and then declining (67.46) while maintaining steady MIS growth.

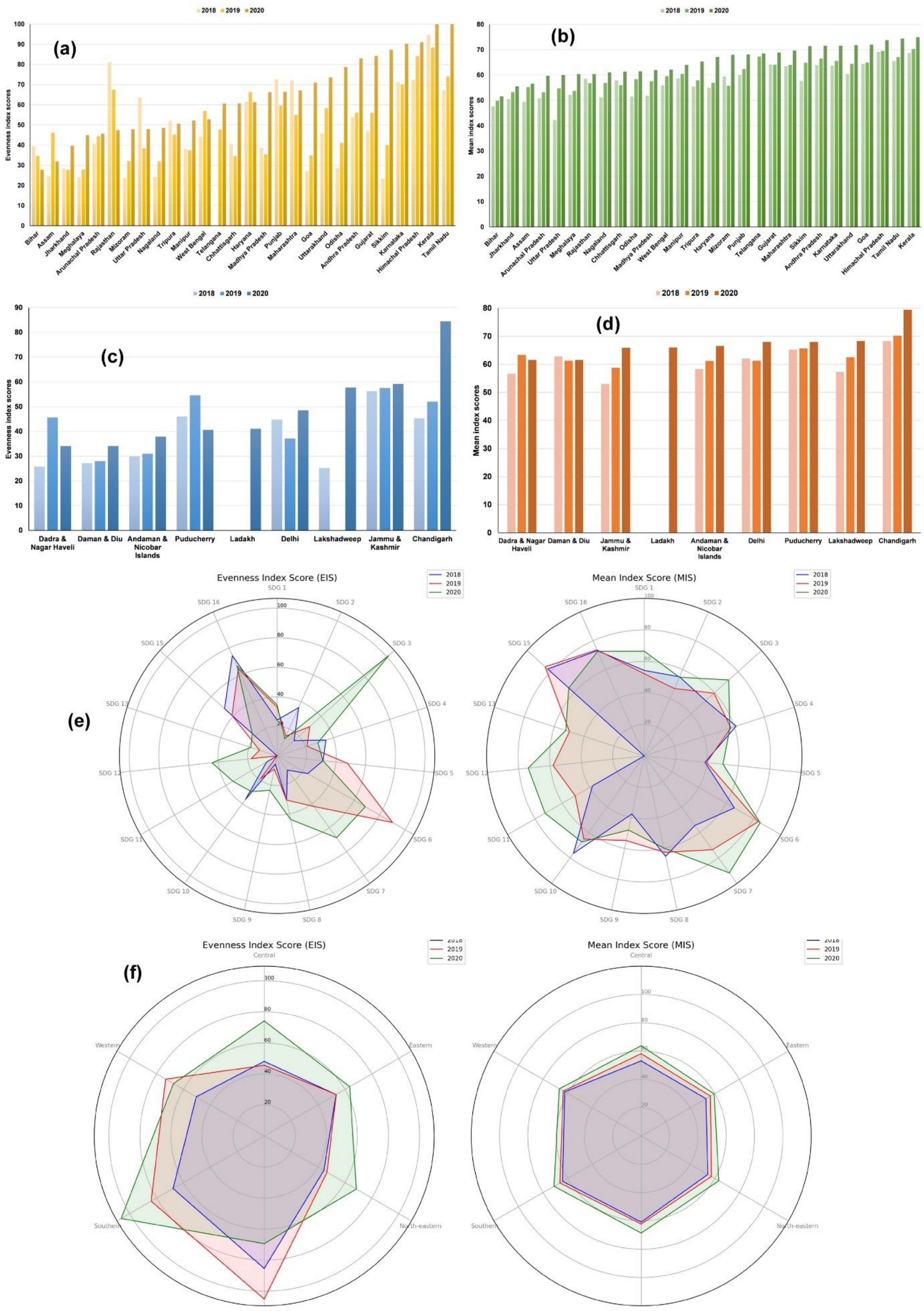

(a)
2018 2019 2020
Evenness index scores
Bihar
Assam
Jharkhand
Meghalaya
Arunachal Pradesh
Rajasthan
Mizoram
Uttar Pradesh
Nagaland
Tripura
Manipur
West Bengal
Telangana
Chhattisgarh
Haryana
Madhya Pradesh
Punjab
Maharashtra
Goa
Uttarakhand
Odisha
Andhra Pradesh
Gujarat
Sikkim
Karnataka
Himachal Pradesh
Kerala
Tamil Nadu
(b)
Mean index scores
(c)
Dadra & Nagar Haveli
Daman & Diu
Andaman & Nicobar Islands
Puducherry
Ladakh
Delhi
Lakshadweep
Jammu & Kashmir
Chandigarh
