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Tackling Non-CO_2 Emissions: Pathways for Himachal Pradesh

Prepared by

Department of Environment, Science Technology & Climate Change (DoEST&CC), Government of Himachal Pradesh

Supported by

Institute for Governance & Sustainable Development (IGSD) and The Energy & Resources Institute (TERI)

For more information
Department of Environment, Science Technology & Climate Change (DEST&CC)
Government of Himachal Pradesh
Paryavaran Bhawan, US Club, Shimla, Himachal Pradesh-171001
www.dest.hp.gov.in
and
Institute for Governance & Sustainable Development (IGSD)

Contributions

Department of Environment, Science Technology & Climate Change (DEST&CC) Team

Sh. S. K Singla, IFS, Envt Secy, DoESTCC, Government of Himachal Pradesh
Sh. D.C. Rana, IAS, Director, DoESTCC, Government of Himachal Pradesh
Dr. Suresh C. Attri, Chief Scientific Officer, DoESTCC, Government of Himachal Pradesh
Sh. D.C. Thakur, Environment Officer, DoESTCC, Government of Himachal Pradesh

IGSD Team

Mr. Akshat Patni, Head of Research
Ms. Zerin Osho, Director
Ms. Pranjali Chowdhary, Research and Policy Associate
Ms. Nehal Sharma, Program Lead
Mr. Asad Ali, Communications Manager
Mr. Nikhil Kumar, Head of Communications
Ms. Ravleen Kaur, Government Affairs Manager
Mr. Shivang Agarwal, Senior Fellow
Mr. Rishi Bakshi, Consultant
Mr. Atharva Deshmukh, Research and Policy Associate
Ms. Bhhavya Kapoor, Research and Policy Associate

TERI Team

Mr. Nimish Singh, Fellow
Mr. Justin Jacob, Research Associate
Dr. Arindam Datta, Senior Fellow
Mr. Prabhat Sharma, Associate Fellow
Mr. Dheeraj Mehra, Research Associate
Ms. Shivani Sharma, Associate Fellow
Md. Hafizur Rahman, Fellow
Dr. Divyansh Sharma, Research Associate
Mr. R Suresh, Senior Fellow & Area Convenor
Ms. Shweta Gautam, Associate Fellow
Ms. Krishnapriya Nair, Research Associate & Area Convenor
Mr. Sai Dinesh, Research Associate
Ms. Suruchi Bhadwal (Advisor), Senior Fellow and Program Director
Dr. Manish Kumar Shrivastava (Advisor), Senior Fellow and Associate Director

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Glossary

Baseline Scenario (BAU): A Business-as-Usual (BAU) scenario that represents the sectoral growth projections for the state of Himachal Pradesh under existing conditions, without considering the implementation of any specific mitigation actions or interventions to address Short Lived Climate Pollutant (SLCP) emissions.

Alternative Scenarios (ALT): These scenarios assume the successful implementation of additional interventions aimed at reducing SLCP emissions. They assess the impact of these measures on both short-term (2030) and long-term (2047) policy targets. The interventions include specific sectoral policies planned by the state or similar measures being implemented in other parts of the country.

Global Warming Potential (GWP): An index to measure the potency of greenhouses gases to absorb infrared thermal radiation over a given time frame after their addition to the atmosphere.

Short-lived Climate Pollutants (SLCPs): They are gases and other pollutants that contribute to global warming but have a relatively shorter lifespan in the atmosphere compared to long-lived greenhouse gases like carbon dioxide. They include substances like BC, methane, tropospheric ozone, and some hydrofluorocarbons (HFCs).

Emission Factors: A coefficient representing the amount of a specific pollutant emitted per unit of activity or fuel consumed in a sector.

Emission Inventory: A comprehensive dataset that estimates emissions of different pollutants from various sources within a defined region and period.

Urban Heat Island (UHI) effect: This refers to the phenomenon where urban areas experience significantly higher temperatures than their surrounding rural areas. This difference in temperature is primarily due to human activities and urban development, which alter land surfaces and environments.

Natural Farming in Rice Cropping: A sustainable agricultural practice that minimizes chemical inputs by relying on natural soil processes, organic matter, and microbial activity to enhance soil fertility.

Heat Stress: A condition resulting from prolonged exposure to high temperatures, often exacerbated by climate change and urbanization. It can lead to adverse health effects such as dehydration, heat exhaustion, and heatstroke, particularly among vulnerable populations.

Co-benefits: Additional advantages gained from implementing climate and air pollution mitigation policies, such as improved public health, food security, and economic benefits

List of Abbreviations

APCDs	Air Pollution Control Devices
AQI	Air Quality Index
BAU	Business-As-Usual
BC	Black Carbon
CAAQMS	Continuous Ambient Air Quality Monitoring Stations
CAFE	Corporate Average Fuel Efficiency
CAGR	Compound Annual Growth Rate
CEA	Central Electricity Authority
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CPCB	Central Pollution Control Board
DMS	Dimethyl sulphide
DSR	Direct Seeded Rice
FAME	Faster Adoption and Manufacturing of (Hybrid) and Electric Vehicles
FGD	Flue Gas Desulfurization
GHG	Greenhouse Gas
GWP	Global Warming Potential
H-CNG	Hydrogen-Compressed Natural Gas
HAMP	Heat Action Management Plan
HFCs	Hydrofluorocarbons
ICAP	India Cooling Action Plan
IPCC	Intergovernmental Panel on Climate Change
ITMS	Integrated Traffic Management System
LPG	Liquefied Petroleum Gas
MNRE	Ministry of New and Renewable Energy
MoEFCC	Ministry of Environment, Forest and Climate Change
MoPNG	Ministry of Petroleum & Natural Gas
MoRTH	Ministry of Road Transport & Highways
NAAQS	National Ambient Air Quality Standards
NAMP	National Air Monitoring Programme
NCAP	National Clean Air Programme
NDDB	National Dairy Development Board
NH_3	Ammonia
NMVOCS	Non-methane Volatile Organic Compounds
NO_x	Nitrogen Oxides
NRRI	National Rice Research Institute
NSSO	National Sample Survey Office
O_3	Tropospheric Ozone
OH	Hydroxide
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter ≤2.5 microns
PM_{10}	Particulate Matter ≤10 microns
SAPCC	State Action Plan on Climate Change
SCR	Selective Catalytic Reduction
SDGs	Sustainable Development Goals
SLCPs	Short-lived Climate Pollutants
SO_2	Sulphur Dioxide
SRI	System of Rice Intensification
UNEP	United Nations Environment Programme
VOCs	Volatile Organic Compounds

Chief Minister
Himachal Pradesh
Shimla-171002

MESSAGE

Himachal Pradesh is a state defined by natural beauty, ecological richness, and environmental responsibility. Our mountains, forests, rivers, and glaciers are not only the foundation of our identity but also critical lifelines for millions of people within and beyond our borders. Protecting this fragile Himalayan ecosystem is not merely a policy priority—it is a duty to our future generations.

This report on Non-CO_2 Emission Reduction Pathways for Himachal Pradesh represents a significant milestone in our journey towards climate leadership. By focusing on Short-Lived Climate Pollutants (SLCPs) such as methane and black carbon, the study highlights the urgent need to address near-term warming and air quality challenges that directly impact our glaciers, agriculture, tourism, and public health. The findings reinforce what science has long shown—reducing SLCPs can deliver immediate climate benefits, slow glacier melt, and improve the quality of life for our citizens.

Himachal Pradesh has already taken progressive steps, from promoting clean cooking and electric mobility to strengthening waste management and advancing renewable energy. However, the path ahead requires greater collaboration, innovation, and sector-specific action. This report provides a data-driven roadmap to reduce emissions across residential energy use, transport, industry, agriculture, livestock, and waste. Its recommendations will support us in integrating SLCP mitigation into our climate strategies, including the State Action Plan on Climate Change.

I commend Department of Environment, Science Technology & Climate Change, Himachal Pradesh, The Energy and Resources Institute (TERI), the Institute for Governance & Sustainable Development (IGSD), and all stakeholders who contributed to this important study. The Government of Himachal Pradesh remains fully committed to translating these insights into action, fostering green jobs, strengthening resilience, and ensuring that our state continues to lead by example.

Let us work together—government, industry, communities, and youth—to protect the pristine Himalayas and secure a cleaner, healthier, and climate-resilient Himachal Pradesh.

(Sukhvinder Singh Sukhu)

Chief Secretary
Himachal Pradesh
Shimla-171002

MESSAGE

Himachal Pradesh stands at a pivotal point in time. As a mountainous state with a fragile ecosystem and rapidly evolving developmental needs, we face a dual challenge—promoting economic growth while safeguarding environmental integrity. Rising temperatures, changing snowfall patterns, forest fires, and strained water resources are early indicators of climate stress that demand urgent and coordinated response.

This report on Non-CO_2 Emission Reduction Pathways provides a comprehensive and first-of-its-kind assessment for the state. By establishing a baseline of Short-Lived Climate Pollutants and other non-CO_2 emissions, and modelling alternative scenarios through 2047, it offers us actionable insights for sectoral planning. The analysis clearly identifies priority sectors—transport, residential energy, industry, agriculture, livestock, and waste—and outlines pathways for emission reduction aligned with state and national missions.

The study's emphasis on SLCPs is particularly relevant for Himachal Pradesh, given their direct link to glacier melt, air quality deterioration, and public health impacts. It underscores the importance of integrating SLCP mitigation into urban planning, mobility strategies, rural energy access, agricultural practices, and waste management systems. Strengthening data systems, enhancing inter-departmental coordination, and enabling capacity building will be key to implementation.

The Government of Himachal Pradesh recognizes the value of evidence-based policymaking. This report will serve as an important frame of reference for departments, boards, and local bodies in designing programmes, mobilizing finance, and aligning interventions under the SAPCC, NCAP, and other state initiatives. We also acknowledge the critical role of communities, civil society, academia, and the private sector in ensuring successful outcomes.

I appreciate the efforts of Department of Environment, Science Technology & Climate Change, Himachal Pradesh, The Energy and Resources Institute (TERI), the Institute for Governance & Sustainable Development (IGSD), sectoral departments, and experts who contributed to this study. The state administration reaffirms its commitment to strengthening institutional mechanisms and accelerating implementation toward a climate-resilient and low-emission future for Himachal Pradesh.

(Sanjay Gupta)

Secretary
(Environment, Science Technology & Climate Change)
Government of Himachal Pradesh

MESSAGE

Air pollution and climate change are no longer distant or abstract challenges for Himachal Pradesh. Our unique Himalayan terrain, high-altitude settlements, and growing urban centres make us particularly vulnerable to the impacts of Short-Lived Climate Pollutants such as black carbon and methane. These pollutants not only degrade air quality but also contribute to accelerated glacier melt—threatening water security, agriculture, hydropower, and disaster resilience.

This report offers a rigorous scientific assessment of non-CO_2 emissions in Himachal Pradesh and highlights practical mitigation pathways across key sectors. Its findings reinforce the need to address emissions from household biomass use, vehicular growth, tourism-driven transport demand, industrial clusters, livestock, and waste management. Importantly, the report shows that targeted SLCP mitigation can yield rapid benefits—cleaner air, reduced health risks, stronger climate resilience, and protection of our critical ecosystems.

As the nodal department for environmental governance, we recognize the importance of mainstreaming SLCP-focused interventions into ongoing programmes. Expanding clean cooking access, accelerating electric mobility in hilly terrains, strengthening waste collection and bio-methanation, adopting climate-smart agriculture, and improving monitoring systems will be essential next steps. Equally important is our commitment to strengthening data transparency, inter-departmental coordination, and public awareness.

I acknowledge the contribution of sectoral experts from Department of Environment, Science Technology & Climate Change, Himachal Pradesh, TERI, IGSD, and all participating departments and experts in preparing this report. It provides a strong foundation for informed decision-making and will guide our efforts as we update and operationalize state climate and air quality frameworks.

Himachal Pradesh is committed to protecting the Himalayas and ensuring a sustainable and healthy future for its citizens. This report is an important step in that direction.

(Sushil Kumar Singla)

Director
(Environment, Science Technology and Climate Change)
Government of Himachal Pradesh

MESSAGE

Climate change and air pollution pose interlinked and growing challenges for Himachal Pradesh, a Himalayan state whose fragile ecosystems, climate-sensitive livelihoods, and mountain hydrology make it particularly vulnerable to rising temperatures and extreme weather events. While long-term mitigation of carbon dioxide (CO_2) emissions remains central to global climate action, there is increasing recognition that addressing non-CO_2 pollutants—especially Short-Lived Climate Pollutants (SLCPs) such as methane, black carbon, hydro fluoro carbons, and tropospheric ozone—offers a powerful opportunity to reduce near-term warming, improve air quality, and protect public health.

It is in this context that the Department of Environment, Science, Technology & Climate Change (DoEST&CC), Government of Himachal Pradesh, has undertaken this first-of-its-kind assessment of SLCPs and other non-CO_2 emissions for the state with IGSD & TERI. Using 2019 as a baseline year, this report establishes a robust, evidence-based emissions inventory and examines future trajectories under business-as-usual and alternative policy scenarios aligned with the state's development priorities and climate commitments.

Himachal Pradesh has already taken significant strides towards a clean and resilient development pathway. Our ambition to become India's first Green Energy State is being pursued through large-scale hydropower, rapid expansion of solar energy, promotion of electric mobility, universal access to clean cooking fuels, decentralised waste management, and emerging initiatives in green hydrogen and biogas to not only reduce CO_2 emissions but also deliver substantial co-benefits in terms of SLCP mitigation, improved air quality, and enhanced climate resilience.

This report builds on these initiatives by identifying priority sectors—such as transport, residential energy use, waste, livestock, and industry—where targeted interventions can yield high-impact reductions in SLCPs. By integrating air quality management with climate action, the study provides a practical framework for informed policymaking, inter-departmental coordination, and strategic investment over the short, medium, and long term.

I hope that this report will serve as a valuable knowledge resource for state departments, urban local bodies, development partners, and other stakeholders, and will support Himachal Pradesh in advancing integrated solutions that safeguard our environment, protect public health, and strengthen the resilience of our mountain systems.

I would like to place on record my appreciation for the technical support provided by the Institute for Governance & Sustainable Development (IGSD) and The Energy and Resources Institute (TERI), and for the cooperation of various state departments that contributed data and insights to this study.

Together, by addressing non-CO_2 emissions alongside sustained CO_2 mitigation, Himachal Pradesh can demonstrate leadership in climate action that is scientifically robust, locally relevant, and globally significant.

(D. C. Rana)

Message from the Director, IGSD

On behalf of the Institute for Governance & Sustainable Development (IGSD), I am pleased to present this report, Tackling Non-CO_2 Emissions: Pathways for Himachal Pradesh. As climate impacts intensify, it is increasingly clear that long-term decarbonisation alone is insufficient. Alongside sustained CO_2 reduction, rapid action on Short-Lived Climate Pollutants (SLCPs) such as methane and BC is essential to curb near-term warming, improve air quality, and reduce climate risks—particularly in sensitive regions like the Himalayas.

Himachal Pradesh occupies a unique and critical position. Its glaciers, forests, and river systems sustain ecosystems and communities far beyond state boundaries, yet the region is warming faster than the global average. Rising pressures from urbanisation, transport, biomass use, waste, and changing agricultural practices are intensifying these risks. SLCPs directly exacerbate these vulnerabilities, accelerating glacier melt, worsening extreme weather, and affecting public health, livelihoods, tourism, and hydropower. The science is clear: reducing SLCPs can slow near-term warming and deliver immediate air-quality and resilience benefits within this decade.

This report establishes a robust 2019 emissions baseline and evaluates Alternative policy pathways through 2047, offering an evidence-based roadmap across transport, residential energy, industry, livestock, agriculture, and waste. It identifies interventions that are technologically feasible, economically viable, and aligned with the State Action Plan on Climate Change. The analysis highlights a major opportunity for Himachal Pradesh to achieve near-term emissions reductions while generating green jobs, improving public health, and strengthening long-term climate resilience.

At IGSD, we support governments in advancing science-based climate action through policy design, capacity building, technology enablement, and access to finance. We believe subnational leadership will shape the next phase of climate action in India, and Himachal Pradesh is well-positioned to emerge as a leader in integrated clean air and climate strategy.

We thank the Government of Himachal Pradesh, the Department of Environment, Science & Technology, TERI, and all contributing experts for their collaboration. This report marks a beginning, not an endpoint. IGSD stands ready to support the state in translating analysis into implementation and impact.

Protecting the Himalayas is not only a regional responsibility—it is a global imperative. Acting decisively on SLCPs today brings us closer to a cleaner, healthier, and more climate-resilient future for Himachal Pradesh and beyond.

Zerin Osho
Director, Institute for Governance & Sustainable Development (IGSD)

Message from the Director General, TERI

Himachal Pradesh, with its fragile mountain ecosystems and rich natural heritage, is particularly vulnerable to the impacts of climate change and air pollution. Against this backdrop, the present report, " Tackling Non-CO_2 Emissions: Pathways for Himachal Pradesh," is both timely and significant. Developed through close consultation with key stakeholder departments and institutions, the report reflects a shared and collective commitment to evidence-based climate action in the State.

This assessment provides a robust and data-driven understanding of Short-Lived Climate Pollutants (SLCPs) and their role in shaping Himachal Pradesh's environmental and climatic outcomes. By establishing a baseline inventory of SLCF emissions for the year 2019 and analysing future trajectories under multiple mitigation scenarios, the report offers valuable insights into both the scale of the challenge and the opportunities for high impact, strategically aligned actions.

The analysis clearly brings out the emission reduction potential of ongoing initiatives and proposed policy measures across priority sectors. Importantly, it emphasizes the need for integrated and synergistic strategies that simultaneously address climate change mitigation, air quality improvement, and sustainable development goals–an approach that is especially relevant for a hill State such as Himachal Pradesh.

I would like to place on record my sincere appreciation for the constructive collaboration and technical support extended by the Institute for Governance & Sustainable Development (IGSD) during the development of this report. I also extend my heartfelt thanks to all the researchers, scientists, government officials, and community stakeholders whose expertise, contributions, and insights have been instrumental in shaping this comprehensive assessment.

I am confident that the findings and recommendations presented in this report will serve as a valuable reference for policymakers, planners, and practitioners. By effectively translating scientific assessment into actionable insights, this report seeks to support informed decision-making and prioritization of interventions and investments that will advance Himachal Pradesh's transition towards a cleaner, climate-resilient, and sustainable future.

Vibha Dhawan
Director General
The Energy and Resources Institute (TERI)

Executive Summary

This report presents a comprehensive and first-of-its-kind emission inventory of Short-Lived Climate Pollutants (SLCPs) and other non-CO_2 pollutants for the state of Himachal Pradesh, using 2019 as the baseline year. It underscores the urgent need to strengthen focus on non-CO_2 pollutants—particularly SLCPs such as CH_4, BC, hydrofluorocarbons (HFCs), and tropospheric O_3, to mitigate near-term climate impacts, while sustaining long-term momentum on CO_2 mitigation.

Adopting a holistic mitigation strategy, the report analyzes projected trends in SLCP emissions and other non-CO_2 pollutants under a Business-As-Usual (BAU) scenario through 2047, alongside a set of policy-driven alternative scenarios (ALT) designed to achieve deeper emission reductions across key sectors.

Two key insights emerge from this assessment:

- First, a sector-wise breakdown of SLCP and other non-CO_2 pollutant emissions, highlighting the relative contribution of sectors such as transport, residential energy use, waste, livestock, and industry across Himachal Pradesh.
- Second, identification of priority sectors and targeted policy interventions that are critical for integrating air-quality management with climate action, based on scenario-based analysis.

State inks MoU with international firms for green initiatives in HP - Afforestation Programme

With rising global temperatures and increasing pollution, Himachal Pradesh is vulnerable to the effects of climate change and air pollution.

Himachal Pradesh is among India's most climate-vulnerable states due to its fragile Himalayan ecosystem, steep terrain, glacier- and snow-fed hydrology, and high dependence on climate-sensitive livelihoods such as horticulture, livestock, and tourism. Climate risks in the state are intensifying rapidly. Between 1 June and 6 September 2025, Himachal recorded 46% excess rainfall, with a sharp rise in extremely heavy (>100 mm) rainfall days, resulting in substantial human casualties and over ₹4,000 crore in damages.[1] At the same time, heat stress is emerging as a growing concern, with heatwave conditions increasingly extending into hill regions, affecting public health especially of outdoor workers, crops, and livestock. Warmer and drier conditions have also increased forest fire incidences, contributing to BC emissions and episodic deterioration of air quality. In valley towns and urban centres, wintertime particulate pollution—driven by transport, residential biomass use for heating, diesel generators, and waste burning—poses rising health risks. Given these overlapping climate and air-quality challenges, mitigating SLCPs offers a high-impact pathway to reduce near-term warming, improve air quality, and protect sensitive mountain systems of Himachal Pradesh.

Himachal Pradesh serves as an important case study for state-level SLCP mitigation. Focusing on short-lived climate pollutants allows the state to address air quality and manage unpredictability of weather in the short & medium term.

Himachal Pradesh has prioritised clean energy transition as the cornerstone of its air quality and climate strategy, with a stated goal of becoming India's first Green Energy State by 2026. The state already meets the vast majority of its electricity demand from renewable sources, led by large hydropower capacity exceeding 10 GW[2], and is rapidly expanding solar energy through rooftop programmes, ground-mounted installations, and the Green Panchayat initiative, under which 500 kW solar plants are being deployed at the gram panchayat level[3]. Emerging initiatives such as green hydrogen and biogas projects further strengthen Himachal's low-emissions energy pathway. These efforts are supported by institutional and climate-finance mechanisms under programmes like Climate Adaptation and Finance in Rural India (CAFRI)[4], which has enhanced state capacity for climate-responsive planning, financing, and integration of mitigation and adaptation actions across sectors. Complementing this, the solid waste sector has seen a shift toward decentralised solid waste management, segregation at source, composting, biomethanation, and waste-to-energy facilities in urban centres such as Shimla and Manali, aimed at reducing methane emissions and eliminating open burning. In the residential sector, Himachal became India's first state to achieve near-universal clean cooking access through PMUY and the Mukhyamantri Grihini Suvidha Yojana, substantially lowering BC and $PM_{2.5}$ emissions, though biomass use for space heating remains an area for further intervention. The transport sector is being addressed through the Electric Vehicle Policy (2022), deployment of electric buses, expansion of charging infrastructure, and retirement of older vehicles, while industrial emissions are regulated under the State Fuel Policy, which restricts polluting fuels and mandates cleaner alternatives and monitoring in clusters such as Baddi–Nalagarh. Together, these priority interventions reflect an integrated, cross-sectoral approach that links air quality management, SLCP mitigation, and clean energy deployment, strengthening Himachal Pradesh's climate resilience in a fragile mountain context.

This study establishes a baseline for SLCPs and other non-CO_2 air pollutant emissions in Himachal Pradesh and assesses their near-term and long-term trajectories under alternative policy scenarios. By doing so, it highlights the emission-reduction potential of targeted, sector-specific policy interventions that align with the state's development and climate priorities.

Two key assessments have been undertaken. First, a baseline emissions inventory for 2019 was developed for SLCPs and other non-CO_2 pollutants using data from state and national government sources, supplemented by relevant academic literature and emission factors appropriate for Himachal Pradesh's Himalayan context. Second, the study develops emissions scenarios, including a Business as usual (BAU) Scenario and Alternative (ALT) Scenarios aligned with Himachal Pradesh's policy direction, clean energy transition, and climate resilience goals. These scenarios incorporate quantifiable targets for 2030, 2040, and 2047, consistent with the state's long-term development vision and India's national commitments. The analysis identifies sector-wise contributions to SLCPs and air pollutants and projects the emission-reduction potential of existing and planned strategies for 2030 and 2047, providing an evidence base to inform integrated air quality and climate action in the state.

Key Findings

The report takes a deep dive into a wide spectrum of SLCPs and other non-CO_2 pollutants that stand as a barrier to HP's clean air goals. It also provides viable policy solutions for the state, which can be implemented for reducing SLCPs and other non-CO_2 pollutants.

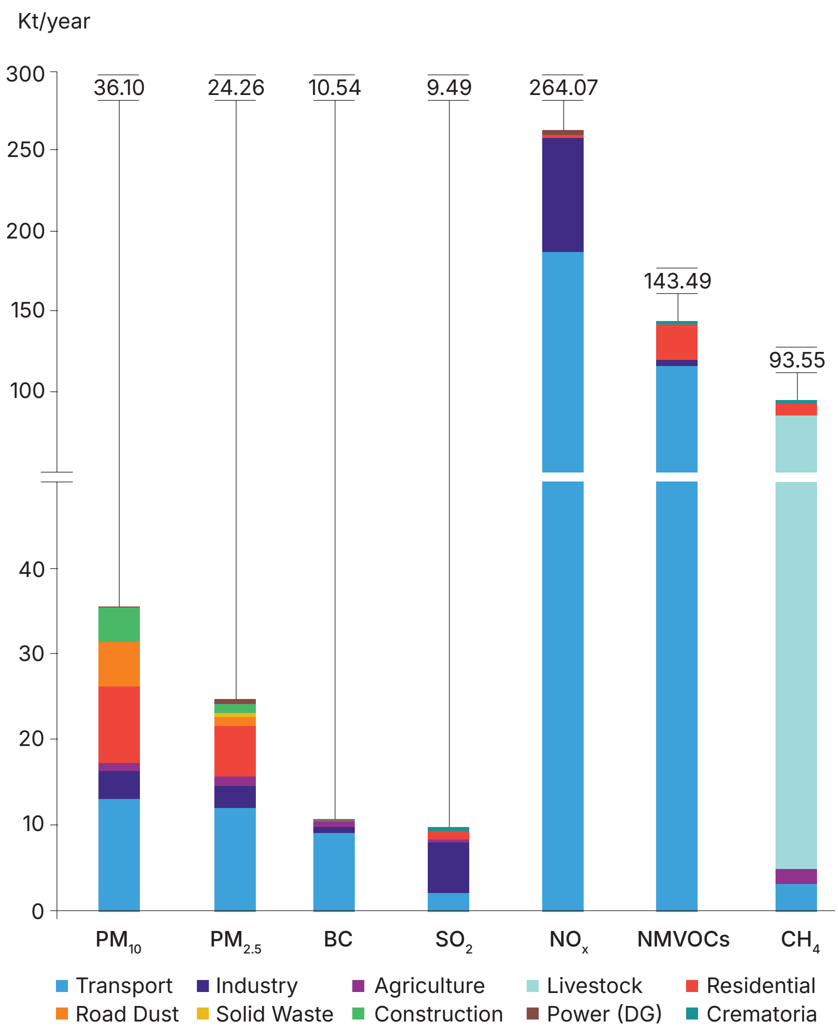

Figure 1: Estimated Annual Emissions of Pollutants from different sectors in Himachal Pradesh during baseline year 2019

Table 1: Sectoral Emissions in 2019 for various pollutants (PM, CH_4, NO_x, NMVOCs, etc.)

Sector	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x	NMVOCs	CH_4
Transport Sector	13.00	12.00	9.00	2.00	187.00	116.00	3.00
Industry sector	3.20	2.80	0.80	6.0	71.50	3.70	2.30
Agriculture Sector	0.90	0.70	0.06	0.20	0.04	0.40	1.80
Livestock Sector	-	-	-	-	-	-	78.00
Residential Sector	9.00	6.00	0.52	1.00	2.00	22.00	7.00
Road dust re-suspension	5.00	1.00	-	-	-	-	-
Solid Waste Sector	0.36	0.05	0.01	0.05	-	-	1.23
Construction	4.00	1.00	-	-	-	-	-
Power (DG sets)	0.24	0.21	0.14	0.23	3.48	0.28	0.01
Crematoria	0.40	0.20	0.01	0.01	0.05	1.11	0.11
Total	**36.10**	**24.26**	**10.54**	**9.49**	**264.07**	**143.49**	**93.55**

As seen from Table 1, NO_x emissions are the highest among all pollutants in Himachal Pradesh, followed by NMVOCs, CH_4, and PM (PM_{10} and $PM_{2.5}$). The dominance of NO_x emissions is driven primarily by the transport sector, reflecting increasing vehicle numbers, tourism-related traffic, and emission concentration in valley towns with limited dispersion, while diesel generator sets and small industrial units contribute locally, particularly in the Baddi–Nalagarh industrial cluster. NMVOC emissions are also largely transport-driven, with significant contributions from fuel evaporation, incomplete combustion, solvent use, and residential activities, making them a key precursor for ozone formation and secondary PM. Methane emissions are dominated by the livestock sector, which emerges as the single largest source of CH_4 in the state, followed by contributions from solid waste management and agriculture. Particulate pollution is largely attributable to residential biomass use, road dust re-suspension, construction activity, and episodic forest fires, which also contribute to BC emissions. Overall, the emissions profile highlights transport, livestock, residential biomass use, and waste management as priority sectors for integrated NO_x, NMVOC, and SLCP mitigation to improve air quality and near-term climate outcomes in Himachal Pradesh.

$PM_{2.5}$ is a critical atmospheric pollutant impacting health while **methane and BC** offer the largest **climate warming mitigation opportunity in near-term and Sulphur di-oxide and Nitrogen oxides are precursors of tropospheric ozone which is known for its critical impact on health, crop yield and near-term atmospheric temperature rise**

Priority sectors for Mitigation

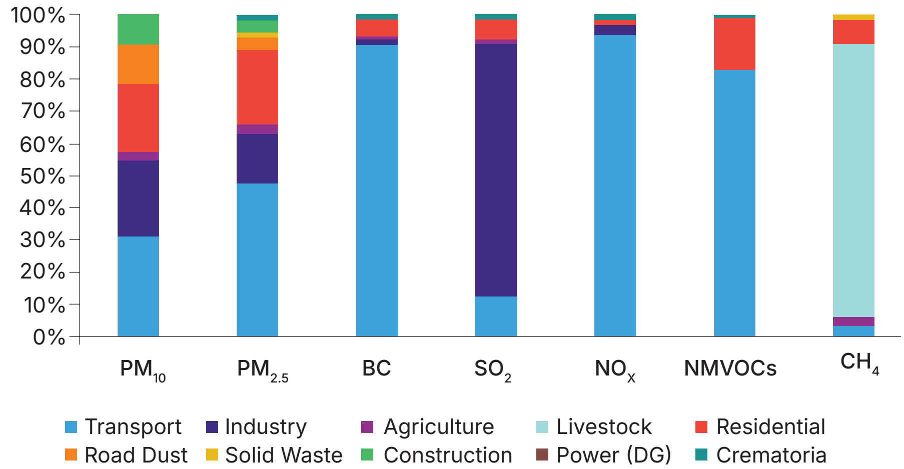

Figure 2: Estimated annual share of different sectors to annual emissions of pollutants during 2019

Table 2: Priority Sectors for Mitigation

Sector	Key Pollutants Addressed	Rationale for Prioritisation
Transport	NO_x, BC, $PM_{2.5}$, NMVOCs	Dominant source of NO_x and BC emissions in the state; ALT scenarios show large reduction potential through electrification, public transport expansion, and tourism-related demand management.
Residential (Cooking)	$PM_{2.5}$, PM_{10}, BC, NMVOCs	Major contributor to winter particulate pollution due to biomass use for cooking ; BAU scenario itself demonstrates strong benefits from clean energy transitions.
Livestock	CH_4	Largest source of methane emissions through enteric fermentation; ALT scenarios indicate substantial reductions via fodder managment.
Solid Waste	CH_4, BC	Methane emissions from landfills and open dumping; ALT scenarios highlight high mitigation potential through organic waste diversion and anaerobic digestion.
Industry & DG Sets	SO_2, PM, NO_x, BC	Localised pollution hotspots in industrial clusters; ALT scenarios show moderate but important reductions through fuel switching and cleaner energy use.

Transport Sector

The transport sector is a major contributor to air pollution in Himachal Pradesh, accounting for approximately 94% of annual NO_x emissions, 91% of CO emissions, and 83% of NMVOC emissions of the state in 2019. It also contributes significantly to annual PM_{10} and $PM_{2.5}$, BC, SO_2, and CH_4 emissions. Diesel-powered vehicles are the dominant sources of PM, BC, and SO_2 emissions due to their extensive use in freight movement, public transport, and inter-district travel, while gasoline-powered vehicles, particularly two-wheelers and private cars, are the primary contributors to CO and CH_4 emissions. Given that the transport sector is the dominant source of NO_x and NMVOCs, it plays a critical role in influencing tropospheric ozone formation, particularly in urban centres and high-tourism districts such as Shimla, Kangra, and Kullu, and must therefore be a central focus of emission reduction strategies.

BAU and ALT Scenarios

The Business-as-Usual (BAU) scenario accounts for already planned interventions in the state. By 2047 in the BAU scenario, the following increase in emissions may be witnessed: emissions of $PM_{2.5}$ and PM_{10} increase by over 30-40%, while NO_x emissions increase by more than 40% compared to the 2019 baseline. Despite improvements in emission intensity per vehicle, the overall rise in emissions is driven by growth in vehicle numbers associated with population increase, tourism, and expanding infrastructure.

The study further evaluates alternative policy scenarios to assess emission reduction potential in the transport sector. Analysis indicates that targeted policy interventions can significantly offset these projected increases, with phased vehicle scrappage and accelerated electrification emerging as the most effective and feasible pathways for controlling PM and nitrogen oxide emissions in the state.

Table 3: Transport Sector ALT Scenario Descriptions

Scenarios	Description
ALT-1 (Vehicle Scrappage Policy)	▪ By 2030, 30% of all 20-year-old petrol and 15-year-old diesel vehicles will be scrapped. ▪ By 2040, 60% of all 20-year-old petrol and 15-year-old diesel vehicles will be scrapped. ▪ By 2047, 80% of all 20-year-old petrol and 15-year-old diesel vehicles will be scrapped.
ALT-2 (Faster EV Adoption)	▪ By 2030, 100% of state transport buses and the entire government fleet will transition to EVs. ▪ By 2040, 50% of all vehicle fleets will transition to EVs. ▪ By 2047, 70% of all vehicle fleets in all districts will be converted to EVs.

Table 4: Changes in Emissions under ALT Scenarios for Transport Sector (BAU vs 2047)

Scenario	$PM_{2.5}$	PM_{10}	SO_2	NO_x	NMVOCs	BC	CH_4
ALT-1	-25%	-33%	-13%	-20%	-16%	-19%	-46%
ALT-2	-29%	-33%	-23%	-24%	-23%	-20%	-60%

Results and Inference

- Estimation indicates **ALT-1 (vehicle scrappage policy) as the most feasible scenario,** in terms of delivering broad-based emission reductions across vehicle categories and aligning with near-term implementation capacity.
- **ALT-2 (Faster EV adoption)** offers targeted emission reduction benefits—particularly for urban gasoline/CNG vehicles and diesel-dominated freight movement respectively—their effectiveness is constrained by infrastructure, enforcement, and fuel-supply limitations.
- A **phased approach centered on ALT-1, complemented by ALT-2 based on district-specific emission profiles,** is therefore recommended for the transport sector.

Key Takeaway

Transport sector emissions in Himachal Pradesh show strong upward trends under BAU, driven by rising vehicle ownership, tourism-related mobility, and freight movement across hilly terrain. However, a phased combination of vehicle scrappages and targeted electrification can deliver substantial near-term reductions in NO_x, BC, and methane, significantly improving urban air quality and reducing near-term warming impacts in ecologically sensitive mountain regions.

Industry Sector

The industry sector is a moderate but policy-responsive contributor to non-CO_2 pollutant emissions in Himachal Pradesh in the baseline year (2019). Emissions are dominated by seven key pollutants – $PM_{2.5}$, SO_2, NO_x, carbon monoxide (CO), non-methane volatile organic compounds (NMVOCs), BC, and methane (CH_4), arising primarily from industrial combustion processes. Although the sector contributes a smaller share of total state-wide emissions compared to transport and residential sectors, it offers high mitigation potential due to the availability of targeted technology and fuel-switching interventions.

Industrial emissions are spatially concentrated in key clusters, particularly the Baddi–Barotiwala–Nalagarh (BBN) industrial region, with additional contributions from Una and Paonta Sahib. The dominance of fuel-intensive manufacturing units and reliance on fossil fuels such as coal and furnace oil amplify emissions of SO_2 and PM, while incomplete combustion leads to elevated BC and CO emissions.

Emissions are influenced by fuel type, combustion efficiency, and the presence (or absence) of APCDs. Limited penetration of cleaner fuels and inconsistent enforcement of pollution control norms constrain emission reductions under BAU.

BAU and ALT Scenarios

The BAU scenario assumes continued industrial activity with existing fuel use patterns and partial compliance with emission standards. Under BAU, emissions remain largely unchanged through the analysis period due to limited structural change in industrial energy systems.

Two alternative scenarios were assessed for the industry sector, focusing on **distinct and non-overlapping mitigation levers:**

- **ALT-1: Transition to Green Hydrogen.** This scenario assumes partial substitution of fossil fuels with green hydrogen in industrial combustion processes. Given the limited penetration and gradual scaling of hydrogen-based systems, emission reductions remain modest but uniform across pollutants, reflecting fuel substitution rather than end-of-pipe controls.
- **ALT-2: Enforcement of Air Pollution Control Devices.** This scenario assumes strict enforcement and widespread adoption of APCDs, particularly wet scrubbers, across industrial units. As APCDs directly target stack emissions, this pathway delivers very high reductions across all pollutants, especially SO_2, NO_x, $PM_{2.5}$, and BC.

Table 5: Industry Sector Alternative Scenarios Descriptions

Scenarios	Assumption
ALT-1	The introduction of Green Hydrogen is assumed to reach 5% and 8% penetration in industries by 2040 and 2047, respectively.
ALT-2	Enforcement of APCDs: Implementation of Wet Scrubbers (WSC) will be enforced by 25%, 50%, and 100% in industries for the years 2030, 2040, and 2047, respectively, to reduce PM and gaseous emissions.

Table 6: Changes in Emissions under ALT Scenarios for Industry Sector (BAU vs 2047)

Scenario	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
ALT-1: Transition to Green Hydrogen	-8%	-8%	-8%	-8%	-8%	-9%	-8%
ALT-2: Enforcement of APCDs	-82%	-88%	-91%	-80%	-85%	-86%	-87%

Results and Inference

- **ALT-1 : Transition to Green Hydrogen** offers incremental reductions and represents a longer-term structural transition rather than an immediate air quality intervention.
- **ALT-2: APCD enforcement** delivers the largest emission reductions across all pollutants due to its direct control over combustion exhaust, making it a highly effective short- to medium-term mitigation strategy.
- While ALT-1, though modest in impact, plays a strategic role in long-term decarbonisation and complements end-of-pipe controls. ALT-2 achieves dramatic reductions, its effectiveness depends on regulatory enforcement, operational maintenance, and compliance monitoring, particularly in SME-dominated clusters.

Key Takeaway

Industrial emissions in Himachal Pradesh exhibit very high mitigation potential when targeted through technology and regulatory enforcement. While BAU pathways sustain current pollution levels, strict enforcement of APCDs can reduce most industrial air pollutants by over 80%, delivering immediate air quality and SLCP benefits. Green hydrogen, while currently limited in impact, represents a critical long-term transition pathway for cleaner industrial energy systems.

Agriculture and Livestock Sector

While SLCP and other non-CO_2 emissions from the agriculture sector are minimal in the state of Himachal, the livestock sector is a major contributor to methane (CH_4) emissions in Himachal Pradesh – representing one of the most important sources of non-CO_2 climate forcing in the state. CH_4 emissions arise predominantly from enteric fermentation in cattle and buffalo, with a smaller contribution from manure management practices. While the agriculture contribute to conventional air pollutants such as PM, SO_2, or NO_x, due to the burning of crop residues (mainly horticulture crops and weeds).

In the baseline year (2019), livestock-related methane emissions were widely distributed across rural districts, reflecting the agrarian nature of the state's economy and the importance of livestock for livelihoods. Districts such as Kangra, Mandi, Shimla, and Chamba account for a substantial share of emissions due to higher livestock populations. The predominance of low-productivity animals, traditional feeding practices, and largely unmanaged manure handling systems contributes to relatively high methane emission intensity per unit of output. As a result, mitigation pathways in this sector are highly targeted and methane-specific, focusing on productivity enhancement and improved management rather than end-of-pipe controls.

BAU and ALT Scenarios

Under the BAU scenario, livestock numbers and milk production changed in line with historical trends. Improvements in productivity and feeding practices remain limited, and manure continues to be managed primarily through traditional systems. As demand for milk and livestock products increases, absolute methane emissions increase over time, with limited reductions in emission intensity.

Three alternative scenarios were assessed for the livestock sector, reflecting feasible and policy-relevant interventions that do not require reductions in livestock populations and are compatible with rural livelihood objectives.

Table 7: Livestock ALT Scenario Descriptions

Scenario	Description
ALT-1 (Fodder Management)	Fodder Management: Balanced feeding reduces CH_4 by 10–15%
ALT-2 (Promotion of indigenous cattle population)	Promotion of Indigenous Cattle under Natural Farming: Crossbreed & buffalo reduced 5% annually. Indigenous cattle increased to meet milk demand.
ALT-3 (Promotion of indigenous cattle vis-à-vis nutritional enrichment)	Integrated Strategy: Indigenous Cattle and Nutritional Management. This combines ALT 1 and ALT 2 for enhanced mitigation.

Table 8: Changes in Emissions under ALT Scenarios for Livestock Sector (BAU vs 2047)

Scenario	CH_4
ALT-1	-12%
ALT-2	43%
ALT-3	27%

Results and Inference

- Under the BAU scenario, livestock numbers and production systems in Himachal Pradesh follow historical trends, with limited improvements in productivity, feeding, and manure management. As demand for milk and livestock products increases, absolute methane emissions rise gradually over time, with only marginal reductions in emission intensity.
- **ALT-1 (Fodder Management)** is the only scenario that achieves a net methane reduction (12%) relative to BAU, driven by improved feed quality and balanced feeding practices that lower emissions per animal by enhancing digestion efficiency. This approach directly targets enteric fermentation without altering herd size or composition, making it well suited to smallholder systems.
- In contrast, **ALT-2 (Promotion of Indigenous Cattle under Natural Farming)** leads to a 43% increase in methane emissions, as the expansion of indigenous cattle numbers to meet milk demand outweighs gains from lower per-animal productivity.
- **ALT-3 (Integrated Strategy)** moderates this increase but still results in a 27% rise in emissions, as nutritional improvements are insufficient to offset herd expansion.

Overall, the results highlight that **feed- and productivity-based interventions are the most effective methane mitigation pathway,** while herd-composition shifts alone can increase total emissions if not paired with strong productivity gains.

Key Takeaway

The livestock sector results show that methane outcomes depend strongly on the type of intervention adopted. While livestock numbers and emissions increase under BAU, **only feed- and productivity-focused measures (ALT-1)** deliver a net methane reduction (12%) by lowering emissions per animal without altering herd composition. In contrast, strategies centred on promoting indigenous cattle to meet rising milk demand (ALT-2 and ALT-3) could lead to higher aggregate methane emissions per unit of milk produced. While overall cattle numbers in Himachal Pradesh are declining, indigenous breeds typically have lower milk yields compared to crossbred animals. As a result, meeting the same level of milk demand would require a relatively larger number of animals, potentially offsetting gains achieved through improved nutrition and management. This highlights a critical policy insight for Himachal Pradesh: natural farming and indigenous breed promotion must be explicitly coupled with strong productivity enhancement, feed optimisation, and herd management measures to avoid unintended methane intensity increases.

Residential Cooking Sector

The residential sector is a major contributor to non-CO_2 air pollutant and SLCP emissions in Himachal Pradesh, particularly for seven key pollutants – $PM_{2.5}$, PM_{10}, BC, CO, NMVOCs, and CH_4. Emissions arise primarily from incomplete solid fuel combustion for cooking, especially the use of fuelwood and biomass in traditional stoves. Emissions durig cooking are associated with inefficient stove technology, incomplete combustion of cooking fuel and fuel handling. Although the state has made significant progress in household LPG coverage and achieved India's first "Smoke-Free State" status in 2022, solid biomass use for residential cooking remains prevalent, particularly in rural and high-altitude regions.

In the baseline year (2019), residential emissions were spatially widespread, with higher intensity observed in cold-climate districts such as Chamba, Kullu, Kinnaur, Shimla, and Lahaul–Spiti, where fuelwood dependence is high.

BAU and ALT Scenarios

Under the BAU scenario, residential energy demand continues to grow with population, while biomass remains a significant component of the cooking fuel mix. Incremental improvements with existing clean cooking schemes estimated to fully offset rising demand of residential cooking fuel, resulting in sustained decline in emissions of pollutants from the sector over the years.

As the BAU scenario indicates sustained decline in emission from the residential cooking activities, there is no need of additional ALT scenarios, rather it is important to continue with the present scenarios to achieve significant reduction from the residential sector.

Key Takeaway

The residential sector is a dominant source of PM and BC emissions in Himachal Pradesh, with strong implications for air quality, health, and Himalayan climate impacts.

However, with the ongoing clean cooking policies, emissions from the residential cooking activities were estimated to decrease significantly over the year. Due to estimated complete coverage of LPG in households, the estimated annual emission from the residential cooking is expected to be zero by 2040.

Solid Waste Sector

Five key pollutants are emitted from the waste sector: CH_4 from landfills and dumpsites, and PM_{10}, $PM_{2.5}$, SO_2, and BC primarily from open waste burning and combustion at disposal sites. The waste sector is a minor contributor to total methane (CH_4) emissions in Himachal Pradesh in the baseline year (2019), emitting approximately 1.33 kt/year of methane, but it represents an important near-term mitigation opportunity due to the high feasibility of reducing emissions through improved waste management practices. Methane emissions arise primarily from the disposal of municipal solid waste in dumpsites and landfills, while BC and PM (PM_{10} and $PM_{2.5}$) emissions are associated with waste transportation open waste burning, including residential waste burning and landfill fires. Although the sector's contribution to overall air pollutant emissions at the state level is relatively small compared to transport and residential combustion, its emissions remain locally significant and relevant for near-term climate mitigation. Limited segregation at source, underutilisation of composting and anaerobic digestion facilities, and continued dependence on landfilling constrain emission reduction potential. These challenges are compounded by Himachal Pradesh's cold climate and hilly terrain, which reduce the efficiency of conventional biological waste treatment technologies unless adapted to local conditions.

In 2019, methane emissions from the waste sector were spatially concentrated, with Kangra, Mandi, and Shimla accounting for nearly half of the state's methane emissions from solid waste, reflecting higher population density, urbanisation, and tourism-related waste generation in these districts. Emissions are further influenced by the continued reliance on unmanaged dumpsites, limited scientific processing of waste, and instances of open waste burning, which contribute to local air quality degradation.

BAU and ALT Scenarios

The BAU scenario reflects existing waste management practices in Himachal Pradesh. Based on analysis using the Solid Waste Emissions Estimation Tool (SWEET), the state demonstrates relatively high waste collection coverage; however, only a limited share of collected waste is treated through scientific processing methods. Under BAU, continued reliance on dumpsites and landfills—particularly in high waste-generating districts—results in persistent methane emissions and continued emissions of PM and BC from open waste burning and associated activities.

The mitigation pathways assessed in this sector build upon existing departmental programmes and policy directions. The alternative scenarios are analytical representations of enhanced implementation and do not imply new regulatory mandates beyond current policy frameworks.

Alternative scenarios that increase diversion of waste towards composting, recycling, and material recovery facilities indicate substantial mitigation potential. Policy-driven and composting-focused pathways deliver moderate reductions in methane emissions, while recycling-prioritised pathways achieve the largest reductions—on the order of 50% or more by 2047, alongside significant reductions in PM, BC & SO_2 emissions.