(d)
(e)
Evenness Index Score (EIS)
Mean Index Score (MIS)
SDG 1
SDG 2
SDG 3
SDG 4
SDG 5
SDG 6
SDG 7
SDG 8
SDG 9
SDG 10
SDG 11
SDG 12
SDG 13
SDG 15
SDG 16
(f)
Central
Eastern
North-eastern
Northern
Southern
Western

Figure 7. Comparative performance of evenness index score (EIS) and mean index score (MIS). EIS (a) & MIS (b) for Indian states. EIS (c) & MIS (d) for Indian UTs. These show year-by-year improvement in both areas in India. EIS (left) & MIS (right) for (e) individual SDGs, and (f) Indian regions (n=6).

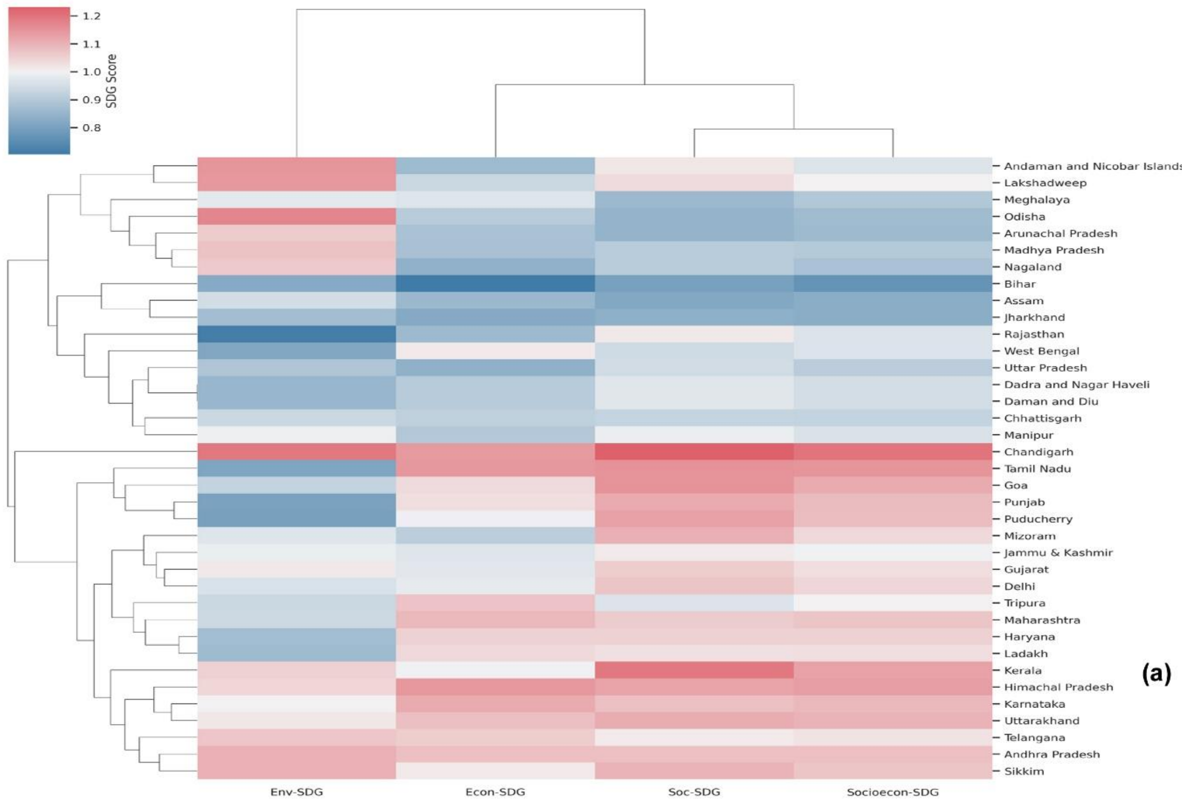
Relative scoring:

Relative performance with national (India), global, East, and South Asian countries (ESA), and lower-middle income (LMI) economies scores were calculated (see Supplementary File 6). Relative to the national scores (Figure 8a), Andhra Pradesh, Odisha, and Sikkim outperformed the env-SDGs, possibly because of stricter environmental regulations and sustainable policies. Southern states (e.g. Kerala, Tamil Nadu), and some northern states (e.g. Himachal Pradesh, Goa) outperformed the national average for soc-SDGs. This suggests advancements in literacy rates, educational attainment, and access to healthcare. Gujarat, Maharashtra, and Tamil Nadu outperformed the national average in terms of the econ-SDGs. This indicates the progress in industrial development, diversification, and infrastructure creation. Bihar and Jharkhand underperform in all SDG groups compared to the national averages. These states require significant improvements in their environmental, social, and economic development. Punjab and Haryana, excel in soc-SDGs but fall short in the env-SDG category. Similarly, northeastern states (e.g. Arunachal Pradesh, Nagaland) might need focused interventions to improve their soc- and econ-SDGs while maintaining their environmental performance.

For Indian UTs, with respect to national scores in grouped SDGs (Figure 8a), Chandigarh emerged as a frontrunner, outperforming the national average in all SDG groups. Andaman and Nicobar Islands and Lakshadweep outperform the national average in env-SDGs. This might be due to stronger environmental regulations aimed at protecting fragile island ecosystems and focusing on conservation and sustainable practices. Chandigarh, Delhi, Puducherry, Jammu, and Kashmir outperformed the national average for soc-SDGs. This points to improvements in the quality of healthcare, access, educational achievement, and literacy rates. Dadra and Nagar Haveli and Daman and Diu underperform in env- and econ-SDGs compared to the national averages. Puducherry, while strong in soc-SDGs, lags behind env-SDGs. Despite its economic strength, Delhi’s performance is below average in the env-SDGs. Sustainable development is essential for effective waste management and pollution control in Delhi.

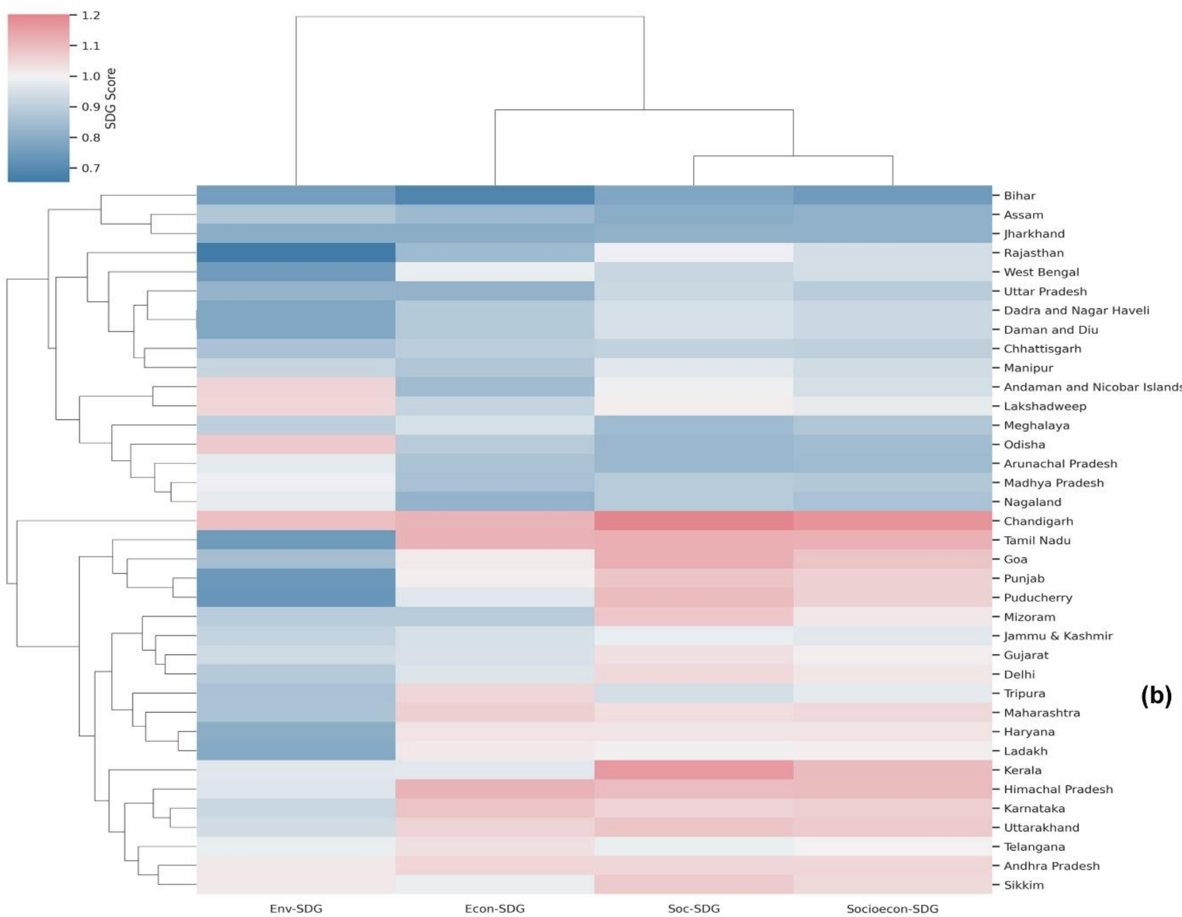
Relative to the global scores (Figure 8b), Goa, Kerala, Mizoram, and Himachal Pradesh excelled in soc-SDGs, possibly because of investments in education and healthcare. Gujarat and Maharashtra outperformed the global average in the econ-SDGs, likely because of their strong industrial bases. Bihar underperformed in all groups, highlighting the need for comprehensive development strategies. The low performance in the env- and econ-SDGs is a concern for Rajasthan. Assam is lagging behind in both env- and soc-SDGs and requires focused interventions. While Andhra Pradesh and Odisha perform well compared to the global average, there is still room for improvement in most states concerning the env-SDGs. States such as Punjab and Tamil Nadu, despite performing well in the soc- and econ-SDGs, were below the global average in the env-SDGs. This highlights the need for a balanced development approach.