Overall, the analysis highlights that strengthening source segregation, scaling up decentralised composting and recycling, and minimising waste combustion offer the most effective and feasible pathway for reducing emissions from the waste sector in Himachal Pradesh, while supporting the state's long-term objective of moving towards zero landfill status.

Table 9: Solid Waste Sector ALT Scenario Descriptions

Scenario	Description
ALT-1 (Policy Driven-Balanced Waste Management Scenario)	▪ 87.6% of waste processed: 26% composting, 17% anaerobic digestion, 29% waste combustion, 28% recycling. ▪ Open burning: 2% at landfill, 2% at residential level.
ALT-2 (Composting Driven Scenario)	▪ 87.6% of waste diverted: 40% composting, 3% anaerobic digestion, 29% waste combustion, 28% recycling. ▪ Open burning: 2% at landfill, 2% at residential level.
ALT-3 (Recycling Driven Scenario)	▪ 87.6% of waste diverted: 26% composting, 17% anaerobic digestion, 17% waste combustion, 40% recycling. ▪ Open burning: 2% at landfill, 2% at residential level.

Table 10: Changes in Emissions under ALT Scenarios for Solid Waste Sector (BAU vs 2047)

Sector	Scenarios	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
Waste	**ALT 1: Policy Driven- Balanced Waste Management Scenario**	-4%	-5%	-	-	-	-9%	18%
	ALT 2: Composting-Prioritized Waste Management Scenario	1%	0%	-	-	-	-8%	16%
	ALT 3: Recycling-Prioritized Waste Management Scenario	-51%	-51%	-	-	-	-19%	1%

Results and Inference

- Analysis reveals that **ALT-3 (recycling-driven pathway) emerges as the most effective strategy** in terms of methane and air pollutant reductions, particularly under Himachal Pradesh's waste composition and tourism-driven generation patterns.
- While **ALT-1 and ALT-2** offer incremental benefits through policy and composting interventions, **ALT-3 delivers the highest emission reduction potential** by maximising diversion of dry recyclables and reducing reliance on waste combustion. However, given constraints related to source segregation, processing infrastructure, and institutional capacity, **a phased and district-specific implementation of ALT-3 should be prioritised**.

Key Takeaway

The estimated emissions from the Solid Waste Sector in Himachal Pradesh contribute a smaller share of overall air pollution but remain critical for methane mitigation. While BAU pathways sustain methane emissions due to continued landfilling and limited processing, prioritising recycling and decentralised organic waste treatment can deliver meaningful near-term reductions in methane and BC, supporting climate mitigation, improving local air quality, and advancing the state's transition towards sustainable and low-emission waste management.

Diesel Generator (DG) Set Sector

The diesel generator (DG) set sector is a small but rapidly growing source of air pollutants and SLCPs in Himachal Pradesh. In the baseline year (2019), DG sets contributed modest absolute emissions at the state level; however, their high emission intensity and strong growth trajectory make them increasingly important from both air quality and climate perspectives. Estimated emissions from DG sets are dominated by NO_x (3.48 kt/year), $PM_{2.5}$ (0.21 kt/year) and PM_{10} (0.24 kt/year), BC (0.14 kt/year), CO (0.75 kt/year), NMVOC (0.28 kt/year), SO_2 (0.23 kt/year), and CH_4 (0.01 kt/year).

DG set usage in the state is driven by the need for reliable backup power across industrial, commercial, hospitality, construction, telecom, and residential sectors. Despite the state's high share of renewable electricity —largely from hydropower—growing electricity demand and grid reliability constraints continue to necessitate DG operation. Spatially, DG set emissions are highly concentrated in industrial and urban districts, with Solan district emerging as the dominant hotspot, followed by Kangra and Bilaspur. Emissions are lowest in sparsely populated and remote districts such as Lahaul and Spiti.

BAU and ALT Scenarios

Under the BAU scenario, diesel consumption for DG sets is projected to grow at a compound annual growth rate (CAGR) of 5.45%, consistent with historical trends reported by the Ministry of Petroleum and Natural Gas. Sectoral diesel consumption shares are assumed to remain constant, and no additional policy measures beyond existing emission standards are introduced. As a result, emissions from DG sets increase sharply over time. Relative to 2019 levels, emissions were estimated to rise by approximately 79% by 2030, 203% by 2040, and 338% by 2047 across all major pollutants, including PM, NO_x, BC, CO, NMVOCs, and CH_4.

The ALT-1 evaluates the impact of large-scale deployment of Retrofit Emission Control Devices (RECDs) on DG sets, supported by stricter regulation, improved enforcement, and higher compliance. RECD penetration is assumed to reach 30% by 2030, 60% by 2040, and 90% by 2047. This scenario does not alter DG activity growth or fuel use but achieves emission reductions through end-of-pipe controls.

RECDs are particularly effective in reducing PM, BC, carbon monoxide, NMVOCs, and CH_4, while offering negligible reductions for SO_2 and NO_x, which are primarily governed by fuel sulphur content and combustion temperature.

Table 11: Diesel Generator Set Sector ALT Scenario Descriptions

Scenario	Description
ALT-1 (RECD Implementation)	▪ 30% of DG sets equipped with Retrofitted Emission Control Devices (RECDs) by 2030. ▪ 60% by 2040. ▪ 90% by 2047.

Table 12: Changes in Emissions under ALT Scenarios for DG Set Sector (BAU vs 2047)

Scenario	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
ALT-1: RECD. Deployment	−63%	+1%	+1%	−63%	−63%	−63%	−63%

Results and Inference

- The results demonstrate that **ALT-1 delivers substantial reductions (up to 63%)** for particulate and carbonaceous pollutants, despite continued growth in DG usage under BAU conditions. These reductions are technically consistent with the performance characteristics of RECDs, which target incomplete combustion products and particulate emissions through filtration and oxidation mechanisms
- However, the analysis also highlights a clear limitation of RECD-based mitigation: emissions of SO_2 and NO_x remain largely unaffected, underscoring the need for complementary measures such as fuel quality improvements, DG-specific emission standards, and reductions in DG dependence through improved grid reliability.

Key Takeaway

The DG set sector represents a high-growth, high-impact source of local air pollution and SLCPs in Himachal Pradesh. Under BAU, emissions rise sharply through 2047, posing increasing risks to air quality and public health. While large-scale deployment of RECDs under ALT-1 can reduce $PM_{2.5}$, BC, CO, NMVOCs, and CH_4 emissions by up to 63%, these measures alone are insufficient to control SO_2 and NO_x. A combined strategy that couples RECD deployment with grid strengthening and reduced reliance on DG set is therefore essential to sustainably curb emissions from this sector.

Introduction

Air pollution and climate change are intrinsically linked global challenges that are increasingly recognized as requiring integrated responses. Their interconnection is driven by complex atmospheric processes involving long-lived greenhouse gases and short-lived climate pollutants (SLCPs) such as methane, BC, and hydrofluorocarbons. These pollutants simultaneously undermine air quality, public health, and radiative balance, contributing to near-term warming. International scientific assessments, including those of the Intergovernmental Panel on Climate Change[5] and the United Nations Environment Programme, underscore that coordinated mitigation of SLCPs can deliver immediate climate benefits while advancing sustainable development and health objectives.[6] Historically, however, many countries—including India—have addressed air pollution and climate change through parallel policy frameworks, thereby limiting the potential for synergistic mitigation strategies and co-benefits.[7]

Within this broader context, Himachal Pradesh—an ecologically sensitive, predominantly mountainous state in the northwestern Himalayas—presents both vulnerabilities and opportunities.[8] While industrial activity remains comparatively limited, air quality pressures arise from transport emissions, residential biomass combustion, seasonal agricultural burning, construction activities, and tourism-related mobility. The state's complex topography, characterized by narrow valleys and high-altitude basins,[9] often restricts atmospheric dispersion and facilitates temperature inversions, leading to localized pollutant accumulation. These geographic factors heighten exposure risks despite relatively modest emission sources.

At the same time, climate change is intensifying systemic risks across the state's fragile mountain ecosystems. Rising temperatures, altered precipitation and snowfall regimes, and increased incidence of forest fires are affecting hydrological systems, biodiversity, and climate-sensitive livelihoods, particularly in agriculture and horticulture.[10] In such contexts, integrated approaches that jointly address air quality management and climate mitigation—aligned with global frameworks and nationally determined contributions—are essential to enhance resilience, safeguard ecosystems, and advance sustainable development pathways.

AQI trend analysis of HP

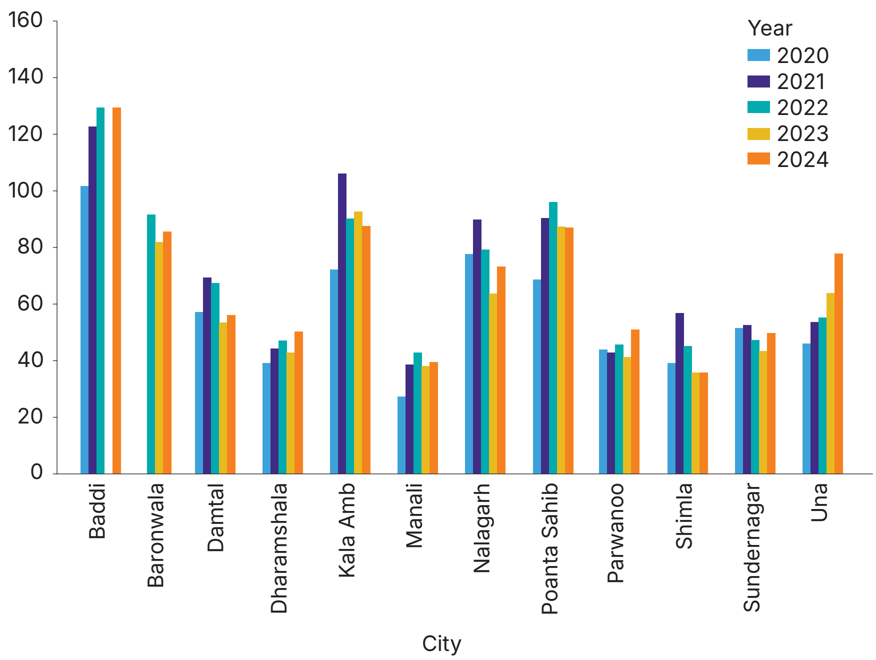

Figure 3: Comparison of average AQI per city by year (2020–2024)

The figure presents a comparative overview of the average Air Quality Index (AQI) across major cities in Himachal Pradesh over the five-year period 2020–2024. Each grouped set of bars represents the mean AQI for a city across the five years, enabling a clear assessment of both temporal change and spatial variability in air quality. The analysis is based on AQI data published by the Himachal Pradesh Pollution Control Board (HPPCB) through its official AQI Calendar portal,[11] which compiles daily AQI values generated from monitoring stations located across the state.

The chart indicates that industrial towns such as Baddi, Parwanoo, and Nalagarh consistently report higher AQI levels compared to predominantly residential or semi-urban locations. Baddi, in particular, records the highest AQI across all five years, with a noticeable rising trend peaking in the later years of the assessment period. Cities such as Kala Amb and Una also show an upward shift, especially after 2021, reflecting increasing emissions from traffic, industrial activity, and urban expansion.

In contrast, locations like Sundernagar and Solan exhibit relatively lower AQI levels, remaining mostly within the "Satisfactory" to "Moderate" category throughout the period. Several cities demonstrate a temporary increase around 2022–2023 followed by slight stabilization in 2024, suggesting the possible influence of post-pandemic economic recovery, changing mobility patterns, and regulatory enforcement cycles.

Overall, the five-year trend highlights that air quality pressures in Himachal Pradesh are more pronounced in growth-driven urban and industrial clusters, while cleaner conditions persist in less industrialized regions.

Recognizing the AQI issues stated above which pose challenges to air quality and climate, the Government of India has implemented several national-level interventions such as the Pradhan Mantri Ujjwala Yojana (PMUY), Unnat Chulha Abhiyan (UCA), and the accelerated transition to Bharat Stage VI (BS-VI) fuel standards (Ministry of Petroleum & Natural Gas, n.d.). The National Clean Air Programme (NCAP) launched in 2019, with the aims to reduce $PM_{2.5}$ and PM_{10} concentrations in non-attainment cities through city-specific action plans. In Himachal Pradesh, seven towns Baddi, Damtal, Kala Amb, Nalagarh, Paonta Sahib, Parwanoo, and Sunder Nagar have been designated as non-attainment cities under the NCAP due to persistently high PM levels. These towns are now implementing targeted air quality improvement strategies.[12]

Moreover, the integration of air pollution control with climate change mitigation has gained prominence in global and national policy dialogues. Internationally, platforms like the United Nations Framework Convention on Climate Change (UNFCCC)[13] and the Climate and Clean Air Coalition (CCAC)[14] emphasise the role of reducing SLCPs in warming mitigation strategies. For Himachal Pradesh, targeting SLCPs such as BC from cookstoves, methane from livestock and waste, and tropospheric ozone offers a strategic pathway to safeguard its glaciers, improve public health, and ensure the sustainability of its agriculture- and tourism-driven economy. Studies have shown that BC deposition on Himalayan snow and ice significantly accelerates glacial melt and alters regional climate patterns[15]. In addition, reducing SLCPs in high-altitude states like Himachal Pradesh can generate immediate air quality and health benefits while reinforcing climate resilience.

In this context, Himachal Pradesh has both an opportunity and the responsibility to demonstrate leadership in integrating clean air strategies with climate action; thus, equipping its people and ecosystems to tackle growing environmental pressures.


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From Air Quality to Climate Action: Leveraging SLCP Mitigation: A path beyond Decarbonization

The scientific community now acknowledges the significant role of air pollutants such as BC, tropospheric O_3, CH_4, and HFCs in driving climate change.[16] These SLCPs not only contribute to global warming but also degrade regional air quality, particularly in sensitive ecosystems like those in Himachal Pradesh. SLCPs such as BC and CH_4 accelerate warming at both global and local levels.[17] Increasing scientific evidence underlines the potential co-benefits of managing air pollution and climate change in an integrated manner. In a state like Himachal Pradesh—characterized by fragile mountainous ecosystems and tourism-driven economies—targeted SLCP mitigation through policy interventions and technology deployment can complement decarbonization strategies and improve public health and livelihoods.

Table 13: SLCPs and their Global Warming Potentials (GWP)

SLCP	Global Warming Potential (GWP)
Methane	More than 80 times that of CO_2 over a 20-year horizon
BC	Thousands of times greater than CO_2 on a per-mass basis (remains in the atmosphere for only a few days to weeks)
Hydrofluorocarbons	GWPs of HFCs vary widely but some HFCs can have GWPs ranging from hundreds to thousands of times that of CO_2 over 20 years
Tropospheric Ozone	Indirect GWP since it is not emitted directly but contributes to warming after its formation

Note: Global Warming Potential (GWP) measures the warming impact of gases relative to CO_2 over a specific timeframe, typically over 100 years. Higher GWP indicates higher warming potential.

The management of short-lived climate pollutants (SLCPs)[18] is critical for achieving near-term climate stabilization while delivering significant air quality and health co-benefits. In the context of Himachal Pradesh, the following pollutants warrant particular attention:

Methane (CH_4):

Methane is a highly potent greenhouse gas, with a global warming potential approximately 84 times that of carbon dioxide over a 20-year timeframe. In Himachal Pradesh, principal sources include enteric fermentation from livestock, limited paddy cultivation, and the decomposition of organic waste in landfills and unmanaged waste streams. Beyond its direct warming effect, methane is a key precursor to tropospheric ozone formation. Elevated ozone concentrations negatively affect respiratory health and reduce agricultural productivity, thereby posing risks to both public health and rural livelihoods.

Tropospheric Ozone (O_3) and Precursors:

Tropospheric ozone is not emitted directly but forms through photochemical reactions involving precursor gases such as methane, nitrogen oxides (NO_x), and non-methane volatile organic compounds (NMVOCs). In Himachal Pradesh, ground-level ozone concentrations are influenced by both local emission sources and regional transboundary transport. Ozone exposure is associated with impaired lung function and aggravated respiratory conditions. It also disrupts plant physiological processes, including photosynthesis, leading to measurable reductions in crop yields and ecosystem productivity.

BC:

BC, a component of fine PM ($PM_{2.5}$), is generated through the incomplete combustion of fossil fuels and biomass. In Himachal Pradesh, key sources include vehicular emissions, residential biomass use for cooking and heating, and forest fires. BC contributes to atmospheric warming by absorbing solar radiation. When deposited on snow and ice surfaces, it reduces surface reflectivity (albedo), accelerating glacier melt. In the Himalayan context, this process has significant implications for long-term water security, downstream river systems, and climate resilience.

Hydrofluorocarbons (HFCs):

Hydrofluorocarbons are synthetic gases widely used in refrigeration, air conditioning, solvents, and foam production as substitutes for ozone-depleting substances. Although present in relatively low atmospheric concentrations, many HFCs possess very high global warming potentials. Growing demand for cooling services in Himachal Pradesh, driven by economic development and rising temperatures, underscores the importance of transitioning toward climate-friendly cooling technologies and low-global-warming-potential alternatives in line with international commitments.

Global Policy Responses to SLCP Emissions: Multilateral Agreements and Processes

Since the early 2000s, multilateral institutions and United Nations processes have increasingly recognized the critical role of SLCPs in accelerating near-term warming while undermining air quality and public health. Organizations such as the United Nations Environment Programme and the Climate and Clean Air Coalition have been instrumental in advancing scientific understanding, policy integration, and coordinated action on methane, BC, and HFCs. Their efforts have emphasized the significant mitigation potential of SLCPs and the associated co-benefits for sustainable development, particularly in vulnerable regions.

Global regulatory frameworks have progressively incorporated SLCP mitigation into binding and voluntary commitments. A landmark example is the Montreal Protocol, originally established to phase out ozone-depleting substances. Through its Kigali Amendment,[19] adopted in 2016, the treaty was expanded to include the phasedown of HFCs—potent climate forcers. The Kigali Amendment introduced differentiated, time-bound reduction schedules for developed and developing countries, reinforcing the Protocol's near-universal participation and transforming it into one of the most effective global instruments for climate mitigation.

For regions such as Himachal Pradesh, alignment with these multilateral commitments provides a robust policy foundation for advancing integrated SLCP strategies. By strengthening implementation of national obligations and promoting climate-friendly technologies, sub national governments can contribute meaningfully to global climate goals while safeguarding local environmental and socio-economic resilience

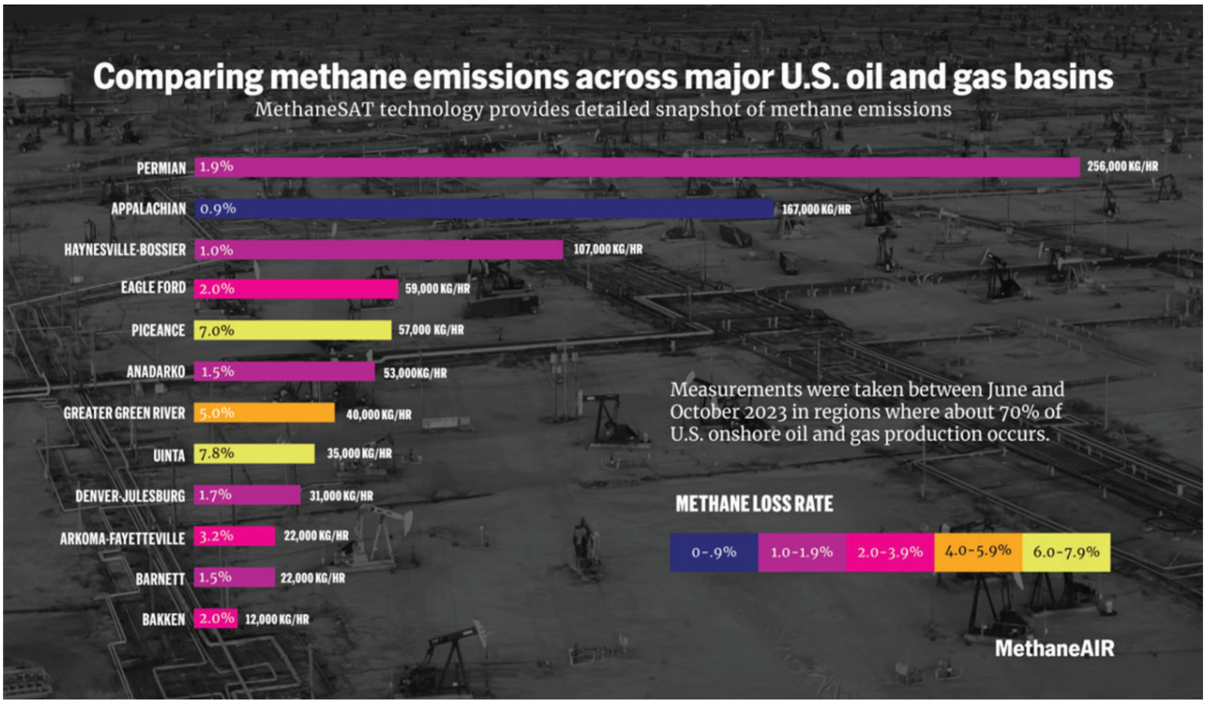
Collaboration with United Nations Development Programme (UNDP)

Response from Various Countries- Integrating: SLCP Mitigation into National Strategies

Several countries and sub national governments have progressively integrated short-lived climate pollutant (SLCP) mitigation into their national climate and air quality strategies. These efforts reflect growing international recognition—within United Nations climate processes and scientific assessments—that addressing methane, BC, and HFCs is essential for near-term climate stabilization, improved public health, and enhanced agricultural productivity.

The following examples illustrate diverse policy approaches that combine climate ambition with air quality management and sustainable development objectives:

United States



Through the Methane Emissions Reduction Action Plan (2021) and the AIM Act (2020), the United States has advanced methane abatement across oil and gas, agriculture, and waste sectors, alongside a phasedown of HFCs. Regional and state-level initiatives, including California's SLCP Reduction Strategy, set quantified reduction targets for methane, BC, and HFCs by 2030.

Countries such as Chile and Mexico have embedded SLCP targets within their Nationally Determined Contributions (NDCs), with Mexico notably including a BC target in its national climate framework. Ghana, Côte d'Ivoire, and Nigeria have adopted multi-sectoral SLCP action plans aligned with low-emission development strategies, prioritizing methane mitigation from waste and agriculture. At the city level, Lagos has strengthened integrated waste management systems to reduce landfill methane emissions.

Europe

European countries have emphasized policy coherence between climate mitigation and air quality improvement. Finland and Norway integrate SLCP reduction within national energy and climate strategies, incorporating health impact assessments and cost-effective prioritization metrics. The United Kingdom has advanced policy alignment between climate and clean air objectives, while cities such as Stockholm promote biogas production from organic waste and low-emission transport zones to reduce methane and BC.

Sub national and Regional Leadership

Sub national governments—including California, New York State, the Basque Country (Spain), and Bangladesh—have demonstrated that regional leadership can drive measurable SLCP reductions. These initiatives commonly integrate methane mitigation in waste and agriculture, HFC phasedown measures, and BC controls through cleaner transport and energy transitions.

Relevance for Himachal Pradesh

The global experience demonstrates that SLCP mitigation is most effective when embedded within broader climate, air quality, and development frameworks, supported by quantified targets, cross-sector coordination, and institutional accountability. For Himachal Pradesh—given its ecological sensitivity and Himalayan context—such integrated approaches can deliver immediate health and agricultural benefits while contributing to national and global climate commitments.

Aligning state-level strategies with international best practices would reinforce policy coherence, enhance resilience, and position the state as a model for mountain regions pursuing low-emission and climate-resilient development pathways.

Table 14. Response from Various Countries- Integrating SLCP Mitigation into National Strategies

Country / Region	Key SLCP Policy Instruments	Core Focus / Outcomes
United States[20,21]	Methane Emissions Reduction Action Plan (2021); AIM Act (2020); OTC; Regional Haze Rule	Methane reduction from waste, agriculture, oil & gas; phasedown of HFCs; inter-state ozone control
Chile[22,23]	SLCPs integrated into NDCs; Green Tax	Economy-wide SLCP mitigation; pricing emissions from industry and transport
Finland[24,25]	National Energy and Climate Strategy; NAPCP	Integration of SLCPs with air quality and public health co-benefits
Norway[26,27]	GTP10-Norway metric; health impact assessments	Cost-effective prioritisation of SLCP mitigation with near-term climate and health focus
United Kingdom[28]	Government report on climate–air pollution alignment (2019)	Policy coherence between climate mitigation and air quality goals
Ghana[29]	Multi-sectoral SLCP coordination team under NDCs	Cross-sector harmonisation and prioritisation of SLCP actions
Mexico[30,31]	BC target in NDCs; Climate Change Law	First country to include BC target; institutionalised cross-ministerial SLCP governance

Country / Region	Key SLCP Policy Instruments	Core Focus / Outcomes
Côte d'Ivoire[32]	National SLCP Action Plan (16 measures)	By 2030: 59% BC, 34% methane, 19% GHG reduction—over half of national mitigation target
Nigeria[33]	22 SLCP abatement measures across 8 sectors	SLCPs embedded in low-emission development strategy
Bangladesh[34] Subnational -	National SLCP Action Plan aligned with NDCs	Targets 20% methane and 53% BC reduction
California (USA)[35]	SLCP Reduction Strategy (2017)	By 2030: 40% methane & HFCs; 50% BC reduction
New York State (USA)[36]	Methane Reduction Plan (2017)	Methane abatement to support 40% GHG reduction by 2030
Stockholm (Sweden)[37]	Biogas from organic waste; Low Emission Zones	Methane reduction and BC control through transport and waste policies
Lagos (Nigeria)[38]	Integrated Waste Management Program	Methane mitigation via improved waste collection and landfill management
Basque Country (Spain)[39]	Climate Change Strategy 2050	Methane reductions from waste and agriculture at the regional level

Key Learning for India

Global and sub national experience demonstrates that the establishment of explicit SLCP reduction targets, supported by coordinated cross-sectoral governance and systematic integration of health and air-quality co-benefits, significantly enhances mitigation effectiveness and policy coherence.

In the context of Himachal Pradesh, these lessons provide a strong foundation for advancing a multi-tiered strategy aligned with India's national climate commitments and clean air objectives. By embedding SLCP mitigation within state planning frameworks—while ensuring coordination across sectors such as transport, energy, agriculture, and waste management—the state can contribute meaningfully to national priorities and global climate goals, while delivering tangible benefits for public health, ecosystem integrity, and sustainable development.

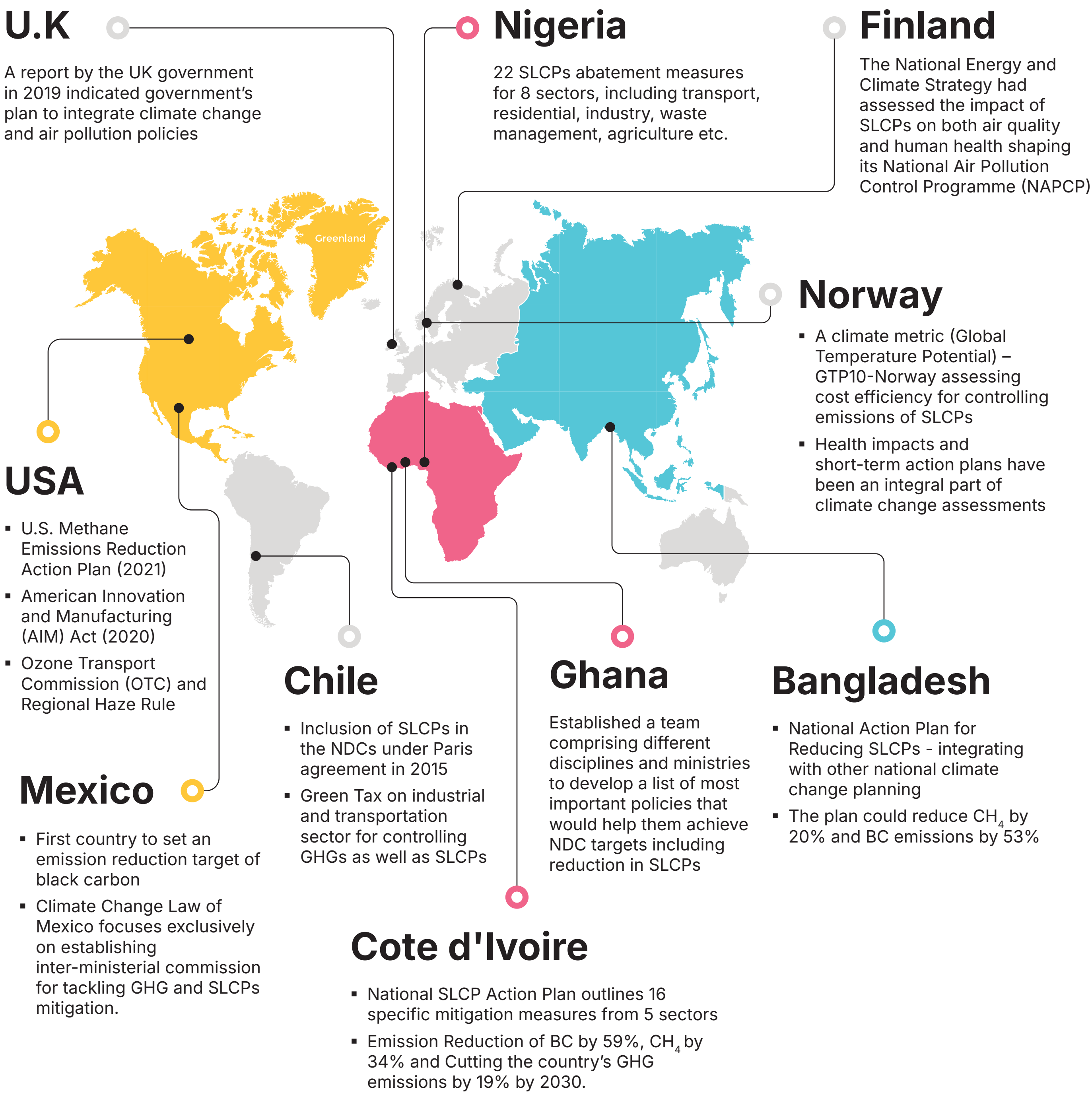


Figure 4: Global Responses in addressing SLCPs

National Perspective: India's Approach to Addressing Short-Lived Climate Pollutants (SLCPs)

India's response to SLCPs is anchored in its commitments under key multilateral environmental agreements, including the Montreal Protocol, the Kyoto Protocol, and the Paris Agreement. Through these frameworks, India has progressively strengthened measures to address CH_4, BC, HFCs, and other climate forcers that simultaneously affect air quality and near-term warming.

The adoption of the Kigali Amendment marked a significant step in phasing down high global warming potential HFCs, reinforcing India's commitment to climate-friendly cooling transitions. Complementary domestic initiatives—such as the National Clean Air Programme (NCAP), the India Cooling Action Plan, and enhanced Nationally Determined Contributions (NDCs)—reflect a growing emphasis on reducing PM, improving energy efficiency, expanding non-fossil fuel capacity, and lowering emissions intensity.

Although air pollution control and climate mitigation are addressed through distinct policy instruments, national strategies increasingly recognize their interconnected nature. Many emission sources—particularly in transport, industry, waste management and residential energy use—contribute to both degraded air quality and greenhouse gas accumulation. Integrated mitigation pathways therefore offer substantial co-benefits for public health, economic resilience, and sustainable development.

For Himachal Pradesh, alignment with these national and international frameworks provides a structured policy foundation for advancing state-level SLCP mitigation. By strengthening implementation across key sectors and harmonizing clean air and climate objectives, the state can contribute meaningfully to India's global commitments while safeguarding its ecologically sensitive Himalayan environment.

1987
Montreal Protocol
India became a signatory aimed at phasing out ozone-depleting substances, including hydrofluorocarbons (HFCs).

2005
Kyoto Protocol
India became a signatory to reducing greenhouse gas emissions, including SLCPs like methane and black carbon.

2010
National Solar Mission
To establish India as a global leader in solar energy, and achieve energy security through large-scale deployment, R&D, and cost reduction to reach grid parity by 2022.

2015
Paris Agreement
India submitted first Nationally Determined Contributions (NDC) – reducing emission intensity of economy by 33–35% from 2005 levels.

2022
India Cooling Action Plan (NCAP)
To promote energy efficient cooling and climate-friendly refrigerant.

2022
Update to NCAP & NDC
NCAP target updated to 46% reduction in atmospheric particulate matter concentration by 2026. NDC target updated to reduce the emissions intensity of its economy by 45% and achieving 50% non-fossil fuel capacity by 2030.

2019
National Clean Air Program (NCAP)
By 2024, reduce atmospheric particulate matter concentration by 20–30% compared to 2017.

2016
Kigali Amendment
India agreed to a phase down of HFCs, reinforcing its commitment to limiting high global warming refrigerants.

Figure 5: India's Actions in addressing SLCPs

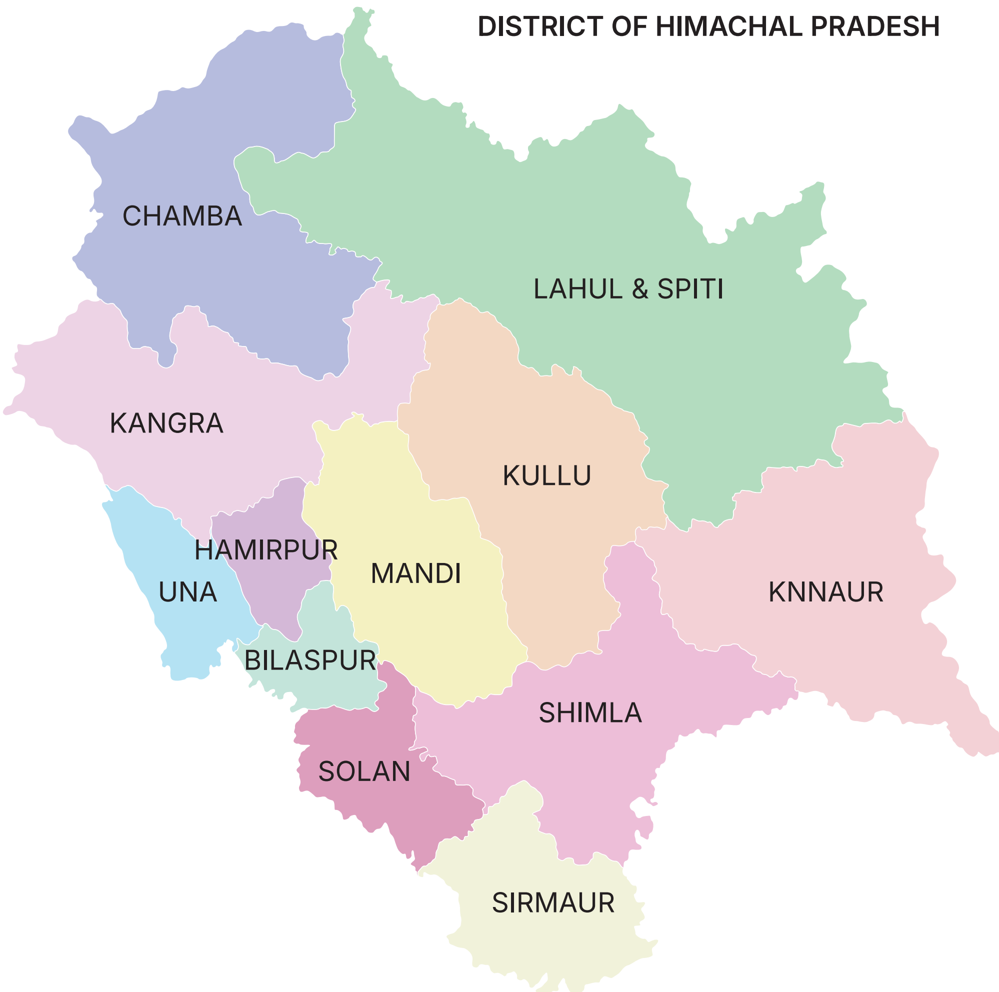


Figure 6: Districts of Himachal Pradesh

Programme and Initiatives: Himachal Pradesh

In alignment with national climate commitments and United Nations sustainable development frameworks, Himachal Pradesh has undertaken a range of sector-specific initiatives that contribute to the mitigation of SLCPs while strengthening air quality management and climate resilience. These measures span transport, residential energy, industry, agriculture, power generation, and waste management.

Table 15: Sector-wise Programmes and Policy Interventions

Programme / Policy	Key Interventions	Climate & Air Quality Relevance
1. Transport Sector		
Smart Cities Mission	Intelligent transport systems; public transport modernization	Reduced congestion, improved fuel efficiency
Himachal Pradesh EV Policy (2022)	Incentives for EV adoption; charging infrastructure	Reduction in BC, $PM_{2.5}$ and GHG emissions
Vehicle Scrappage Policy (2025)	Phasing out old and polluting vehicles	Lower vehicular emissions
Rajiv Gandhi Self-Employment Startup Yojana	~40% subsidy for electric taxis	Promotion of zero-emission livelihoods
HRTC E-Bus Procurement (FY 2025–26)	Induction of 500 electric buses	Reduced diesel consumption and urban air pollution
2. Industry and Mining Sector		
State Fuel Policy (2019)	Promotion of cleaner fuels	Reduced industrial emissions
Industrial Investment Policy (2019)	Incentives for sustainable industry	Energy efficiency and low-carbon growth
Green Energy Open Access	Renewable energy procurement by large consumers	Lower carbon intensity
State Action Plan on Climate Change (2021–2030)	Sectoral mitigation and adaptation roadmap	Integrated climate governance
Mining Policy (2024)	Strengthened environmental safeguards	Emission control in extractive sector
Continuous Emission Monitoring Systems (CEMS)	Real-time monitoring in mining areas	Improved compliance and pollution control
Greenhouse Gas Inventory (2012–13)	Carbon intensity assessment	Evidence-based mitigation planning
3. Agriculture and Livestock Sector		
Rajiv Gandhi Prakritik Kheti Khushal Kisan Yojana	Promotion of natural farming; large-scale farmer adoption	Reduced chemical inputs and associated emissions
Rajiv Gandhi Van Samvardhan Yojana	Plantation of fruit trees on degraded lands	Carbon sequestration and ecosystem restoration
Saur Sinchayee Yojana	Subsidized solar-powered irrigation	Reduced diesel use and emissions
Pashu Mitra Policy (2022)	Strengthened livestock services; fodder support	Improved manure management and methane mitigation potential
Crop Diversification Scheme	Climate-resilient cropping patterns	Sustainable land use and reduced vulnerability

Programme / Policy	Key Interventions	Climate & Air Quality Relevance
Continuous Emission Monitoring Systems (CEMS)	Real-time monitoring in mining areas	Improved compliance and pollution control
4. Residential Sector		
Pradhan Mantri Ujjwala Yojana	LPG connections for households	Reduced biomass burning and BC
Mukhyamantri Grihini Suvidha Yojana	Clean cooking fuel support	Improved indoor air quality
125 Units Free Electricity Scheme	Enhanced electricity access	Reduced reliance on solid fuels
Gobar Dhan Scheme	Community-level biogas systems	Methane capture and renewable energy generation
Rooftop Solar Subsidies (Budget 2025–26)	Financial incentives for solar installations	Decentralized renewable energy transition
State Environment Master Plan	Integrated environmental planning	Mainstreaming climate and air quality considerations
5. Solid Waste Sector		
Swachh Bharat Mission	Improved waste collection and sanitation	Reduced open burning and methane emissions
State Environment Plan (2024)	Integrated environmental management framework	Strengthened municipal waste systems
Action Plan for Municipal Solid Waste Management (2017)	Scientific processing and landfill management	Methane mitigation and improved urban air quality
Solid Waste Management Rules (2016)	Regulatory compliance framework	Systematic waste segregation and processing
6. Power and Renewable Energy Sector		
Swaran Jayanti Energy Policy (2021)	Target of 10,000 MW green capacity by 2030	Accelerated renewable energy transition
Green Panchayat Scheme	Panchayat-level solar installations	Decentralized clean energy generation
UJALA Scheme	Distribution of LED bulbs and efficient appliances	Energy efficiency and reduced electricity demand
Rajiv Gandhi Swarozgaar Start-Up Yojana	Youth-led solar projects (100–500 kW)	Inclusive green entrepreneurship

Transport Sector

The transportation sector has seen a transformative shift toward electric mobility. Under its 2022 EV Policy, Himachal Pradesh set ambitious targets: 15% of new vehicles sold to be electric by 2025, progressing toward 100% by 2030. The state has invested heavily in electric public transport, including procurement of 500 electric buses, and is converting government fleets to EVs. Charging infrastructure is rapidly expanding: the state has approved 402 EV charging stations at key public locations such as petrol stations, government buildings, and tourist rest houses. Of these, 23 chargers are already operational at petrol pumps, and 90 more stations are expected to be installed by the end of 2025, particularly along six designated EV corridors to improve long-distance connectivity and support adoption across districts[40].

Industry Sector

Himachal Pradesh is proactively steering its industrial sector towards a low-carbon future through a multifaceted approach that encompasses policy reforms, technological advancements, and financial incentives. Recognizing the significant contribution of industries, particularly cement manufacturing, to the state's GHG emissions, the government has implemented targeted strategies to mitigate environmental impacts while promoting sustainable industrial growth[41].

To address industrial emissions, Himachal Pradesh enforced its State Fuel Policy in 2019, which bans or restricts the use of highly polluting fuels such as pet coke and furnace oil. Industries are required to use cleaner fuels like natural gas or biomass blends, and to install Continuous Emission Monitoring Systems (CEMS) to track pollutants in real time[42]. These regulations have resulted in significant reductions in SO_2, NO_x, and PM emissions[43]. Evidence from Himachal Pradesh and comparable international studies highlights the scale of reductions enabled by these industrial fuel interventions. For example, under the amended State Fuel Policy (2023), pet-coke-fired boilers in the state are required to achieve approximately 90% reduction in SO_2 emissions through fuel switching or pollution control devices[44]. Similarly, global best practices from industrial sectors show that transitioning from heavy liquid fuels like furnace oil to natural gas can result in up to 96% reduction in PM_{10}, 72% in SO_2, and 24% in NO_x emissions[45,46]. These reductions align with the state's objective to curb SLCPs and air toxics at the source, particularly in emission-intensive clusters like Baddi–Nalagarh and Kala Amb.

The state also offers incentives for adopting energy-efficient technologies in industrial operations, aligning with national energy performance programs[47]. The state also promotes electric mobility by offering subsidies for e-vehicles and developing green corridors along highways. Additionally, the Green Energy Open Access initiative allows large consumers to procure renewable energy directly, fostering a shift towards cleaner industrial power consumption[48]. Another effort towards low carbon development is the formulation of a Green Hydrogen Policy that is in the making and establishment of green hydrogen plants which aim to leverage the state's abundant renewable resources to promote green hydrogen production and establish the state as a hub for this clean energy source[49].

To address emissions from the brick kiln sector—one of the significant sources of BC and PM—Himachal Pradesh has actively promoted the adoption of cleaner brick production technologies. In line with the Ministry of Environment, Forest and Climate Change (MoEFCC)'s 2016 notification, the state has mandated a shift from Fixed Chimney Bull's Trench Kilns (FCBTKs) to cleaner options such as Zig-Zag kilns, Vertical Shaft Brick Kilns (VSBKs), and fly ash-based brick manufacturing units[50]. The State Pollution Control Board has made it compulsory for existing kilns to retrofit or upgrade their designs to zig-zag configurations to improve combustion efficiency and reduce PM and CO_2 emissions by up to 30–40%. Additionally, environmental clearances and operational permissions are increasingly tied to the adoption of cleaner technologies. In districts with high brick kiln density like Solan, Una, and Kangra, enforcement has been supplemented with awareness drives, technical training, and incentives to promote compressed stabilized earth blocks and fly ash bricks—especially near thermal power plant regions. These measures not only reduce emissions but also support a transition toward resource-efficient, climate-resilient construction practices[51,52].

A vehicle scrappage policy was introduced in 2025 to remove old, polluting vehicles from circulation, and measures like fuel restrictions, green taxes, and traffic regulations (e.g., odd-even rules during smog events) are being used to manage emissions in urban areas[53]. Furthermore, urban freight movement is being addressed through local action plans such as Shimla's Low Carbon Urban Freight Plan, which promotes the use of electric cargo vehicles and optimizes delivery networks to reduce emissions from commercial logistics[54]. Between 2011 and 2025, Himachal Pradesh implemented several key initiatives aimed at reducing air pollution and promoting cleaner transportation. The enforcement of Bharat Stage VI fuel norms and restrictions on the entry of older diesel vehicles is expected to reduce PM and CO emissions by 30-40%. Additionally, the state encouraged the adoption of four-stroke engines in two-wheelers and three-wheelers, significantly lowering hydrocarbon emissions by 50% compared to traditional two-stroke engines.

Mining Sector

Himachal Pradesh has pivoted toward a more regulated and sustainable model under the new Mineral Policy 2024, which seeks to balance economic development with ecological protection. The policy emphasizes the adoption of scientific and mechanical mining methods to minimize environmental degradation, especially in ecologically sensitive zones[55]. One of the central features is the digitization of mining operations through an integrated online portal that facilitates transparency and allows real-time monitoring of licensed sites. The policy also promotes in-state value addition by encouraging the establishment of mineral-based processing industries, aiming to reduce dependence on raw material exports and increase local employment. These reforms not only modernize the mining sector but also align it with the state's broader environmental objectives, particularly in reducing particulate emissions and preserving riverine ecosystems affected by unregulated extraction. Additionally, in sensitive zones, only low-sulfur diesel is permitted for mining machinery, helping to limit BC and sulfur emissions[56].

Agriculture and Livestock Sector

Himachal Pradesh has taken multiple steps to make its agricultural sector more sustainable and environmentally friendly. Since 2018, the state has promoted natural and organic farming through the Rajiv Gandhi Prakritik Kheti Khushhal Kisan Yojana or Natural Farming for Prosperous Farmers Scheme, which encourages farmers to reduce their dependence on chemical fertilizers and pesticides[57]. As of 2025, over 2.23 lakh farmers had adopted this practice covering approx 38500 hectares of land, with an additional 1 lakh farmers targeted for inclusion.[58] In parallel, the Government launched ambitious afforestation and agroforestry programs to improve soil health and sequester carbon. Through the Rajiv Gandhi Van Samvardhan Yojana, local youth and women's groups receive financial support to plant fruit trees on degraded lands, enhancing both ecological and economic resilience[59]. Additionally, the Saur Sinchayee Yojana supports the transition to solar-powered irrigation, providing heavy subsidies on solar pumps to small and marginal farmers, thus replacing diesel usage and reducing carbon emissions[60].

Furthermore, in the livestock sector, the Pashu Mitra Policy-2025 aims to recruit 1,000 multi-task workers to support animal husbandry services, while increasing fodder grants for stray cattle to improve their management[61].To tackle methane emissions from livestock waste and improve rural energy access, Himachal Pradesh has also encouraged the use of biogas plants to be able to divert animal waste properly[62]. These small-scale digesters, installed in cattle-owning households, convert animal waste into usable cooking gas, thereby reducing reliance on firewood and improving indoor air quality. Continuing these efforts, the state has recently introduced the *Him Unnati Yojana*, aimed at creating 2,600 integrated agricultural clusters by converging efforts across agriculture, horticulture, animal husbandry, and allied sectors. Launched in 2023–24 with a budget of ₹25 crore in its first year, the scheme targets small and marginal farmers, especially women and those from SC/ST and BPL categories, by promoting high-value crops, fencing support, and 100% soil test–based nutrient application. Complementing this is the *Paramparagat Krishi Vikas Yojana (PKVY)*, which has supported both organic and natural farming clusters across Himachal Pradesh. By 2023, over 12,000 hectares had been brought under natural farming through 605 groups registered under the Bharatiya Prakritik Krishi Paddhati (BPKP) initiative. These efforts reinforce Himachal's commitment to environmentally sustainable and climate-resilient agriculture, while contributing to India's broader goals under the National Mission on Sustainable Agriculture.