Relative to global scores (Figure 8b), Chandigarh, Delhi, Ladakh, and Lakshadweep excelled in soc-SDGs, whereas Chandigarh and Puducherry outperformed the econ-SDGs, possibly because of the focused industrial or service sectors. Dadra, Nagar Haveli, Daman, and Diu underperformed in all groups. The Andaman and Nicobar Islands and Lakshadweep stand out for exceeding the global benchmark in the env-SDGs. However, the social and economic performance of the Andaman and Nicobar Islands require improvement. Chandigarh and Puducherry performed well in the socioecon-SDG, likely because of their combined focus on social development and economic opportunities. Relative score calculations in comparison to East and South Asian countries (ESA, Figure S10) and lower-middle income economies (LMI, Figure S11) were also assessed.



SDG Score
1.2
1.1
1.0
0.9
0.8
Andaman and Nicobar Islands
Lakshadweep
Meghalaya
Odisha
Arunachal Pradesh
Madhya Pradesh
Nagaland
Bihar
Assam
Jharkhand
Rajasthan
West Bengal
Uttar Pradesh
Dadra and Nagar Haveli
Daman and Diu
Chhattisgarh
Manipur
Chandigarh
Tamil Nadu
Goa
Punjab
Puducherry
Mizoram
Jammu & Kashmir
Gujarat
Delhi
Tripura
Maharashtra
Haryana
Ladakh
Kerala
Himachal Pradesh
Karnataka
Uttarakhand
Telangana
Andhra Pradesh
Sikkim
Env-SDG
Econ-SDG
Soc-SDG
Socioecon-SDG

(a)



SDG Score
1.2
1.1
1.0
0.9
0.8
0.7
Bihar
Assam
Jharkhand
Rajasthan
West Bengal
Uttar Pradesh
Dadra and Nagar Haveli
Daman and Diu
Chhattisgarh
Manipur
Andaman and Nicobar Islands
Lakshadweep
Meghalaya
Odisha
Arunachal Pradesh
Madhya Pradesh
Nagaland
Chandigarh
Tamil Nadu
Goa
Punjab
Puducherry
Mizoram
Jammu & Kashmir
Gujarat
Delhi
Tripura
Maharashtra
Haryana
Ladakh
Kerala
Himachal Pradesh
Karnataka
Uttarakhand
Telangana
Andhra Pradesh
Sikkim
Env-SDG
Econ-SDG
Soc-SDG
Socioecon-SDG