Residential Sector

In a landmark achievement, Himachal Pradesh became India's first "smoke-free" state in 2022, achieving 100% household LPG coverage through the Central Pradhan Mantri Ujjwala Yojana (PMUY) and the state-run Mukhyamantri Grihini Suvidha Yojana[63]. These programs provided free LPG connections and refills to low-income households, significantly reducing indoor air pollution and atmopsheric pollutants emissions from traditional biomass cooking methods[64]. Complementing these efforts, the state continues to promote energy-efficient appliances and solar water heaters in residential areas, along with enforcing building codes that mandate rainwater harvesting and reduce energy use[65].

To enhance residential energy access, the government has increased subsidies for rooftop solar installations, offering up to ₹6,000 per kW, in addition to central government incentives[66]. The net metering policy allows residential consumers to install solar systems up to 500 kW, enabling them to offset electricity bills by feeding surplus energy back into the grid[67]. Furthermore, the state provides 125 units of free electricity to over 14 lakh domestic consumers, promoting equitable energy access[68].

Solid Waste Sector

The state has implemented innovative waste management strategies, focusing on waste-to-energy (WtE) technology and solid waste processing through the Action Plan for Municipal Waste Management and State Environment Plan[69,70]. Notable projects include gasification plants in Shimla and Manali, designed to convert municipal solid waste into electricity while reducing methane emissions from landfills by diverting waste into the WTE plants[71]. Furthermore, the installation of composting units and baling machines in urban centers has improved waste segregation and recycling[72]. Himachal Pradesh has also led in plastic regulation, enacting one of India's earliest plastic bans in Shimla in 1996 and continually updating these rules to prohibit low-micron and non-woven plastic bags[73]. Moreover, enforcement has been strengthened through the launch of an SUP Ban Challan app, alongside improved waste segregation infrastructure such as installing bins in public transport. The state has also notified the Himachal Pradesh Deposit Refund Scheme (DRS) in 2025 to implement Extended Producer Responsibility (EPR) in the state. The scheme applies the polluter pays principle to ensure systematic collection, recovery, and recycling of non-biodegradable packaging waste, reducing littering and improper disposal while promoting environmental protection and a circular economy.

Due to the intricate scientific linkage between air quality and climate change, clear policy guidance embedding the interaction between the two can result in enhanced co-benefits for climate, human health, and ecosystems. Even from the point of view of Sustainable Development Goals (SDG), there is a great opportunity to contribute by including the air quality and climate change linkages in designing policies to address them. Several multilateral agreements and individual countries across the world have already undertaken this linkage in their policies, which are detailed in the section below. These may be useful for India in rolling out collective climate action policies.

Power Sector

Himachal Pradesh is advancing a comprehensive energy strategy that emphasizes renewable energy adoption, grid modernization, and inclusive economic development. The state's Swaran Jayanti Energy Policy (2021) targets the addition of 10,000 MW of green energy capacity by 2030, focusing on hydro, solar, and other renewable sources[74]. Complementing this framework is the Himachal Pradesh Solar Power Policy (first issued 2016; updated 2022), which sets specific solar capacity milestones—700 MW by 2022 and roughly 2 GW by 2030—while offering incentives such as zero stamp duty land leases, concessional wheeling charges, and a state roof top solar subsidy of up to ₹6,000 per kW to accelerate private and community projects[75]. These policies promote participation from state, joint, central, and private sectors and aims to develop an efficient transmission network to support timely execution of energy projects.

The power sector in Himachal Pradesh has already witnessed a major shift toward renewables. With abundant hydropower potential, the state already meets a significant portion of its energy needs through greener sources[76]. Rooftop and panchayat-level solar installations are being promoted under the Green Panchayat Scheme, ensuring energy independence for local communities. The state's emphasis on energy efficiency has also been significant, with large-scale distribution of LED bulbs, tube-lights, and energy-efficient fans under the UJALA scheme, leading to annual CO_2 savings in the range of hundreds of thousands of tons[77]. Simultaneously, grid upgrades and subsidies for solar installations in remote areas are helping integrate renewables more effectively into the power infrastructure.

To foster entrepreneurship and employment, the Rajiv Gandhi Swarozgaar Start-Up Yojna encourages youth aged 21–45 to establish solar power projects ranging from 100 kW to 500kW on their land[78]. Participants receive monthly income based on project capacity, contributing to the state's clean energy goals and rural economic development. In parallel with these renewable energy advancements and efficiency measures, Himachal Pradesh is also addressing residual sources of emissions from the power sector, particularly those arising from DG sets.

To reduce emissions of SLCPs and air pollutants from DG sets in Himachal Pradesh, the state is undertaking several focused actions. It is actively expanding the implementation of the PM-KUSUM Yojana, increasing financial support and simplifying access for small and marginal farmers to accelerate the transition from diesel-based agricultural pump sets to solar-powered alternatives. In sectors where DG sets remain essential such as industry, commercial establishments, and telecom infrastructure; the state is promoting the retrofitting of existing generators with particulate and hydrocarbon control devices to reduce emissions. Simultaneously, Himachal Pradesh is working to enhance the reliability and coverage of the electricity grid, particularly in remote and hilly regions, to reduce dependence on backup diesel generators. By ensuring a continuous power supply with minimal interruptions, the state is effectively trying to curb diesel consumption across sectors.

Encouragement for use of bicycles to mitigate carbon emissions

Short-Lived Climate Pollutants (SLCPs): Rationale for Sub-National Action in Himachal Pradesh

A centralized, one-size-fits-all approach to mitigate SLCPs and air pollution is insufficient for a country as diverse as India. States like Himachal Pradesh, with their unique geographic, climatic, socio-economic, and sectoral characteristics, require customized action plans to address SLCPs effectively. Sub-national strategies are vital to reflect ground realities and to design interventions that are feasible, impactful, and sustainable. Some of the reasons, that make sub national action imperative for SLCP mitigation have been explained below:

- **Diverse Sources of SLCPs and Local Impact:** Himachal Pradesh has a distinct emissions profile dominated by BC from biomass burning, wood-fired heating, diesel transportation, and open burning of agricultural and forest waste. Methane emissions mainly originate from agriculture (especially livestock), waste management, and enteric fermentation. Given the hilly terrain, low industrial activity, and a high share of rural households dependent on traditional fuels, national strategies focused on urban-industrial SLCP sources fail to capture the reality of emissions in the state. Thus, tailored solutions such as promoting biogas, cleaner cookstoves, and decentralized waste treatment are necessary[79].
- **Geographic and Climatic Vulnerability:** As a Himalayan state, Himachal Pradesh is uniquely vulnerable to BC deposition on snow and glaciers, which accelerates melting and disrupts regional hydrology[80]. Unlike the Indo-Gangetic plains, where temperature inversions trap pollutants, Himachal's steep valleys and dynamic wind patterns contribute to pollutant transport and deposition in glaciated regions. Methane-driven warming further shifts precipitation patterns, increasing the risks of flash floods, landslides, and glacial lake outburst floods[81.]
- **Public Health Risks:** SLCPs like BC and tropospheric O_3 contribute significantly to the region's health burden. Fine PM can lead to respiratory illnesses, cardiovascular diseases, and increased hospital admissions, especially in colder months when biomass burning peaks. Additionally, elevated ozone levels caused by methane can aggravate asthma, bronchitis, and other respiratory disorders, particularly among children and the elderly. As climate change increases the frequency of extreme weather events, the burden of waterborne diseases, mental health disorders, and heat stress is expected to rise[82].
- **Livelihood, Food Security, and Economic Stability:** The agrarian economy of Himachal Pradesh is highly sensitive to climatic variations influenced by SLCPs. Changes in temperature and precipitation patterns can disrupt agricultural cycles, leading to reduced crop yields and affecting the quality of produce. Horticultural activities, particularly apple farming, which is a significant contributor to the state's economy, are vulnerable to these climatic shifts. Farmers have reported declining apple yields and a shift in suitable cultivation zones to higher altitudes due to rising temperatures[83],[84]. Additionally, the tourism sector, a major economic driver in the state, faces challenges from environmental degradation and the increased occurrence of natural disasters.
- **Governance and Implementation Needs:** Local governance mechanisms in Himachal Pradesh have made progress in implementing the State Action Plan on Climate Change (SAPCC) and climate-health linkages, but institutional capacity varies across districts. Strengthening decentralized implementation, especially through panchayats and urban local bodies, is key to enforcing SLCP-related policies. Monitoring and enforcement must be customized to local geography—such as valley-specific pollution dispersion patterns and local waste management systems—rather than relying solely on national enforcement mechanisms[85,86].
- **Maximizing Co-Benefits Through Localized Policies**: Targeted mitigation of SLCPs can generate substantial co-benefits for Himachal. Reducing BC from biomass cookstoves improves both indoor and ambient air quality, reducing the health burden on rural households. Methane capture from decentralized waste treatment not only curbs emissions but also generates energy

and reduces land and water pollution. Integrating SLCP mitigation with sustainable agriculture, clean energy, and climate-resilient tourism can advance the state's development priorities while building environmental resilience.

While a national SLCP mitigation framework is necessary for overall policy direction, funding, and international alignment, state-specific action plans are essential to account for India's regional diversity. Variations in emission sources, climatic conditions, economic constraints, governance capacity, and sectoral priorities require localised solutions that go beyond a one-size-fits-all approach. Strengthening state-level planning will not only accelerate SLCP mitigation but also maximise co-benefits for air quality, public health, and climate resilience.

Building on this understanding, Himachal Pradesh serves as a crucial case study for state-level SLCP mitigation.

The region's SLCP emissions come from biomass burning for heating and cooking, diesel-powered transport on hilly terrain, and agricultural and livestock-related methane emissions, particularly in rural areas. The air quality challenges here are compounded by forest fires and waste burning in small urban centres.

In Himachal Pradesh, exposure to SLCPs and associated air pollutants—such as $PM_{2.5}$, PM_{10}, BC, CO, and ozone precursors—is intensified by temperature inversions in valleys, especially during winter. These inversions trap pollution close to the ground, increasing exposure. Populations living in mountain towns and rural areas are particularly at risk, including elderly residents, children, pregnant women, especially those relying on traditional biomass for heating and cooking. The combination of pollution and high-altitude hypoxia increases cardiopulmonary risks, while ozone from methane emissions affects crop yields, impacting food security[87].

Adding to the complexity is the glacial albedo effect[88,89].

Himachal Pradesh is already experiencing the effects of climate warming, with observed increases in mean temperatures and shrinking snowlines. Current summer temperatures in mid-altitude zones range from 22°C to 35°C, while high-altitude areas are witnessing rising minimum temperatures, leading to reduced snow accumulation and altered precipitation. Projections suggest a temperature increase of 1.6–2.1°C by the 2030s, and 3.2–4.0°C by the 2080s under RCP 8.5 scenarios. These changes are also increasing the frequency of extreme weather events such as heavy rainfall, landslides, and cloudbursts, threatening agriculture, infrastructure, and lives[90].

Climate-sensitive sectors like apple plantation, wheat farming, and tourism are experiencing growing disruptions. For example, apple production zones are shifting to higher altitudes, while traditional cultivation belts face reduced chilling hours and higher yield losses. Tourism—especially snow- and nature-based tourism—is increasingly affected by unpredictable snowfall, landslides, and heat stress in summer months. This puts both seasonal income and public infrastructure at risk[91,92].

The demand for heating and cooling purposes is also rising. During winters, traditional biomass stoves are used for space heating, while warming temperatures are increasing summer demand for fans and air-conditioning in urban areas like Shimla and Dharamshala. This dynamic increases electricity load, GHG emissions, and pollution, especially when diesel generators or inefficient biomass use persists.

Therefore, targeted SLCP mitigation efforts in Himachal Pradesh provide multiple co-benefits. These include improving public health, protecting glacial resources, securing livelihoods in agriculture and tourism, and building climate resilience across vulnerable populations and ecosystems. Himachal Pradesh has recognized these interlinked challenges through actions like the promotion of clean energy (LPG access, solar heaters), EV-friendly tourism plans, early warning systems, and forest fire mitigation programs. However, further action is needed to scale sub-national air quality and climate governance, especially in remote and ecologically fragile zones.

Emissions Analysis: Approach and Methodology

Estimating Base Year Emissions

The selection of 2019 as the baseline year is based on its relevance to national air quality planning, as it aligns with the NCAP mandate, which requires states to assess emission reductions relative to this year. The base year analysis encompasses key sectors such as transportation (tailpipe emissions), industry (industrial combustion and mining), diesel generator set, thermal power plants, residential (household cooking), agriculture (covering open burning of agricultural residue and emissions related to cultivation), livestock (including emissions from enteric fermentation and manure management), and waste (open burning of municipal solid waste, and landfills). Additionally, to ensure a comprehensive assessment of the base year, smaller sectors such as crematoria, construction, and road dust were also included to assess an emission profile of the state in 2019. Emission estimates were based on activity types, emission factors, pollution abatement technologies used, and control efficiency.

The basic equation followed in the study is,

$$Ep = \sum_R \sum_S \sum_F A_{R,S,F} \times EF_{R,S,F} \times (1 - \alpha_{R,S,F}) \times X_{p,R,S,F}$$

where, Ep is the annual emission of a pollutant (p) (Kt); R is the district/state; S is the sector; F is the type of fuel; A is the activity data (fuel consumption or other emission related data); EF is the emission factor (Kt per unit of fuel use) of the pollutant (p); α is the removal efficiency (%) of pollutant (p) with the installed pollution control technology and X is the actual application rate of the control technology[93]. The activity data (A) for 2019 across different sectors was primarily gathered from published datasets published by various ministries of the Government of India. However, some data gaps were addressed using information from published peer-reviewed literature. Figure 4 illustrates the overall framework for emission estimation used in this study. Detailed sector-specific methodologies for developing emission inventories, along with comprehensive emission inventories for each sector, are provided in Annexure 1. It is important to note that the emission inventory represents a macro-level estimate and does not constitute a fully detailed bottom-up assessment due to the limited availability of disaggregated data.

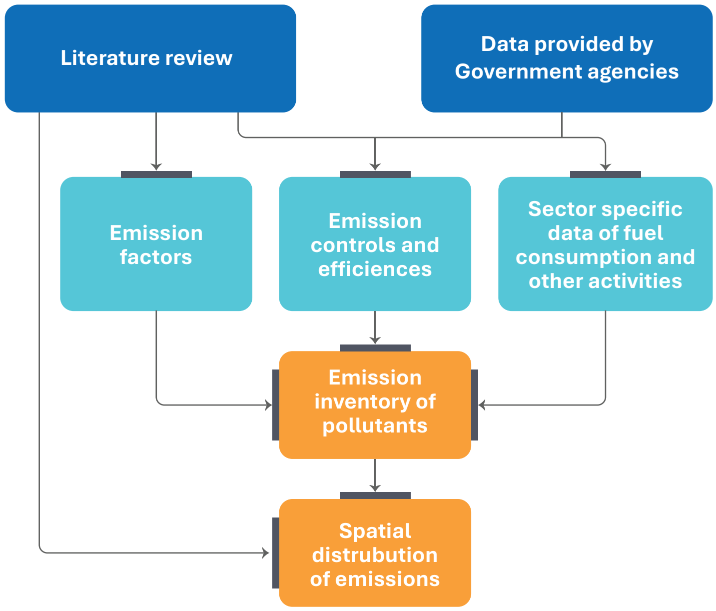


Figure 7: Emission Estimation Framework followed in the Study

Building Scenarios for the Study

To evaluate the potential of existing policies to reduce SLCP emissions, examine their ambition levels, identify gaps and suggest additional strategies, and determine the emission reduction potential of various interventions, the study analysed the emission growth trajectories of different SLCPs and air pollutants in HP for the years 2030, 2040 and 2047. Emissions scenarios—Baseline and Alternative—were considered, with each scenario representing distinct combinations of policy ambitions and strategies, calculating emission trajectories for milestone years (2030, 2040, and 2047). These scenarios align with the state's sector-specific policies. In the absence of such policies, national policies have been applied, or relevant sectoral policies and reports from other states have been referenced. The scenarios are as follows:

- **Baseline Scenario (BAU):** This scenario reflects the sectoral growth projections for Himachal Pradesh under current conditions. It takes into account certain interventions that have already been implemented and addresses SLCP emissions.
- **Alternative Scenarios (ALT):** These scenarios assume the successful implementation of additional interventions aimed at reducing SLCP emissions. These scenarios evaluate the impact of proposed measures on short-term (2030), mid-term (2040), and long-term (2047) policy targets. The year 2047 has been chosen as the long-term target as it aligns with the Government of India's 'Viksit Bharat by 2047' initiative, which envisions transforming India into a developed nation by its 100th year of independence. This timeline also corresponds with the Samriddh Himachal Vision 2045, the state's long-term development blueprint that emphasizes sustainability, clean energy, and inclusive growth. The interventions include specific sectoral policies planned by the state.

Baseline Scenario

The Baseline Scenario represents a Business-as-Usual (BAU) approach. It assumes that starting from the 2019 emission levels, sectoral activities grow according to the specified growth rates as outlined below and policy measures, which are already being implemented by the state government, have been accounted for in these sectors. In this scenario, the state's emissions are expected to increase since the fuel mix for the state's total primary energy remains the same and other activities, such as agriculture, livestock rearing, and waste management, continue with their existing practices. Essentially, the BAU scenario serves as the reference point against which we compare the effectiveness of mitigation interventions in the Alternative scenarios. By contrasting the BAU emissions with those in the Alternative scenarios, we can assess the efficacy of various mitigation strategies. These insights inform policymaking, helping the state make informed decisions to combat SLCP emissions and work toward a more sustainable future.

Table 16: Reference Points for Sector-Wise Growth Projections

Sector	Growth Rate (Annual)	Rationale	Reference
Transport	4.8%	Derived from the average annual growth of the transport sector between 2012–13 and 2020–21. Growth in vehicle registrations estimated from VAHAN and MoRTH data.	VAHAN Dashboard, MoRTH
Industry	6.4%	Calculated using the long-term growth trend (2010–11 to 2022–23) of state-level industrial GSDP.	RBI Handbook (2022-2023)
Livestock	0.2%	Total livestock population in the state represents a declining trend during 2012 to 2019 census. However, cattle and buffalo population in the state increased by 1.34% and 1.06% in the same period. On the other side, milk production in the state increased from 1.57 Mt in 2019-20 to 1.82 Mt in 2024-25. Milk production growth projected using its 0.86% share of national output. Aligned with increase in India's projected annual milk demand 5.85% (CAGR 2014-15 to 2022-23).	National Dairy Development Board Ministry of Fisheries, Animal Husbandary and Dairying, Government of India
Residential Cooking	- Population : 0.29% (Rural), 4.15% (Urban) - LPG Consumption: 5.90%	Population growth rate was taken from the Population projections report for India and states 2011-2036 (MoHFW). District level domestic LPG consumption (2019-20, 2021-22 and 2022-23) information provided by Food, Civil Supplies and Consumer Affairs department; Government of Himachal Pradesh were used to project the LPG using households during future years	MoHFW 2020
Solid Waste	3.97%	Waste generation growth derived from historical trends in waste collection (2014–2021) as per CPCB reports.	CPCB SWM Rules Reports;
DG set	Diesel Consumption CAGR: 5.45%	Diesel consumption for DG sets is projected to grow at a CAGR of 5.45% under the BAU scenario, consistent with historical trends reported by MoPNG. Sectoral diesel consumption shares remain constant. No additional policy measures are assumed, so diesel use and associated emissions continue to rise in line with historical demand trends.	MoPNG (various years); PPAC, 2021

Alternative Scenarios

The Alternative Scenarios in this study represent a combination of ongoing and planned sectoral interventions by the state and the projected emission reduction outcomes resulting from their implementation. The inclusion of these hypothetical interventions helps assess the potential for achieving more ambitious reductions in SLCP emissions if such measures were implemented in Himachal Pradesh.

These scenarios evaluate the overall quantitative impact on sectoral activity levels for the years 2030, 2040, and 2047. The selection of specific policy interventions for quantification was guided by two main criteria: (i) the direct relevance of the policy to major SLCP emission sources within the state, and (ii) the feasibility of quantifying its impact based on defined targets that enable measurement of emission reduction benefits.

Since many of the relevant policies are indicative or directional in nature and lack clearly defined activity-level targets, assumptions had to be made to estimate quantitative impacts. These assumptions are detailed in the sectoral write-ups in Section 6. Wherever state-level policies provided explicit numerical targets, these were used as a basis and extrapolated to fill data gaps. Table 17 outlines the specific policies that form the foundation of the different alternative scenarios assessed in this analysis.

The assumptions for sectoral targets are based on observed activity trends from 2020 onwards, reflecting progress toward the full implementation of policies envisioned for the 2020–2030 period. Projections are further informed by Himachal Pradesh's sector-specific policies and regulatory documents, supplemented by relevant national targets where state-level data is unavailable.

Emissions for each scenario were estimated based on the projected activity data under the BAU baseline, adjusted for the effects of fuel substitution with cleaner alternatives, and the adoption of low-emission technologies and practices.

The chronology of these ALTs within one sector indicates the ease of implementation and also accounts for higher reductions in successive ALTs. While quantitative goals may exist, our additional quantified inputs until 2047 help understand how helpful interventions will be for SLCP emission reductions.

Table 17: Reference Policies for Quantifying SLCP Mitigation in Alternative Pathways

Sector	Scenario	Policy Rationale behind Selected Intervention(s)	Description of Interventions and Targets Assumed
Transport	ALT-1	National Vehicle Scrappage Policy (2024) promotes retirement of old vehicles to reduce emissions and improve fleet efficiency.	Scrappage of Old Vehicles ▪ 30% scrappage of 20-year-old petrol and 15-year-old diesel vehicles by 2030. ▪ 60% scrappage of such vehicles by 2040. ▪ 80% scrappage by 2047.
	ALT-2	Himachal Pradesh Electric Vehicle Policy (2022) aims to promote state-wide electric mobility with a focus on government and public transport fleet conversion.	EV Fleet Electrification ▪ 100% conversion of state transport buses and complete transition of government fleets to EVs by 2030. ▪ 50% conversion of all vehicle types (buses, two-/three-wheelers, cars, LCVs) to EVs by 2040. ▪ 70% conversion of all vehicle types to EVs across all districts by 2047.
Industry	ALT-1	HP Green Hydrogen Policy, 2023	The introduction of Green Hydrogen is assumed to reach 5% and 8% in industries by 2040 and 2047, respectively.

Sector	Scenario	Policy Rationale behind Selected Intervention(s)	Description of Interventions and Targets Assumed
	ALT-2	NCAP Industrial Emission Guidelines (MoEFCC, GoI)	The implementation of community boilers is expected to result in a 30% reduction in fuel consumption in the years 2030, 2040, and 2047. Implementation of Wet Scrubbers (WSC) will be enforced by 25%, 50%, and 100% in industries for the years 2030, 2040, and 2047, respectively, to reduce PM and gaseous emissions.
Livestock	ALT-1	Recommendations from the National Dairy Development Board and initiatives by the Himachal Pradesh Animal Husbandry Department on improving dairy feed quality and fodder availability.	Feeding of Dairy Animals Development and popularisation of 'Green Fodder Production Technologies' and implementation of the Ration Balancing Programme to promote balanced feeding, including optimized fodder ratios and supplements.
	ALT-2	Indigenous breed promotion supported under the Rashtriya Gokul Mission, Himachal Pahari Cattle Conservation Project, and initiatives by the Himachal Pradesh Animal Husbandry Department.	Promotion of Indigenous Cattle Focused breeding and conservation of native breeds like Himachal Pahari cattle to enhance productivity and resilience, with reduced methane emissions compared to cross-breeds.
	ALT-3	Integrated approach combining feed optimization with native breed conservation to maximize livestock-related SLCP and GHG reductions.	Combined Strategy Implements both ALT-1 and ALT-2: improved fodder practices alongside indigenous cattle promotion for holistic impact on livestock emissions.
Solid Waste	ALT-1	Himachal Pradesh State Solid Waste Management Action Plan.	87.6% is the total diverted waste, out of which: ▪ 26% is diverted for composting ▪ 17% is diverted for anaerobic digestion ▪ 29% is diverted to waste combustion plant ▪ 28% for recycling Open burning is taken at 2% at landfill and 2% at residential level.
	ALT-2	Himachal Pradesh State Solid Waste Management Action Plan.	87.6% is the total diverted waste, out of which: ▪ 40% is diverted to composting ▪ 3% for anaerobic digestion ▪ 29% for waste combustion ▪ 28% for recycling. Open burning is taken at 2% at landfill and 2% at residential level.

Sector	Scenario	Policy Rationale behind Selected Intervention(s)	Description of Interventions and Targets Assumed
	ALT-3	Himachal Pradesh State Policy on Solid Waste Management.	87.6% is the total diverted waste, out of which: ▪ 26% is diverted to composting ▪ 17% for anaerobic digestion ▪ 17% for waste combustion ▪ 40% for recycling. Open burning is taken at 2% at landfill and 2% at residential level.
DG set	ALT 1	Stricter regulations, increased enforcement, and a growing sense of social responsibility among the public	It is assumed that 30% of DG sets will be equipped with RECDs by 2030, increasing to 60% by 2040 and 90% by 2047.

This table outlines the reference policies and strategies considered for quantifying SLCP mitigation under various alternative pathways across key sectors. Each scenario (ALT-1, ALT-2, etc.) draws upon existing national and state-level initiatives that are either currently under implementation or formally announced. The inclusion of these policies ensures that the alternative scenarios are grounded in realistic, implementable actions aligned with Himachal Pradesh's development trajectory. By anchoring the analysis in officially endorsed schemes, the pathways maintain policy relevance and reflect the state's commitment to achieving co-benefits for air quality and climate.

Data limitations and Resolution

- Owing to the lack of region-specific emission factors (EFs), EFs from similar regions have been utilized.
- Due to a lack of state-specific targets and fuel transition forces, the assessment relied on central government goals, which may not align with the local context.
- Certain small sectors were not included in the emission inventories. However, their overall impact at the state level is negligible, particularly for those sectors whose data are not compiled at the state level and rely on primary surveys, such as roadside eateries.
- Household fuel consumption data for cooking and heating in the residential sector is collected every ten years. Changes in consumption patterns have been estimated using the 76th NSSO report by the Ministry of Statistics and Programme Implementation.
- Limited information on vehicle de-registration in different districts, the central government directive has been employed as being implemented uniformly across the state.
- The specific implementation of policies across different areas or industries is not fully known. Thus, uniform assumptions have been made based on government directives, such as control efficiency, for similar industries.
- Owing to limited knowledge on location-specific strategy implementation in future years, it has been assumed that the interventions are uniformly implemented across the state.

Sectoral Contributions and Scenario Analysis

Estimated Emissions during Base Year:

In 2019, the total emissions of key pollutants in Himachal Pradesh were estimated to assess the state's air quality and climate-related challenges. The emissions inventory highlights a range of contributors to particulate and gaseous pollution, including both urban and rural activities. Emissions of PM_{10} and $PM_{2.5}$ were estimated at 42.90 kt/year and 25.46 kt/year, respectively, raising growing concerns about ambient air quality and impacts on human health. BC emissions were 9.91 kt/year, reflecting the role of incomplete combustion in the state's emission profile. CH_4 emissions totalled 91.45 kt/year, indicating the substantial influence of the livestock and residential sectors. Among gaseous pollutants, NO_x had the highest emissions (199.57 kt/year), followed by NMVOCs (140.29 kt/year) and SO_2 (16.49 kt/year). Additionally, the sectoral emissions data in 2019 offers valuable insights into the primary contributors to pollution in the state. Based on the estimates, the transport, industries, residential, agriculture and livestock sectors emerge as the dominant sources of different pollutants.

Table 18: Sector-wise emissions (kt/year) of different pollutants in Himachal Pradesh at Baseline

Sector	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x	NMVOCs	CH_4
Transport Sector	13.00	12.00	9.00	2.00	187.00	116.00	3.00
Industry Sector	3.20	2.80	0.80	6.00	71.50	3.70	2.30
Agriculture Sector	0.90	0.70	0.06	0.20	0.04	0.40	1.80
Livestock Sector	-	-	-	-	-	-	78.00
Residential Sector	9.00	6.00	0.52	1.00	2.00	22.00	7.00
Road dust re-suspension	5.00	1.00	-	-	-	-	-
Solid Waste Sector	0.36	0.05	0.01	0.05	-	-	1.23
Construction	4.00	1.00	-	-	-	-	-
Power (DG set)	0.24	0.21	0.14	0.23	3.48	0.28	0.01
Crematoria	0.40	0.20	0.01	0.01	0.05	1.11	0.11
Total	**36.10**	**24.26**	**10.54**	**9.49**	**264.07**	**143.49**	**93.55**

Transport Sector: A Dominant Source of NO_x, NMVOCs, and BC

The transport sector in Himachal Pradesh is the dominant source of key air pollutants, notably contributing around 94% of total NO_x emissions (187 kt/year), 83% of NMVOCs (116 kt/year), and 90% of BC emissions (9 kt/year). These high contributions are primarily driven by diesel combustion in commercial vehicles and the lack of stringent vehicular emission controls, particularly in the challenging hilly terrain of the state, which demands greater engine power and fuel use. Additionally, the increasing number of vehicles, rising tourist influx, and limited public transportation infrastructure, especially in high-altitude regions, are exacerbating the problem, highlighting an urgent need for clean mobility interventions such as electric vehicles, improved public transport, and stricter emission standards.

Industry Sector: Key Source of SO_2

Industrial activities are the largest contributors to SO_2 emissions, accounting for 13 kt/year (over 80% of total SO_2 emissions). This is attributed to small- and medium-scale industries and combustion of coal or furnace oil in industrial boilers and brick kilns. Though particulate emissions from the industrial sector (PM_{10}: 9.86 kt/year; $PM_{2.5}$: 3.68 kt/year) are modest compared to transport, they remain a concern in industrial pockets like Baddi and Paonta Sahib, calling for stricter implementation of Air Pollution Control Devices (APCDs).

Residential Sector: Second-largest source of PMs, NMVOCs and CH_4

The residential sector is the second largest (15.7% of total) source of NMVOCs, (22 kt/year), primarily from biomass-based cooking. In addition, this sector emits PM_{10} (8.82 kt/year), $PM_{2.5}$ (6 kt/year), BC (0.52 kt/year), indicating the urgent need for sustained use of LPG throughout the state

Agricultural sector: Moderate Source of PM and Methane

Open burning of agricultural residue is negligible in the state due to limited farming. Burning of residues from the pruning of horticulture crops , resulting in negligible PM_{10} (0.90 kt/year) and $PM_{2.5}$ (0.71 kt/year) emissions based on the season. Further, due to limited flooded paddy cultivation in the state, it results in quite less CH_4 (1.8 kt/yr) emissions.

Livestock Sector: Largest Source of Methane

Methane emissions from livestock alone are estimated at 78 kt/year, accounting for nearly 85% of total annual estimated methane emission in the state. These emissions arise from enteric fermentation and manure management. Reducing methane from this sector requires improved feed practices, better manure handling, and expansion of biogas programs, especially in rural and hilly regions where livestock rearing is widespread.

Solid Waste Sector: A Manageable but Persistent Source of Methane and $PM_{2.5}$

The waste sector accounts for 1.23 kt/year of CH_4 and 0.35 kt/year of $PM_{2.5}$, arising mainly from solid waste decomposition and open burning. Inadequate waste management practices, especially in smaller towns and rural areas, contribute to these emissions. Implementation of scientific waste processing, landfill gas recovery, and segregation at source will be pivotal for emissions control.

Road Dust Re-suspension: Notable Contributor to Coarse PM

Road dust re-suspension contributed 5 kt/year of PM_{10} and 1 kt/year of $PM_{2.5}$, making it a significant source of coarse particulate pollution, especially in urban areas like Shimla, Mandi, and Dharamshala. The prevalence of unpaved roads, dry conditions, and lack of mechanical cleaning intensifies this issue. Paving unsealed roads and enhancing road maintenance will be critical for controlling fugitive dust emissions.

Construction, DG Sets and Crematoria: Minor Sources with Localised Impact

The construction sector emits 4 kt/year of PM_{10} and 1 kt/year of $PM_{2.5}$, while DG sets contribute 0.2 kt/year of $PM_{2.5}$, 0.14 kt/year of BC, 0.23 kt/year of SO_2, 3.48 kt/year of NO_x, 0.28 kt/year of NMVOCs, and 0.01 kt/year of CH_4. Although these emissions are relatively small in magnitude, their impacts are localised yet noticeable, particularly in rapidly urbanising towns and densely populated neighbourhoods. Strict enforcement of dust-control norms at construction sites, proper covering and handling of loose materials, and promotion of cleaner or more efficient backup power options can significantly reduce these localised air quality impacts.

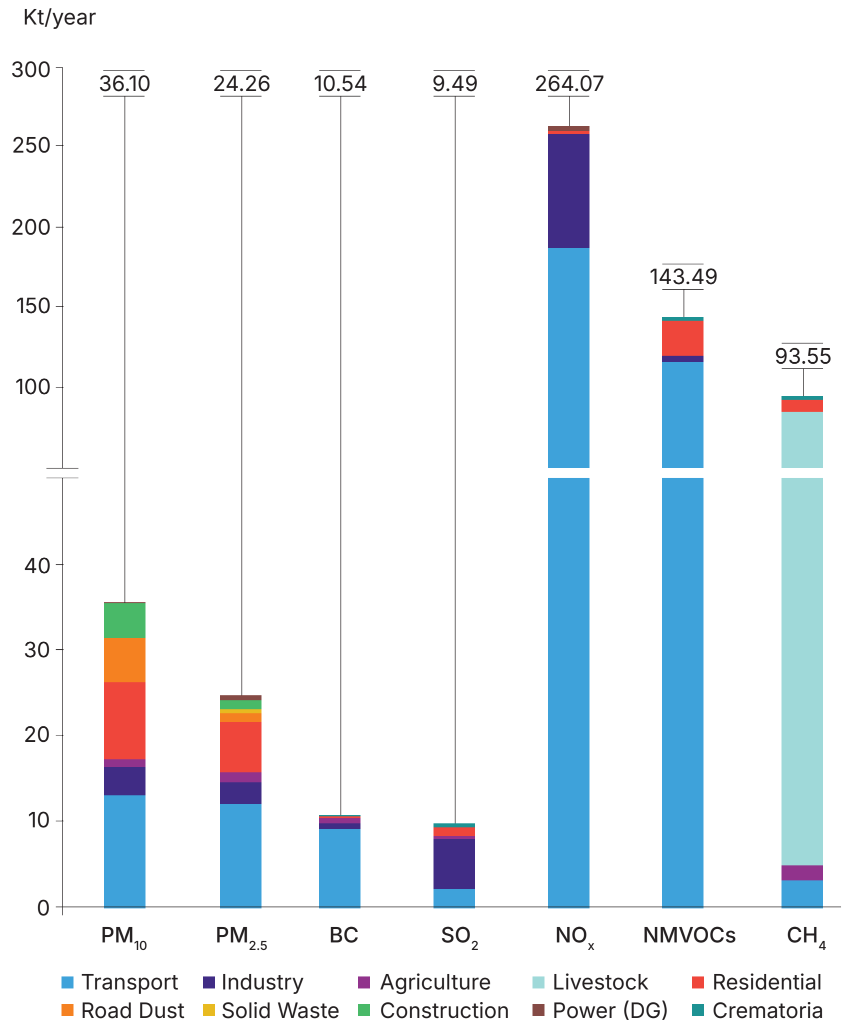


Figure 8: Sectoral contribution in 2019 for different pollutants in Himachal Pradesh (Kt/Year)

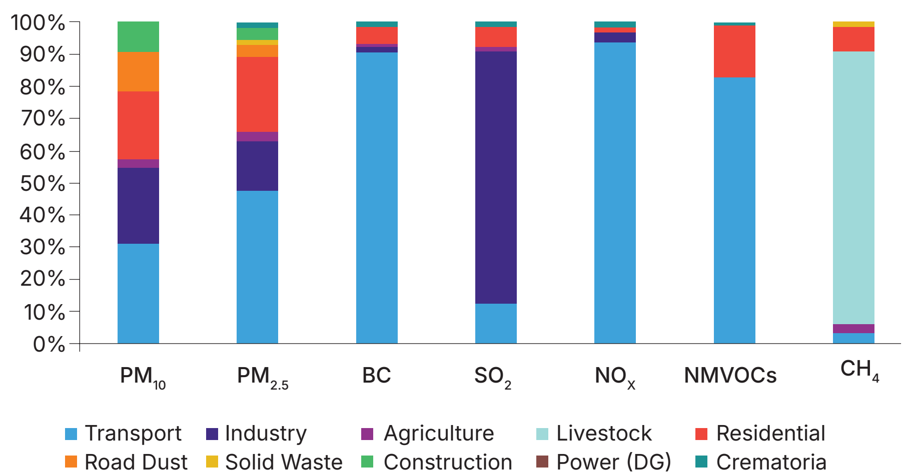


Figure 9: Percentage Sectoral contribution in 2019 for different pollutants in Himachal Pradesh

In summary, the transport, industry, residential, and livestock sectors are the dominant contributors to SLCPs and air pollution in Himachal Pradesh. The transport sector leads in emissions of NO_x, NMVOCs, and BC. The industrial sector is the major source of SO_2, while the livestock sector contributes the highest share of CH_4. Residential combustion remains a significant cross-cutting source of PM, NMVOCs, and methane emissions.

To effectively mitigate these emissions, focused interventions are required across sectors:

- Promoting electrification of the transport sector and improving fuel quality standards
- Ensuring stricter enforcement of APCDs in industries
- Accelerating transition to clean cooking fuels in the residential sector
- Enhancing livestock and manure management practices
- Strengthening waste processing and methane recovery infrastructure.

Following the unique topography, climatic sensitivity, and socio-economic profile of the state, a comprehensive, sector-specific, and regionally adaptable approach is essential to achieve sustainable improvements in air quality and secure climate co-benefits.

Next section, include assessment of changes of emissions from these sectors in future years and evaluate the potential impacts of various mitigation strategies. This assessment will provide critical insights into the effectiveness of different policy measures and help identify the most efficient pathways for reducing emissions and improving air quality in the state.

Sectoral Emissions

Pollution in Himachal Pradesh arises from a variety of sources, each contributing specific pollutants in the state with distinct environmental and health impacts. While overall emission estimates offer a general picture, a detailed sector-wise analysis is crucial for designing effective and targeted mitigation strategies tailored to the state's unique context.

Sectors such as transport, industry, residential cooking, agriculture, livestock, and soild waste management each have unique emission profiles, demanding customised interventions rather than blanket solutions. For example, transport contributes significantly to NO_x and BC, while the industrial sector is a major source of SO_2, and the livestock sector is the largest emitter of CH_4. Without clear identification of these sectoral contributions, policy efforts may fall short or be misaligned with actual pollution sources.

A sector-wise emissions assessment also allows policymakers to prioritise actions based on both their potential impact and implementation feasibility. Sectors with high emissions and direct health consequences, such as residential biomass burning and vehicular pollution, should be addressed with urgency. At the same time, sectors poised for growth, like expanding road transport and industrial activity, require forward-looking measures to prevent future deterioration in air quality.

Moreover, understanding emissions by sector is essential to aligning air quality goals with broader climate and sustainability objectives. Many air pollutants, including methane and BC, are also powerful climate forcers. Tackling emissions in a targeted manner can deliver dual benefits, improve public health and contribute to climate mitigation, paving the way for a more resilient and sustainable development trajectory for Himachal Pradesh.

While the study estimates a comprehensive set of pollutants—including PM_{10}, $PM_{2.5}$, BC, SO_2, NO_X, NMVOCs, CO and CH_4—spatial distribution maps are presented for $PM_{2.5}$, BC, CH_4, NO_X, and NMVOCs. These pollutants were selected based on their significance for air quality and climate co-benefits, regulatory relevance, and ability to act as proxies for broader pollutant categories. For example, $PM_{2.5}$ captures the most health-damaging fraction of particulates and reflects proxy hotspots of BC. Similarly, NO_2 and NMVOCs are effective indicators of troposheric ozone formation. This focused representation avoids redundancy and supports a clearer understanding of emission hotspots and sectoral impacts.

The following sections provide a detailed examination of sectoral emissions, identifying key pollutants, emission sources, and potential strategies for mitigation.

Himachal Pradesh Taking Lead in Transforming Transport Sector

The transport sector in the state plays a pivotal role in facilitating the state’s tourism industry, agricultural supply chains, and overall connectivity to remote and hilly areas. However, the sector also faces significant environmental challenges due to its reliance on road-based transport, which is the primary mode of travel in the state. With its rugged terrain and reliance on fossil fuels, transportation in Himachal Pradesh contributes to local air pollution, GHG emissions, and related health concerns. The state's transport network, which includes an extensive network of roads, highways, and narrow

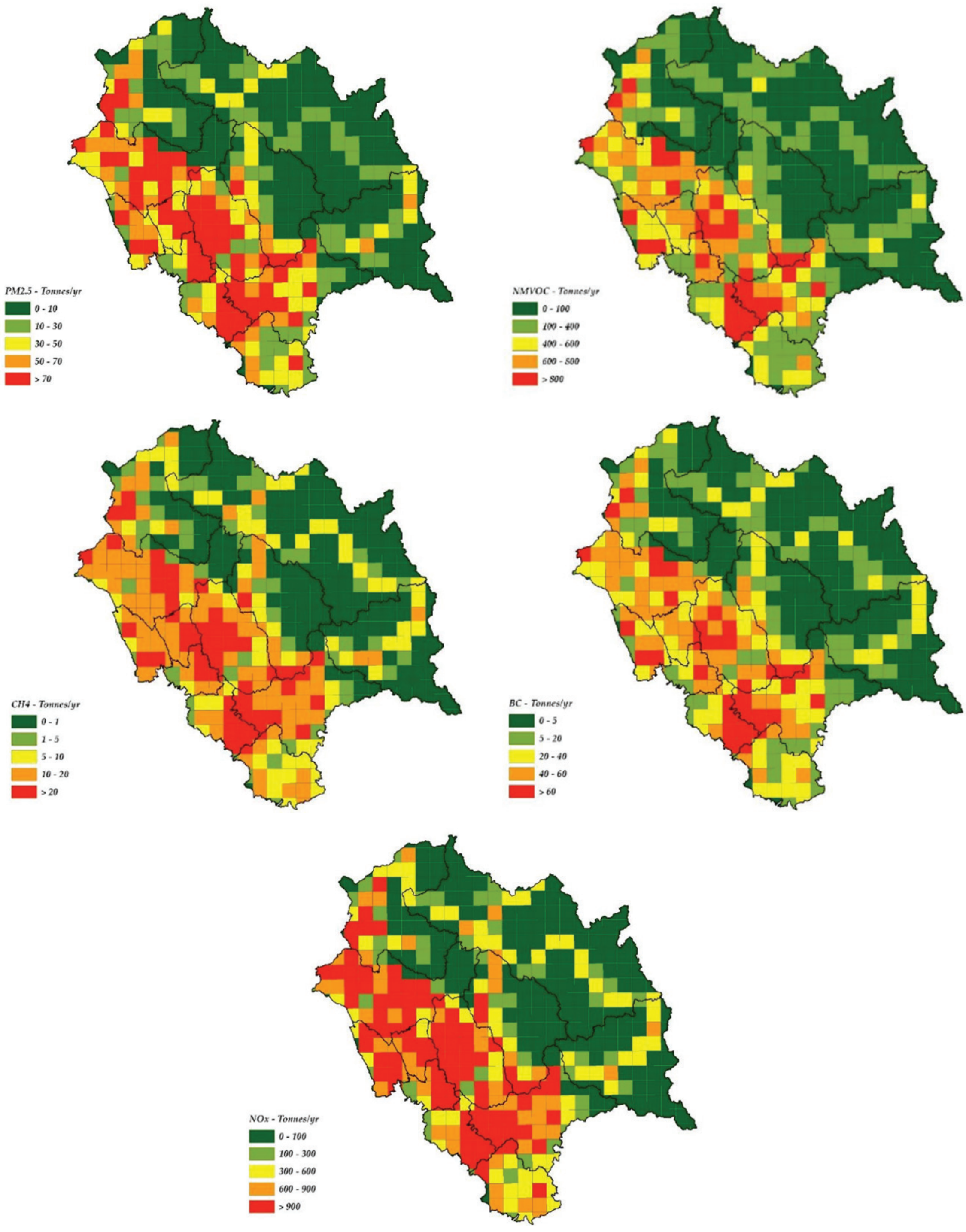


Figure 10: Spatial distribution (12 km X 12 km) of estimated annual emissions of different pollutants from the transport sector

mountain passes, is heavily dependent on vehicles running on conventional fuels such as diesel and petrol. This reliance contributes notably to air pollution and greenhouse gas emissions, particularly in urban centres and popular tourist destinations such as Shimla, Manali, and Dharamshala. According to this study's estimates, vehicular emissions emerge as a major source of all selected pollutants in Himachal Pradesh. The emission calculations are based on registered vehicle numbers across fuel types, with detailed methodologies provided in the annexure.

In Himachal Pradesh, diesel-powered vehicles are the predominant contributors to emissions of PM (PM_{10} and $PM_{2.5}$), BC, and SO_2, primarily due to their extensive use in inter-city transport, freight movement, and public transportation across the state's challenging hilly terrains. Gasoline-powered vehicles, which dominate the two-wheeler and private car segments, are the main sources of CO and CH_4 emissions. Although compressed natural gas (CNG) vehicles are less prevalent in Himachal Pradesh, where they are present, they contribute modestly to emissions of nitrogen dioxide (NO_2), NMVOCs, and SO_2.

The spatial distribution of these emissions has been modelled based on road length density within 12 km×12 km grid cells, including both arterial highways and local mountain roads, as illustrated in Figure 10. Emission hotspots are most prominent in districts with high vehicular densities and frequent tourist traffic, such as Shimla, Kangra, and Kullu. These areas exhibit elevated levels of $PM_{2.5}$, NO_2, and NMVOCs due to traffic congestion, idling during peak tourist seasons, and steep road gradients that demand higher fuel consumption. Conversely, districts such as Lahaul & Spiti and Kinnaur, which have sparse vehicle populations and limited road infrastructure, show relatively lower emissions, though localised pollution persists along national highways and strategic border roads.

In response to the growing environmental and mobility challenges, the Himachal Pradesh government has undertaken several initiatives to promote sustainable and low-emission transportation across the state. One of the notable strategies includes the Himachal Pradesh Electric Vehicle Policy, which aims to accelerate the adoption of electric vehicles by targeting a significant share of EVs in new vehicle registrations, especially in urban centres and tourism hotspots. Given the state's hilly terrain and reliance on public and freight transport, efforts are being made to electrify public transport fleets, particularly buses and taxis, through collaboration with private sector partners and support under central schemes like PM E-DRIVE scheme or previously through Electric Mobility Promotion Scheme or the FAME-II.

To strengthen the electric mobility ecosystem, the government is also promoting the development of EV charging infrastructure along key routes and within municipal areas, ensuring reliable support for inter- and intra-city travel. Pilot projects for e-buses in tourist destinations such as Shimla, Manali, and Dharamshala have been initiated, offering clean alternatives to diesel-powered vehicles and reducing emissions in ecologically sensitive zones. In parallel, road infrastructure improvements are being implemented, especially on district and rural roads, to enhance connectivity and reduce vehicle idling and emissions.

These initiatives are in alignment with national objectives under NCAP and the broader "Make in India" framework, which emphasises localised manufacturing of EV components and clean technologies. Himachal Pradesh is also focusing on tightening vehicle emission norms, encouraging the transition to BS-VI fuels, and reducing the dependence on conventional fuels through CNG and battery-electric alternatives. Public awareness campaigns are ongoing, promoting walking, cycling, and the use of shared mobility solutions to reduce congestion and emissions.