(b)

Figure 8. Relative performances of Indian states and UTs with (a) national (Indian average), and (b) global scores. The performances were assessed for grouped SDG categories (viz. Env-SDGs, Soc-SDGs, Econ-SDGs, and Socioecon-SDGs). As per performance, the Indian states and UTs, have been grouped into 2 major and 6 sub-clusters, in both cases.

Discussion

To address RQ1 on the progress and challenges in achieving SDGs, we analysed trends in individual and composite SDG scores across states and UTs over the 2018-2020 period. RQ2 on SDG interrelationships was examined using Pearson's correlation analysis at both goal and indicator levels. The clustering of states and UTs (RQ3) was achieved through Hierarchical Clustering Analysis, whereas the relative efficiency in converting environmental inputs to socioeconomic outputs (RQ4) was assessed using Data Envelopment Analysis. To investigate the evolution of inequality in SDG achievements (RQ5), we employed Theil index analysis. Evenness and mean index score analysis (RQ6) provided insights into the balance and overall level of SDG achievement. A comparative analysis against national and global benchmarks (RQ7) was conducted using relative scoring techniques. Finally, policy recommendations were derived from the synthesis of all analytical results.

Despite social and economic improvements, persistent inequality in the environmental SDGs necessitates integrated policy approaches. This aligns with the recommendations of Ningrum et al. (2024) for enabling local actions on the SDGs. However, our findings emphasise the need for such integration at the state level in India.

The superior SDG performance of the southern and northern states can be attributed to historical investments in social infrastructure, particularly education and healthcare, aligning with Panda and Mohanty's (2019) findings on health-related SDGs in India. This long-term investment likely created a strong foundation for broader SDG achievements. The lagging performance of the central and eastern states, particularly in SDGs related to poverty reduction and economic growth, may be linked to historical patterns of industrialisation and agricultural development. As noted by Jatav (2021), states like Bihar and Jharkhand have faced persistent challenges in attracting investment and diversifying their economies, which our findings suggest will continue to impact their SDG progress. The clustering of the state and UT based on SDG profiles enables peer learning and knowledge exchange, echoing Saiu and Blečić's (2022) approach to Italian regions. For instance, Kerala's success in balancing social development with environmental sustainability could offer valuable lessons for other states in its cluster.

The complex interrelationships we observed between the SDGs, particularly the trade-offs between economic growth and environmental sustainability, echo the findings of Mainali et al. (2018) in their study of South Asian countries. However, our subnational research paints a more complex picture of these linkages in India. The interrelationships between individual SDGs point to both synergies and trade-offs, which policymakers must navigate to provide a foundation for broader SDG achievements (Kroll et al. 2019). However, the complex and sometimes negative linkages among industrialisation, resource consumption, and environmental protection underscore the challenges of balancing economic growth with sustainability.

Our identification of distinct regional clusters based on SDG profiles builds upon the work of Senadjki et al. (2022) and Zhilin et al. (2020), who emphasised the importance of regional archetypes in sustainable development planning. Our findings extend this concept to the Indian context and offer valuable insights into targeted policy interventions. For example, Himalayan states share common environmental challenges that may benefit from collaborative solutions. Conversely, the unique positioning of union territories like Chandigarh and Lakshadweep suggests the need for governance models tailored to their distinct urban and island characteristics.

Our efficiency analysis, which identified 'benchmark' states, offers a novel approach to optimising resource utilisation in the Indian context. This builds on the work of Gao et al. (2021) in China; however, our focus on environmental inputs and socioeconomic outputs provides a unique perspective on sustainable development efficiency. More intricate linkages between the environmental, social, and economic elements are highlighted by the analysis of slacks and returns to scale, which helps inform more balanced policy actions.