Through these comprehensive efforts, Himachal Pradesh is positioning itself as a forward-looking state in the domain of clean and sustainable transportation. This study presents emission projections under different future scenarios, assessing the impact of ongoing and proposed interventions. It highlights the emission reductions achievable through technological shifts and robust policy support. However, continuous monitoring and evaluation of these measures will be essential to ensure their effectiveness and to guide the development of well-defined, low-emission pathways that maximise air quality and climate co-benefits for the state.

BAU Scenario of the Transport Sector in Himachal Pradesh

As Himachal Pradesh continues to grow in terms of population, tourism, and infrastructure development, the transport sector faces increasing challenges in balancing the need for connectivity with environmental concerns. The state's mountainous terrain and reliance on road-based transport pose unique challenges to its air quality. Given the growing demand for transportation across urban centres, rural areas, and popular tourist destinations, it is crucial to understand how transport emissions might evolve under a BAU scenario.

To project transport emissions under the BAU scenario (2019), we have used vehicle registration growth rates from the VAHAN database and relevant data from the Ministry of Road Transport and Highways (MoRTH). Vehicle numbers in Himachal Pradesh are assumed to grow at an annual rate of approximately 4.8%, based on current trends and without additional regulatory interventions. This growth rate reflects the increasing number of vehicles on the road due to population growth, urbanisation, and the increasing number of tourists, especially in major hill stations and transit points. The introduction of BS-VI emission norms in 2020 has been factored into the projections, which are expected to reduce emissions per vehicle in comparison to older vehicles. However, the overall increase in the number of vehicles, particularly in private and commercial sectors, may still lead to an overall rise in transport emissions unless there are significant policy interventions.

Emission projections are provided for the years 2030, 2040, and 2047, considering the growth of the vehicle fleet and the adoption of BS-VI norms. These projections estimate emissions of key pollutants, which include $PM_{2.5}$, PM_{10}, NO_x, CO, CH_4, BC, SO_2, and NMVOCs. The BAU scenario offers insights into the future trajectory of transport emissions, serving as a baseline for developing policy measures to curb pollution and promote sustainable mobility. The projections are illustrated in Figure 11, offering a detailed look at the future emissions landscape under business-as-usual conditions.

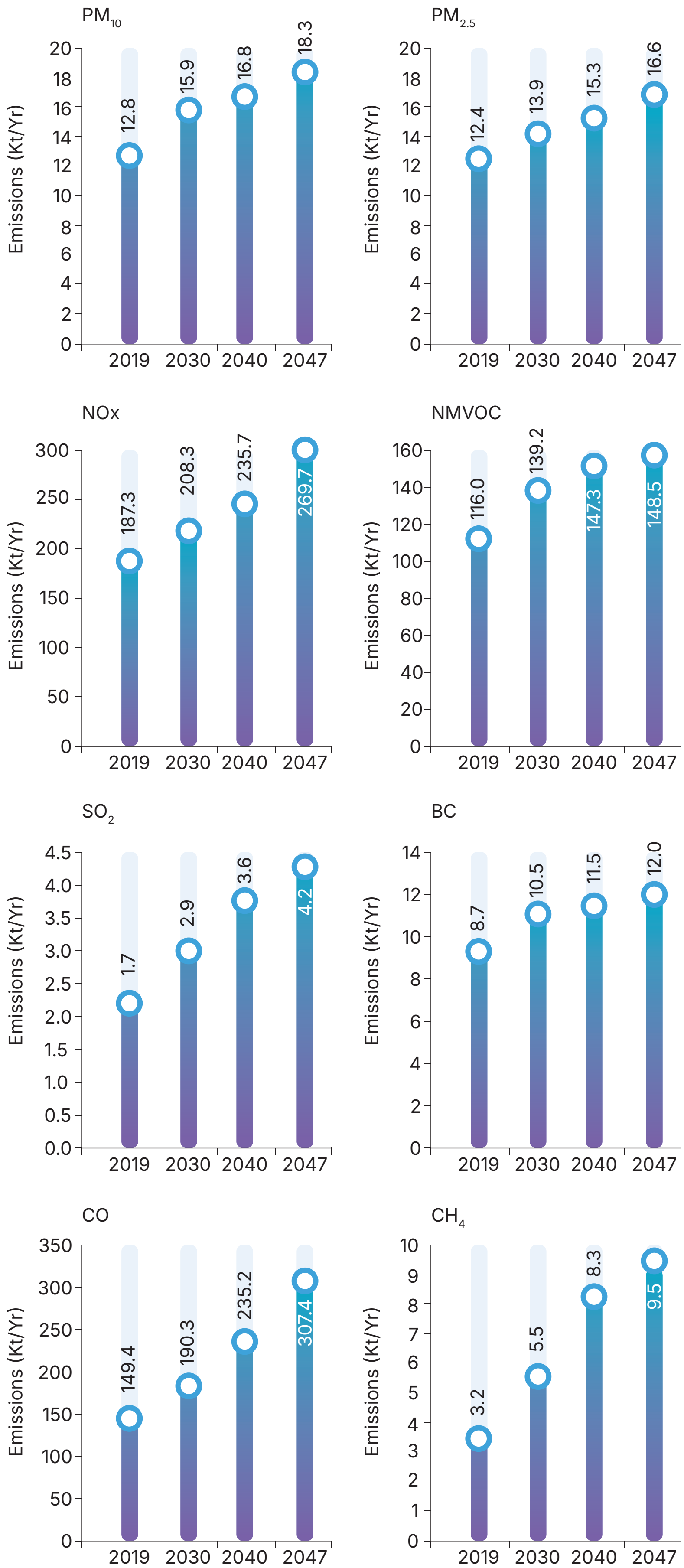


Figure 11: Estimated annual emission (kt) of different pollutants from the transport sector under the BAU scenario

Under the BAU scenario, emissions from Himachal's transport sector are projected to rise significantly over time. PM_{10} emissions increase by 44%, reaching 18.3 kt in 2047, while $PM_{2.5}$ emissions grow by 34%, reaching 16.6 kt by the same year. NO_X emissions show a substantial rise of 44%, from 187.3 kt in 2019 to 269.7 kt in 2047. CO emissions see a sharp increase of 106%, reaching 307.4 kt in 2047, while CH_4 emissions surge by 193%, from 3.2 kt in 2019 to 9.5 kt in 2047. BC emissions also rise by 39%, reaching 12.0 kt in 2047. SO_2 emissions more than double, increasing by 152%, while NMVOC emissions see a relatively moderate increase of 28%, reaching 148.5 kt in 2047.

Despite these increases, the implementation of BS-VI norms is expected to moderate the rate of emission growth. However, without additional policy interventions, emissions will continue to escalate. These projections underscore the need for comprehensive transport policies, including the promotion of public transport, adoption of electric vehicles, and implementation of stricter emission control measures, to mitigate the environmental impact of the transport sector in Himachal Pradesh.

ALT Scenarios of the Transport Sector

To construct the alternative scenario, intervention analysis is performed to estimate the emissions reduction potential of different control strategies in the transport sector. Two Alternative scenarios were assessed: faster adoption of electric vehicles (ALT-1), vehicle scrappage policy (ALT-2). These interventions align with the existing policies of the Himachal Pradesh government and help quantify the impacts of different policy measures. A detailed description of the assumed control strategies in the sector, tested for their emission reduction potential, is provided below.

Table 19: Descriptions of the Alternative Scenarios assessed in the Transport Sector

Scenarios	Description
ALT-1 (Vehicle Scrappage Policy)	▪ By 2030, 30% of all 20-year-old petrol and 15-year-old diesel vehicles will be scrapped. ▪ By 2040, 60% of all 20-year-old petrol and 15-year-old diesel vehicles will be scrapped. ▪ By 2047, 80% of all 20-year-old petrol and 15-year-old diesel vehicles will be scrapped.
ALT-2 (Faster EV Adoption)	▪ By 2030, 100% of state transport buses and the entire government fleet will transition to EVs. ▪ By 2040, 50% of all vehicle fleets will transition to EVs. ▪ By 2047, 70% of all vehicle fleets in all districts will be converted to EVs.

The ALT-1 scenario involves phasing out older vehicles through a vehicle scrappage policy targeting petrol and diesel vehicles beyond their respective age limits. The ALT-2 scenario assumes accelerated electrification across vehicle segments, including two-wheelers, three-wheelers, four-wheelers, and buses.These alternative scenarios offer significant emission reduction potential and align with national and state-level clean mobility goals. A higher penetration of electric vehicles, combined with a scrappage policy can accelerate the transition towards a low-emission transport sector in Himachal Pradesh.

ALT-1: Vehicle Scrappage Policy

(Based on National Vehicle Scrappage Policy, 2024)

The ALT-1 scenario evaluates the impact of implementing a structured vehicle scrappage policy in Himachal Pradesh to phase out older, high-emission vehicles and promote a cleaner, more sustainable transport system. This initiative is aligned with the state's broader environmental and air quality management objectives, aimed at reducing harmful emissions from ageing petrol and diesel vehicles.

Under this scenario, the scrappage policy targets the progressive removal of 20-year-old petrol and 15-year-old diesel vehicles from the roads. The policy sets phased targets of scrapping 30% of such vehicles by 2030, increasing to 60% by 2040, and reaching 80% by 2047. This structured approach supports the transition toward cleaner fleets, especially in environmentally sensitive regions of the state.

This phased intervention is expected to yield substantial reductions in emissions compared to the BAU scenario. By 2047, the policy is expected to deliver even greater benefits. PM_{10} emissions are projected to decrease by 33%, $PM_{2.5}$ by 25%, and NO_x by 20%. CO emissions are expected to fall by 35%, and CH_4 by 46%. Reductions in BC, SO_2, and NMVOCs are projected at 19%, 13%, and 16%, respectively.

The vehicle scrappage policy not only improves air quality but also encourages the replacement of outdated vehicles with newer, cleaner, and more fuel-efficient alternatives, contributing significantly to Himachal Pradesh's long-term sustainability and public health goals.

ALT-2: Faster EV Adoption

(Based on State EV Policy, 2022)

In the ALT-2 scenario, the impact of electrifying the public and government vehicle fleet across Himachal Pradesh is assessed to align with the state's commitment to clean transport and air pollution mitigation. Himachal Pradesh has shown strong leadership in advancing electric mobility through progressive policies that emphasise clean energy, financial incentives, and the expansion of EV infrastructure across the state's hilly and urban terrains.

This scenario envisions a phased and comprehensive transition to electric mobility. By 2030, Himachal Pradesh aims to achieve 100% electrification of its state transport buses and the entire government fleet. By 2040, the target is to convert 50% of all transport modes—including public, private, and freight vehicles—to electric. This transition intensifies further by 2047, with 70% of all vehicle fleets across all districts expected to be electrified.

The implementation of this scenario is supported by a strategic rollout of EV charging stations, favourable subsidy frameworks, and cost-reduction policies that make electric vehicles more accessible and viable for public adoption. These efforts are complemented by public awareness campaigns and incentives for local manufacturing and innovation in clean transport technologies.

The ALT-2 scenario is projected to deliver substantial reductions in air pollutant emissions compared to the BAU scenario. By 2047, PM_{10} emissions are expected to decline by 33%, $PM_{2.5}$ by 29%, and NO_x by 24%. Reductions in other gases are also notable, with CO emissions expected to drop by 43%, and CH_4 by 60%. Furthermore, emissions of BC are projected to fall by 20%, SO_2 by 23%, and NMVOCs by 23%.

This analysis underscores the transformative potential of accelerated electric vehicle deployment in improving air quality and achieving climate co-benefits in Himachal Pradesh. Successful implementation of the ALT-2 scenario will require coordinated efforts across state departments, transport authorities, energy providers, private sector stakeholders, and the public. Through this initiative, Himachal Pradesh can emerge as a frontrunner in clean and sustainable transport in India's mountainous regions.

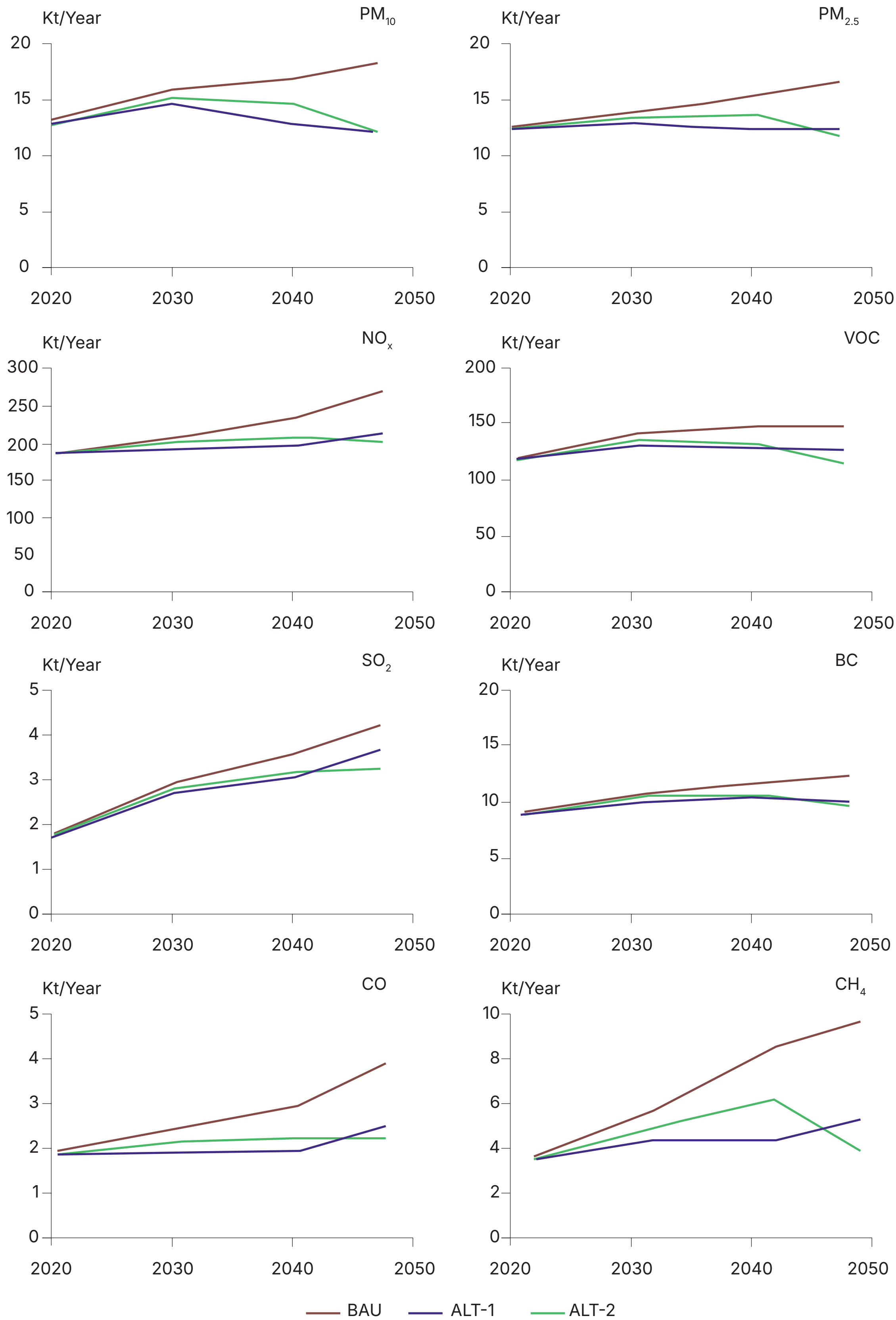


Figure 12: Estimated annual emissions from the Transport sector under different ALT scenarios

Table 20: Change in estimated emissions from the transport sector under Alternative Scenarios, Compared to the BAU emission scenario during 2047

Sector	Scenarios	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
Transport	ALT 1: Vehicle Scrappage Policy	-25%	-13%	-20%	-35%	-16%	-19%	-46%
	ALT 2- Accelerated EV adoption	-29%	-33%	-23%	-24%	-23%	-20%	-60%

Key Insights from the Transport Sector Analysis

The transport sector in Himachal Pradesh is a major contributor to air pollution, accounting for approximately 91% of the state's BC emissions, 94% of NO_x, and 83% of NMVOCs as of 2019. These emissions vary based on the type of fuel used. Diesel-powered vehicles are the dominant source of BC, contributing around 75% of the transport sector's BC emissions. In contrast, NO_x emissions are largely from gasoline and CNG vehicles, contributing 23% and 2%, respectively. Similarly, 28% of NMVOCs emissions are from gasoline-powered vehicles, followed by 8% from CNG-powered ones.

Emissions from the transport sector are projected to rise considerably under the BAU scenario by 2047. NO_x emissions are expected to increase by 44%, continuing to make transport one of the largest sectoral contributors. CH_4 emissions are projected to increase by 193%, BC by 39%, NMVOCs by 28%, and SO_2 emissions could more than double, rising by 152%. While BS-VI vehicle standards will help mitigate some of this growth, their impact alone will be insufficient without additional targeted interventions.

To address this, two alternative policy scenarios were evaluated.

ALT 1, focuses on implementing a vehicle scrappage policy, accelerating the retirement of older, high-emitting vehicles and encouraging adoption of cleaner, fuel-efficient fleets. This policy supports broad-based emission reductions across all vehicle types.

ALT 2, promotes the adoption of EVs, in alignment with HP's EV Policy, PM E-DRIVE scheme or previously the Electric Mobility Promotion Scheme and the FAME policy. This scenario is particularly effective in reducing NO_x and NMVOCs emissions in urban areas, where gasoline and CNG vehicles are most prevalent.

Effective implementation in Himachal Pradesh will require overcoming several critical challenges. ALT 1 (vehicle scrappage policy) may face resistance due to low public awareness, weak enforcement mechanisms, and the lack of formal scrappage infrastructure in many regions. The establishment of regionally distributed, authorised scrappage facilities, combined with streamlined incentive structures directly linked to the purchase of newer, cleaner vehicles, will be crucial. Incorporating scrappage verification into vehicle registration and inspection systems will strengthen compliance.

While for ALT 2 (EV adoption), key constraints include the limited availability of public charging infrastructure, particularly in tier-2 towns and rural areas, and the high upfront cost of EVs, which remains a barrier even with existing subsidies. To address these, the state must invest in the expansion of a reliable EV charging network, comprising fast-charging corridors along highways and strategically placed urban charging stations. Furthermore, targeted financial incentives and accessible financing schemes, especially for tourist and commercial fleets, will be essential to drive market uptake.

District-level prioritisation is essential. Urban centres such as Shimla, Dharamshala, Mandi, and Solan, where gasoline and CNG vehicle usage is high, should focus on EV deployment and scrappage policy implementation, supported by robust infrastructure and enforcement. Moreover, capacity constraints at the municipal level—especially in smaller towns, may limit the pace of rollout. Strengthening institutional capacity through targeted training, integrating emission goals into transport and urban planning, and leveraging public-private partnerships will be essential to ensure technically robust and sustained implementation across Himachal Pradesh.

The alternative (ALT) transport scenarios assessed in this report build upon Himachal Pradesh's existing policy framework. The modelling does not introduce standalone regulatory mandates but rather illustrates the emission reduction potential achievable through accelerated and strengthened implementation of ongoing measures, including phased electrification of state transport buses, vehicle scrappage initiatives, and compliance with Bharat Stage-VI standards. In this sense, the ALT pathway represents an enhancement of the State's ongoing clean mobility transition rather than a departure from it.

To operationalize this transition, the State has already introduced comprehensive fiscal incentives, including 100% waivers on registration fees, permit fees, and token tax, along with a 50% reduction in Special Road Tax. Additional support is provided under the Rajeev Gandhi Swarozgar Start-up Yojana (2023), which offers a 40% subsidy for conversion of eligible ICE taxis to electric vehicles. Complementing these measures, the State is expanding charging infrastructure by designating six major highways as green corridors, upgrading 79 petrol pumps into EV charging stations, identifying 41 government-owned sites for development under the PPP mode, and facilitating charging installations across private hotels, tourism properties, rest houses, and government establishments.

Given Himachal Pradesh's mountainous terrain, tourism-driven mobility demand, and dispersed settlement patterns, a phased and district-specific approach to transport decarbonisation remains essential. Strengthening public transport systems, prioritising charging infrastructure along high-traffic corridors, and aligning scrappage implementation with urban air quality objectives can significantly enhance outcomes. Integrated within existing planning and financing frameworks, this accelerated clean mobility pathway can simultaneously reduce NO_x, BC, and methane emissions while improving urban air quality and strengthening near-term climate resilience.

Industry Sector

The state has a well-established industrial sector, with approximately 55,500 industrial units operating across the state. These industries have been developed with an investment exceeding Rs 52,000 crore and employing over 4.63 lakh individuals. The state's industrial landscape is predominantly composed of Micro, Small, and Medium Enterprises (MSMEs), accounting for 98.6% of all units. Additionally, Himachal Pradesh ranks 16th in the Ease of Doing Business (EoDB) rankings under the Business Reforms Action Plan by the Department for Promotion of Industry and Internal Trade, Ministry of Commerce & Industry, Government of India. Alongside MSMEs, large-scale industries, including food processing, paper and pulp manufacturing, textiles, cement production, and pharmaceuticals, form the backbone of HP's industrial economy.

Despite the economic benefits brought by industrial expansion, rapid industrialization in HP has also led to significant environmental challenges, particularly concerning air quality. The widespread reliance on fossil fuels to meet the state's industrial energy demands has resulted in the emission of PM_{10} and $PM_{2.5}$, SO_2, NO_x, and SLCPs, such as CH_4 and BC. These emissions, which encompass various air pollutants, are released into the atmosphere through industrial stacks even after passing through APCDs. These pollutants not only deteriorate air quality but also pose serious public health risks and contribute to climate change.

Recognizing the environmental impact of industrial pollution, the Central Pollution Control Board (CPCB) classifies industries into Red (highly polluting), Orange (moderately polluting), and Green (non-polluting) categories based on their emission levels. Further, these industries are categorized into small, medium, and large-scale enterprises according to their operational capacity. For this study, only industries falling under the red and orange categories have been considered for emission estimation. According to data from the Himachal Pradesh State Pollution Control Board (HPSPCB), there are more than 600 air-polluting industries within the state. To quantify emissions from these industries, an approach based on fuel consumption activity data, fuel type, and the efficiency of APCDs installed has been employed.

The manufacturing industries in Himachal Pradesh exhibit a mixed fuel consumption pattern, with diesel being the predominant energy source, accounting for approximately 30% of profile total fuel usage. This significant dependence on diesel is a major contributor to industrial air pollution and greenhouse gas emissions in the state. Rice Husk is the second major fuel, comprising around 20%, followed by other biomass (~16%), indicating that biomass-based fuels together form a major share of the energy mix. Among fossil solid fuels, pet coke (~4.9%) and coal (~3.6%) contribute a smaller but still notable share, while other fuels (natural gas, LSHS, furnace oil, LPG, etc.) are collectively minor (each <0.5%). The use of cleaner alternatives such as liquefied petroleum gas (LPG), which accounts for 0.16%, remains negligible. This fuel distribution highlights the need for strategic interventions to reduce reliance on carbon-intensive fuels and promote cleaner, low-emission energy sources in Himachal Pradesh's industrial sector.

The spatial distribution of industrial emissions in Himachal Pradesh (Figure 15) is highly localised, with a few key districts contributing disproportionately to the overall industrial pollutant load. Una (Mehatpur, Haroli, Amb) is the most dominant contributor, leading for $PM_{2.5}$, BC and showing exceptionally high NMVOC and CH_4, indicating concentrated high-emitting industrial activity even after controls. Kangra (Indora, Sansarpur, Nagrota) forms the second major hotspot, with very large emissions of $PM_{2.5}$, BC and substantial NMVOC. Sirmour (Kala Amb) also shows consistently high levels across multiple pollutants, reinforcing its importance for targeted action. Furthermore, NMVOCs and CH_4 are moderately elevated in Mandi compared to several other low emitting districts, though they remain far lower than the major industrial hotspots such as Una and Kangra. This spatially uneven emission pattern underscores the importance of implementing district-specific mitigation strategies, focusing particularly on high-emission zones to effectively reduce industrial pollution in the state.