Our findings on significant SDG performance variations across Indian states and UTs align with studies of other regions or countries, such as Wang et al.'s (2020) observations in Chinese provinces. However, our results reveal more pronounced disparities between the southern/northern and central/eastern regions of India, highlighting the unique challenges of India's diverse socioeconomic landscape. Despite improvements in social and economic dimensions, the stark disparities in environmental SDG performance highlight the complex challenges of balancing development with sustainability across India. This aligns with Roy and Pramanick's (2019) observations regarding the trade-offs between water resource management (SDG 6) and other development goals in India. Our subnational analysis reveals that these trade-offs are particularly pronounced in rapidly industrialising states, such as Gujarat and Maharashtra.

The Evenness study provided a complex picture of India's progress towards subnational SDGs. The dramatic improvement in the EIS of SDG 3 likely reflects the heightened focus on health systems owing to the Covid-19 pandemic, demonstrating the potential for rapid progress when resources are concentrated. Conversely, the downward trend in the EIS of SDG 2 indicated growing disparities in addressing food security and nutrition. Regional analysis further illuminates geographical variations, with the southern region showing remarkable improvement, while the northern region exhibits significant volatility. These findings underscore the importance of tailoring interventions to regional contexts and fostering interstate learning to promote more balanced and equitable progress across all SDGs.

Overall, this sub-national analysis of India's sustainable development landscape underscores the complexity of the challenges faced and the critical need for contextualised, evidence-based policymaking (Ningrum et al., 2024; Purwaningrum et al., 2020; Szetey et al., 2020). India can achieve the SDGs more inclusively and sustainably by leveraging subnational experiences, strengthening institutions, and promoting inter-state collaboration.

Like any other study, this study has a few limitations that need to be mitigated in the future.

(a) *Limited timeframe*: The study's data from 2018-2020 (data for 2021-2022 are exactly the same as the data for 2020) may not fully capture long-term trends or policy impacts, necessitating future studies to extend the timeframe for a more comprehensive analysis.

(b) *Data limitations*: Population-weighted indices were not computed because of the lack of official annual population statistics. Future research should use more comprehensive and updated demographic data.

(c) *Focus on quantitative metrics*: This study may not fully capture the qualitative aspects of sustainable development, suggesting future research using mixed methods, including qualitative assessments and case studies.

(d) *Lack of stakeholder perspectives*: This study relies on statistical data and lacks direct input from policymakers, citizens, or stakeholders, suggesting that future research should include interviews, surveys, or focus groups.

These modifications in subsequent research may contribute to a more thorough assessment of India's subnational progress towards sustainable development.

Policy recommendations:

This section outlines the key policy recommendations (Figure 9) derived from our analyses, addressing the environmental, social, and economic dimensions of achieving SDGs. By focusing on these areas, policymakers can create a more sustainable and equitable future.

(a) For Environment:

1. *Integrate environmental considerations into development planning*: Integrate environmental considerations into development planning by establishing state-level Sustainable Development Committees to review major projects through an SDG perspective. For instance, the high-performing clusters in the env-SDGs, including Andhra Pradesh, Himachal Pradesh, and Sikkim, could serve as benchmarks for sustainable practices.

2. *Prioritise sustainable consumption and production*: Encourage resource efficiency and waste reduction, particularly in states such as Tamil Nadu and Punjab, which showed lower env-SDG scores despite their strong economic performance. Introduce state-level tax incentives for businesses adopting circular economy practices and implement extended producer responsibility (EPR) schemes across all areas.

3. *Balance economic growth with environmental protection*: Adopt clean technologies and robust environmental governance, especially in rapidly developing states such as Gujarat and Maharashtra, which outperformed economic SDGs but lagged in environmental metrics. Develop and implement state-specific Green GDP indicators to measure economic growth while accounting for environmental costs. Use of these indicators in state budget allocation.

4. *Develop region-specific environmental strategies*: Tailor approaches to local challenges, as exemplified by the successful environmental performance of island territories like Lakshadweep and the Andaman & Nicobar Islands. Create a national platform for states to share best practices in environmental management. Allocate central funds for states to develop and implement tailored environmental action plans.

(b) For Society:

1. *Foster equitable development*: Address social and environmental concerns alongside economic growth, particularly in states like Bihar and Jharkhand, which consistently underperformed across

all SDG dimensions. Establish an SDG Equalisation Fund that provides additional resources to underperforming states, with disbursements linked to specific SDG targets and milestones.

2. *Strengthen the nexus between poverty, hunger, and education*: Invest in quality education for vulnerable groups, focusing on states such as Uttar Pradesh and Madhya Pradesh, which faced persistent challenges in SDGs 1 and 2. Implement integrated social protection programs that link cash transfers to school attendance and nutrition outcomes, tailored to the specific challenges of each state.

3. *Enhance governance and institutional capacity*: Improve the ability of government agencies and civil society to implement SDG policies effectively, drawing lessons from high-performing states such as Kerala and Himachal Pradesh. Launch a National SDG Capacity Building Programme, providing training and resources to state-level officials on SDG implementation, monitoring, and reporting.

4. *Promote inter-state and inter-UT collaboration*: Facilitate knowledge sharing and joint initiatives, particularly among states within the same cluster, as identified in hierarchical clustering analysis. Establish formal SDG partnerships between high-performing and low-performing states, facilitated by NITI Aayog, with regular knowledge exchange workshops and joint projects.

(c) **For Economy:**

1. *Develop region-specific economic strategies*: Tailor interventions based on the distinct SDG profiles identified in the clustering analysis, such as focusing on infrastructure development in the northeastern state cluster.

2. *Leverage high-performing areas as benchmarks*: Identify and disseminate best practices from efficient states such as Rajasthan and Kerala, as highlighted in the Data Envelopment Analysis.

3. *Foster economic diversification and innovation*: Promote entrepreneurship and skill development, particularly in states such as Bihar and Jharkhand, which showed consistently low scores in economic SDGs.

4. *Improve efficiency and productivity*: Optimise resource utilisation based on the Malmquist Index analysis, which revealed productivity changes over time. For example, states such as Arunachal Pradesh and Haryana, which have shown significant improvements, could offer valuable insights.

5. *Strengthen inter-regional economic cooperation*: Facilitate resource pooling and joint projects among states within the same economic cluster, as identified in the hierarchical clustering analysis of economic SDGs.

Overall, we advise creating a centralised SDG Data Portal (if possible sectoral, with public access) that standardises data collection methodologies across states and provides real-time tracking of SDG indicators at the district level towards data-driven policymaking. Based on the empirical findings of this study, these policy proposals provide an informed strategy to address India's unique sustainable development concerns sub-nationally.

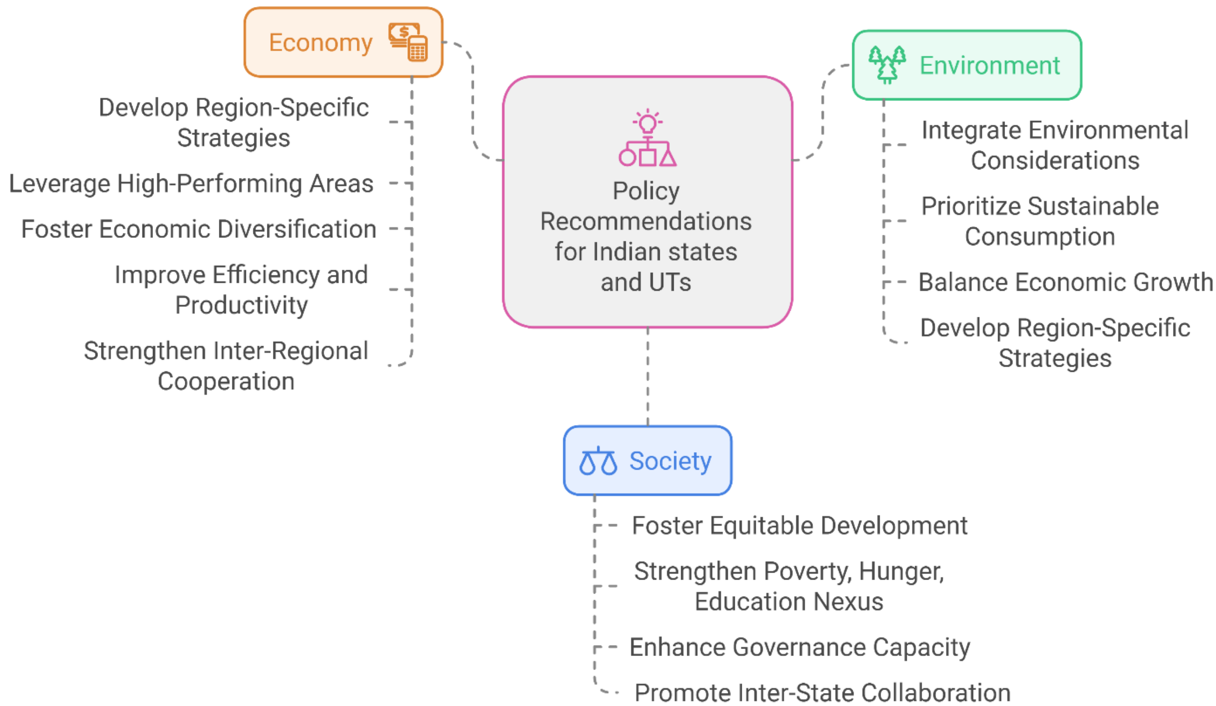


Figure 9. Sectoral policy suggestions for Indian states and union territories.

Conclusion:

This report offers a comprehensive overview of the obstacles facing India's subnational SDG progress. The stark variations in performance across states and union territories highlight the importance of moving beyond national-level assessments to develop tailored, context-specific policies and strategies.

The key findings of this study are as follows:

- Significant disparities in SDG performance between the southern/northern and central/eastern states underscore India's complex developmental landscape.
- Five distinct state clusters, based on SDG profiles, offer insights into peer learning and targeted interventions.
- SDGs exhibit complex interrelationships with synergies and trade-offs, particularly between economic growth and environmental sustainability.
- Persistent inequality in environmental SDGs despite improvements in social and economic dimensions highlights the need for more integrated policy approaches.
- The identification of high-performing 'benchmark' states through efficiency analysis, providing valuable insights for optimising resource utilisation.

This study contributes to the existing literature by providing the first comprehensive subnational analysis of SDG progress in India, and offers a methodological framework applicable to other diverse systems globally. Our results highlight the necessity of implementing context-dependent policies that balance the social, economic, and environmental SDGs.

Future research should address these limitations and build upon our findings in several ways.

- Extending the analysis timeframe will provide deeper insights into long-term SDG progress trends, allowing for a more comprehensive tracking of sustainable development efforts.
- Incorporating more qualitative data, such as case studies and stakeholder interviews, can enrich the context of quantitative analyses and offer a more holistic understanding of the factors driving SDG progress.
- Advancing modelling techniques will enhance our ability to project future SDG trajectories and assess the impacts of various policy interventions, contributing to more robust decision-making frameworks.
- Comparative analyses with other areas (regions or countries) will help identify shared challenges and successful strategies for subnational SDG implementation, broadening the applicability of the findings.
- Investigating the influence of governance structures and institutional capacities will deepen our understanding of how different contexts shape the outcomes of subnational SDG.

- Exploring the role of non-state actors, including businesses and civil society organisations, can shed light on their contributions to driving progress at the local level, offering insights into collaborative efforts for sustainable development.
- Examining the interplay between SDG progress and other development indicators not formally included in the SDG framework can uncover additional synergies or trade-offs, thus providing a fuller picture of sustainable development dynamics.

This research provides policymakers with a starting point for monitoring the advancement of the subnational SDG’s in India. Leveraging diverse subnational experiences, strengthening institutions, and fostering inter-state collaboration can accelerate India's progress towards the SDGs. Subsequent investigations into this topic will be essential to improve our comprehension of the prospects and difficulties associated with sustainable development in intricate government structures, such as India.

Annex:

Table. List of UN SDGs and their names.

SDGs	Names
SDG 1	No Poverty
SDG 2	Zero Hunger
SDG 3	Good Health and Well-being
SDG 4	Quality Education
SDG 5	Gender Equality
SDG 6	Clean Water and Sanitation
SDG 7	Affordable and Clean Energy
SDG 8	Decent Work and Economic Growth
SDG 9	Industry, Innovation, and Infrastructure
SDG 10	Reduced Inequalities
SDG 11	Sustainable Cities and Communities
SDG 12	Responsible Consumption and Production
SDG 13	Climate Action
SDG 14	Life Below Water
SDG 15	Life on Land
SDG 16	Peace, Justice, and Strong Institutions
SDG 17	Partnerships for the Goals

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