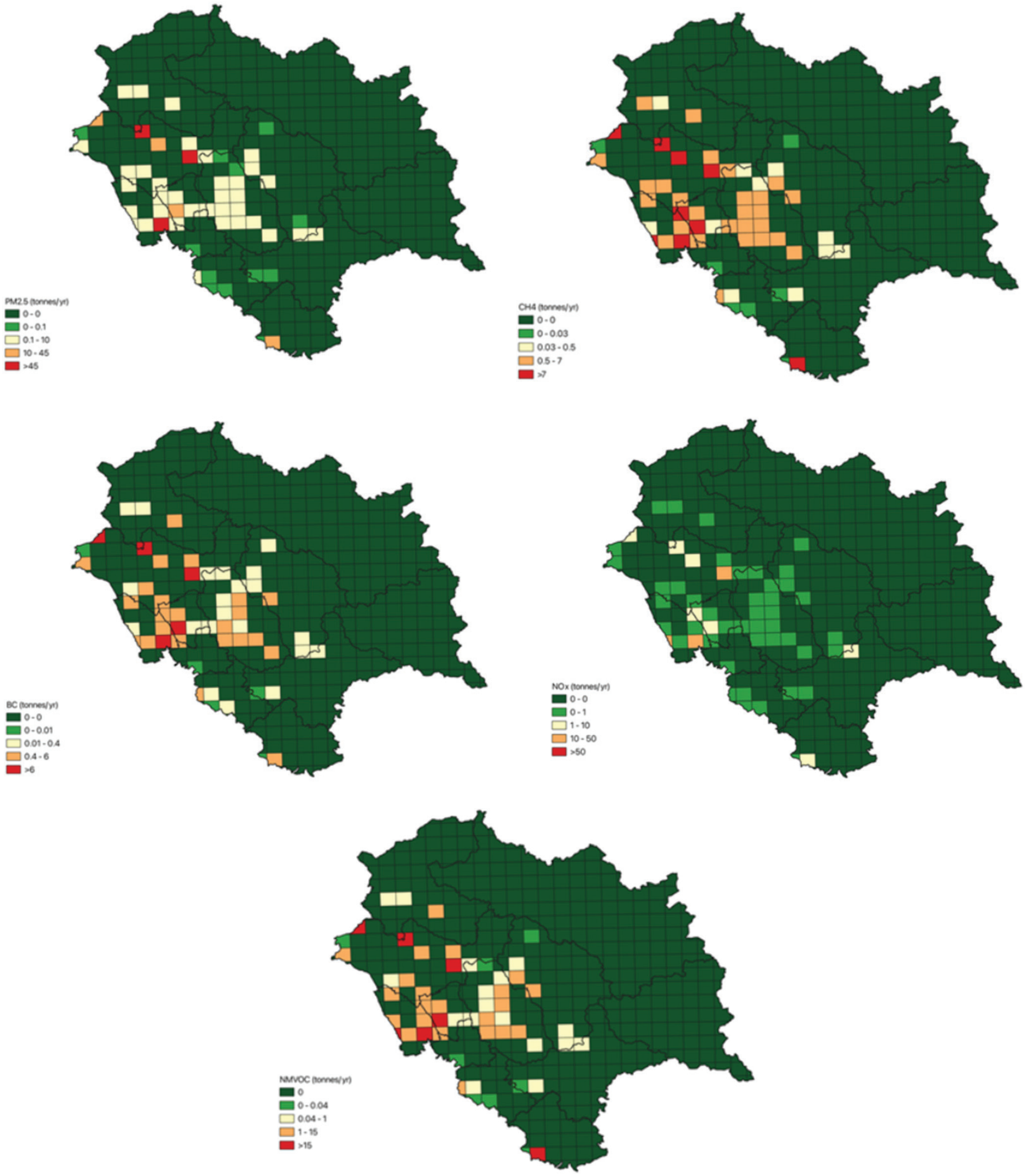


Figure 13: Spatial distribution (12 km x12 km) of estimated annual emissions of industry sector during baseline

By systematically assessing industrial emissions, this study aims to provide insights into the air pollution challenges in Himachal Pradesh and support the development of effective air quality mitigation strategies. In the following section, the BAU and ALT scenarios for industrial combustion emissions have been estimated. Unlike some other states, Himachal Pradesh does not have significant coal mining activity, and therefore, coal mining emissions are not considered in this analysis.

Industrial combustion emissions in Himachal Pradesh are largely driven by the combustion of diesel, which is the dominant fuel used in manufacturing, along with substantial use of biomass-based fuels such as rice husk, biomass residues, wood, and bagasse. Together, these fuels form the bulk of industrial energy consumption and are key contributors to emissions of PM_{10}, $PM_{2.5}$, BC, CO,

and NMVOCs, with diesel additionally contributing to NO_x and SO_2 emissions. The relatively smaller but still relevant shares of coal and petroleum coke add to localized SO_2 and particulate burdens in specific industrial clusters. By evaluating these emissions under both the BAU and ALT scenarios, the analysis ensures a focused understanding of fuel-specific contributions and mitigation opportunities. This approach enables the design of tailored interventions aimed at reducing industrial emissions, supporting improved air quality, and aligning with the state's climate and environmental goals.

BAU Scenario of the Industry Sector in Himachal Pradesh

A BAU scenario of emissions from the industrial sector in Himachal Pradesh has been projected for the years 2030, 2040, and 2047 (Figure 14), based on Gross Domestic Product (GDP) growth (6.4%) of the industrial sector in 2019, as reported in the RBI Handbook for Himachal Pradesh (2022–2023).

Under this scenario, emissions from the industrial sector are projected to increase at a Compound Annual Growth Rate (CAGR) of approximately 6%. By 2047, emissions of PM_{10}, $PM_{2.5}$, SO_2, NO_x, NMVOCs, BC, and CH_4 are estimated to be about five to six times higher than their 2019 levels. These projections highlight the urgent need for cleaner energy transitions, industrial process optimisation, and robust policy interventions to manage and mitigate future air quality impacts in Himachal Pradesh.

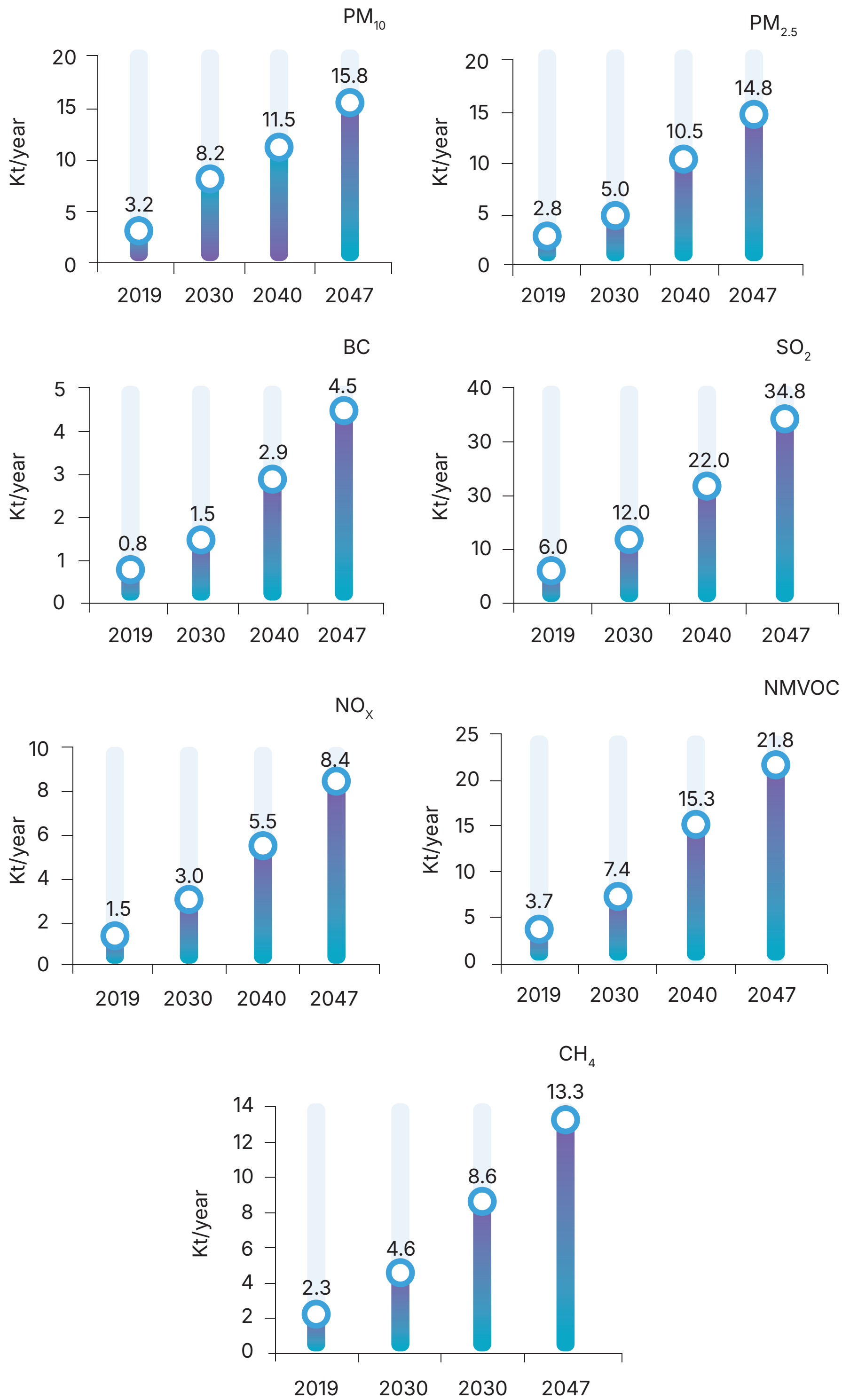


Figure 14: Estimated annual emissions of pollutants from the industry sector under the BAU scenario

ALT Scenarios for Industry Sector

In the industrial sector, two key measures were explored: the introduction of green hydrogen as a fuel source by 2040 (ALT-1) and the enforcement of Wet Scrubbers (WSC) to reduce PM and Gaseous emissions (ALT-2). These interventions aim to significantly reduce emissions, enhance energy efficiency, and support Himachal Pradesh's transition to a low-carbon economy. A detailed description of the assumed control strategies in the sector, tested for their emission reduction potential, is provided in Table 9. The following section delves into the detailed analysis of emissions trends and the projected impact of these strategies under the ALT Scenario.

Table 21: Descriptions of the Alternative Scenarios Assessed in the Industry Sector

Scenarios	Assumption
ALT-1	The Transition to Green Hydrogen is assumed to reach 5% and 8% penetration in industries by 2040 and 2047, respectively.
ALT-2	Enforcement of APCDs: Implementation of Wet Scrubbers (WSC) will be enforced by 25%, 50%, and 100% in industries for the years 2030, 2040, and 2047, respectively, to reduce PM and gaseous emissions.

ALT-1: Transition to Green Hydrogen

(Based on Green Hydrogen Policy, 2023)

In the ALT1 scenario, the use of green hydrogen is explored as a low-emission alternative fuel in Himachal Pradesh's industrial sector. Green hydrogen is generated through electrolysis powered by renewable energy sources like hydro, solar, or wind, making it a clean substitute for fossil fuels currently used in industrial processes. Himachal Pradesh, with its abundant hydropower resources, is well-positioned to lead this transition.

This scenario envisions that green hydrogen will replace 5% of the conventional industrial fuel mix by 2040 and 8% by 2047. Although the penetration levels are modest, the fuel switch is projected to yield measurable emission reductions due to the near-zero emission profile of green hydrogen.

By 2047, ALT1 yields modest but consistent reductions relative to BAU: PM_{10} (8.1%), $PM_{2.5}$ (8.2%), SO_2 (8.1%), NO_X (8.3%), CO (8.0%), NMVOCs (8.0%), CH_4 (8.3%), and BC (9.3%). This highlights the role of green hydrogen in industrial decarbonization and as a step toward fulfilling climate and clean air goals for the state.

ALT-2: Enforcement of APCDs

(Based on NCAP Industrial Emission Guidelines)

In the ALT2 scenario, the focus is on enforcing APCDs, specifically Wet Scrubbers (WSCs), across industrial units in Himachal Pradesh. WSCs are effective at removing PM and gaseous pollutants from industrial emissions through physical and chemical interactions with a liquid scrubbing medium.

The implementation plan for WSCs assumes a phased rollout, with enforcement reaching 25% of industrial units by 2030, 50% by 2040, and 100% coverage by 2047. This scenario directly targets end-of-pipe control measures to mitigate pollutants released during combustion and manufacturing processes.

By 2047, the enforcement of WSC is projected to achieve emission reductions of 64% for PM_{10}, 82% for $PM_{2.5}$, 88% for SO_2, 91% for NO_2, 80% for CO, 85% for NMVOCs, 86% for BC, and 87% for CH_4 by 2047, relative to the BAU scenario.

These substantial reductions demonstrate the high effectiveness of APCDs in curbing industrial air pollution. The ALT 2 scenario represents a critical intervention for achieving cleaner industrial operations, particularly in regions like Himachal Pradesh, where coal, charcoal, and biomass still dominate the fuel mix.

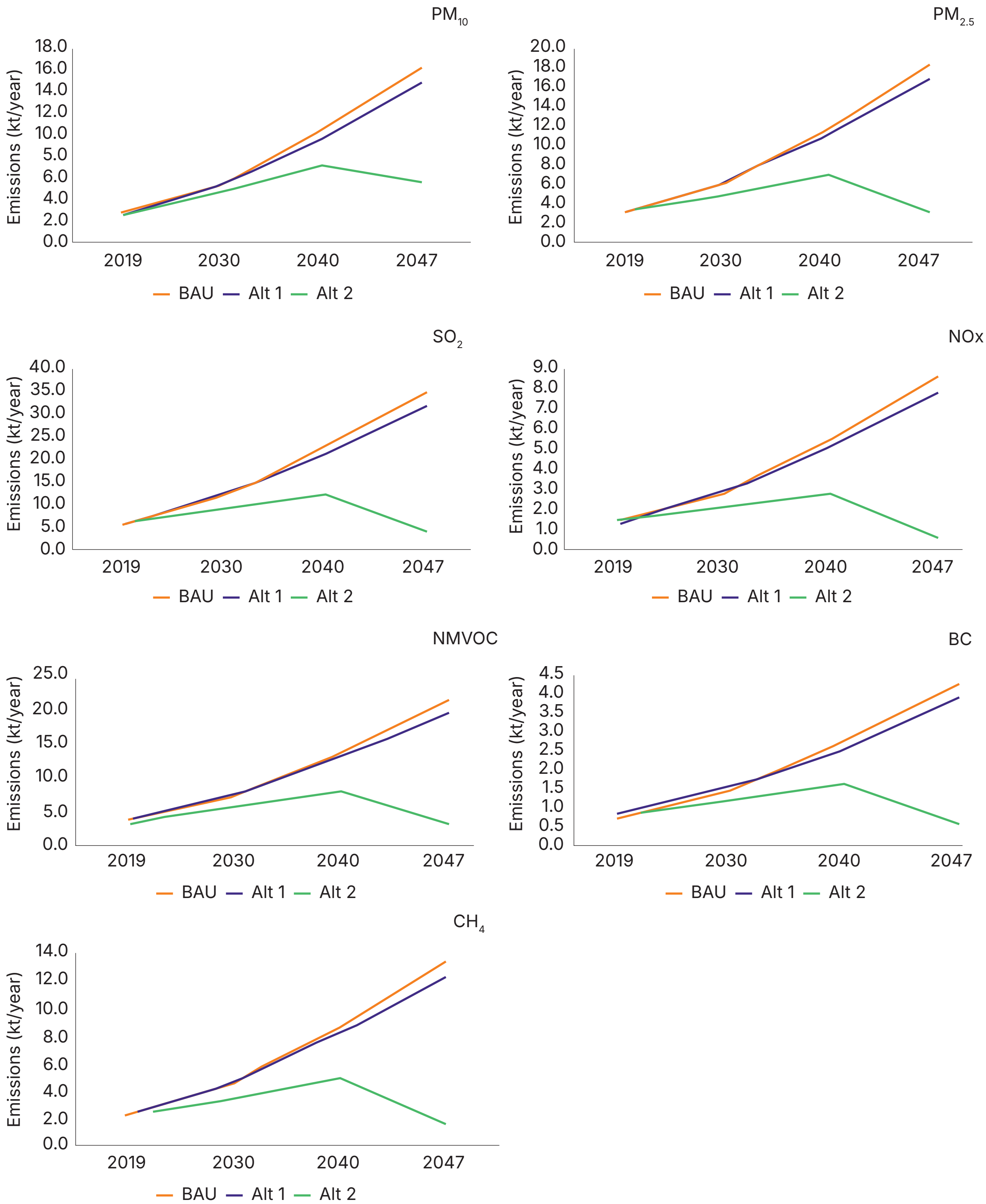


Figure 15: Estimated annual emissions of pollutants from the Industry Sector under different scenarios

Table 22: Change in estimated emissions of pollutants from the industry sector under Alternative scenarios compared to the BAU scenario during 2047

Sector	Scenarios	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
Industrial combustion	ALT 1: Transition to Green Hydroge	-8%	-8%	-8%	-8%	-8%	-9%	-8%
	ALT 2: Enforcement of APCDs (WSCs)	-82%	-88%	-91%	-80%	-85%	-86%	-87%

Key Insights from the Industry Sector Analysis

The industry sector in Himachal Pradesh, , contributes notably to localized air pollution and climate-relevant emissions. In 2019, industrial emissions were highly clustered, with substantial spatial disparities across districts and distinct pollutant profiles. These emissions are largely driven by combustion of diesel (the dominant fuel), alongside extensive use of biomass-based fuels (rice husk, other biomass residues, and wood), with smaller but important contributions from petcoke and coal in specific clusters. As a result, industrial activities contribute to a wide range of pollutants including PM_{10}, $PM_{2.5}$, BC, SO_2, NO_x, CO, NMVOCs, and CH_4, depending on local fuel use and the effectiveness of emission control systems.

District-level results show that Una is the most dominant industrial emission hotspot under controlled emissions, leading for PM_{10}, $PM_{2.5}$, and BC and also recording an exceptionally high CO load. Una additionally contributes the highest NMVOCs and CH_4, indicating a concentrated industrial base with strong combustion-related emissions even after controls. Kangra emerges as the second major hotspot, with very high PM_{10}, $PM_{2.5}$, BC and substantial CO and NMVOCs, reinforcing its significance for particulate and combustion pollutant mitigation.

Solan records the highest SO_2 emissions along with high NO_2. These emissions suggest district-specific fuel and process characteristics (including the use of sulphur-bearing fuels and combustion systems) that drive elevated gaseous emissions despite controls. Sirmaur also stands out with consistently high emissions across multiple pollutants, making it another priority district for targeted action. The remaining districts (Bilaspur, Chamba, Mandi, Hamirpur, Shimla) contribute relatively smaller loads, highlighting that industrial emissions are spatially uneven and concentrated in a few districts.

Looking ahead, two alternative scenarios (ALT1–ALT2) offer a pathway for reducing industrial emissions in Himachal Pradesh:

- **ALT1: Transition to Green Hydrogen:** In this scenario, the gradual integration of green hydrogen—produced via electrolysis powered by renewable energy—into industrial fuel use is assessed. By 2040, green hydrogen is projected to replace 5% of conventional fuels, increasing to 8% by 2047. Compared to the BAU trajectory in 2047, emissions reduce by approximately 8–9% across pollutants: PM_{10} (8.1%), $PM_{2.5}$ (8.2%), SO_2 (8.1%), NO_x (8.3%), CO (8.0%), NMVOCs (8.0%), CH_4 (8.3%), and slightly higher for BC (9.3%). These reductions are particularly relevant for combustion-heavy hotspots such as Una and Kangra, where broad-based reductions in PM, CO, NMVOCs and CH_4 would yield local air-quality co-benefits.
- **ALT2: Enforcement of APCD:** This scenario emphasizes stronger enforcement and scaling of pollution control measures, particularly in high-emission districts. By 2047, ALT2 delivers deep reductions compared to BAU, especially for particulate and combustion-related pollutants: $PM_{2.5}$ (82.4%), SO_2 (87.8%), NO_x (91.7%), NMVOCs (84.5%), BC (86.0%) and CH_4 (86.5%), while CO reduces by 80.0%. These results demonstrate that strong end-of-pipe controls and enforcement can significantly curb industrial emissions—especially in districts with high SO_2/NO_x burdens (e.g., Solan and Kullu) and those dominated by PM/CO/NMVOC loads (e.g., Una and Kangra).

Together, these strategies highlight the importance of location-specific and technology-driven interventions for industrial air quality management in Himachal Pradesh. While the industrial sector may not dominate emissions at the state scale, the high concentration of pollutants in specific districts and proximity to residential areas necessitate focused mitigation actions. These measures not only promise improvements in ambient air quality but also support broader climate change mitigation goals through reductions in short-lived climate pollutants and methane.

Agriculture and Livestock: A Potential Sector for Building Resilience

The diverse topography and climate of Himachal Pradesh significantly influence its agricultural practices and animal husbandary. The state's agriculture is predominantly rain-fed, with a significant portion of the population engaged in farming activities. According to the latest data, most farmers in Himachal Pradesh belong to the small and marginal category, accounting for approximately 83.7% of the total farming community.

Agriculture in Himachal Pradesh is marked by the cultivation of a variety of crops, including cereals, pulses, fruits, and vegetables. The state's unique agro-climatic conditions allow for the cultivation of both temperate and subtropical crops. The land use pattern in Himachal Pradesh reveals that a substantial portion of the agricultural land is dedicated to horticulture, with apple cultivation being particularly prominent. The state has also seen a growing interest in natural farming practices, with initiatives like the Rajiv Gandhi Prakritik Kheti Khushhal Kisan Yojna promoting sustainable and chemical-free farming methods.

Open agriculture residue burning is negligible in the state, only some horticulture crop residues and tree pruning residues occasionally burnt in different districts. This results in the least amount of air pollutant emissions attributable to the agriculture sector. Under the study, we obtained the Fire Radiative Power data from the VIIRS satellite and the amount of biomass burning observed has been restricted to Kangra and Bilaspur districts. Further, the emissions estimated and allocated using the FRP data, the study infers that the Kangra district has a certain number of emissions, which is quite negligible compared to the rest of India where this kind of residue burning is prominent.

Livestock farming is an integral part of the rural economy in Himachal Pradesh. The state has a diverse livestock population, including cattle, sheep, goats, and poultry. The livestock sector not only provides livelihood opportunities but also contributes significantly to the state's agricultural output. The promotion of indigenous cattle breeds and balanced feeding practices are key strategies employed to enhance productivity and sustainability in the livestock sector. The state's efforts toward improving livestock management practices are aimed at reducing methane emissions from enteric fermentation, thereby contributing to climate change mitigation.

The methane emissions from the agriculture and livestock sectors in Himachal Pradesh show significant variations. In Himachal Pradesh, rice is grown on about 70 thousand hectares of land during the kharif season, producing about 116 thousand tons of rice. The rice cropland in the state was estimated to emit 1.84 kt of CH_4 in 2019–20. The emission of CH_4 from the enteric fermentation of cattle was estimated as 78 kt during 2019-20 in Himachal Pradesh. The annual milk production in the state during the period was 1.6 Mt, which is about 1% of total milk production in the country.

Figure 16 illustrates district-wise variations in livestock emissions which highlight the significant contributions of certain districts. For example, Kangra and Mandi districts, with high cattle and buffalo populations, show the highest emissions. Districts like Kinnaur, and Lahul and Spiti, have minimal emissions due to their lower livestock numbers. This detailed assessment underscores the importance of targeted mitigation strategies in high-emission districts.

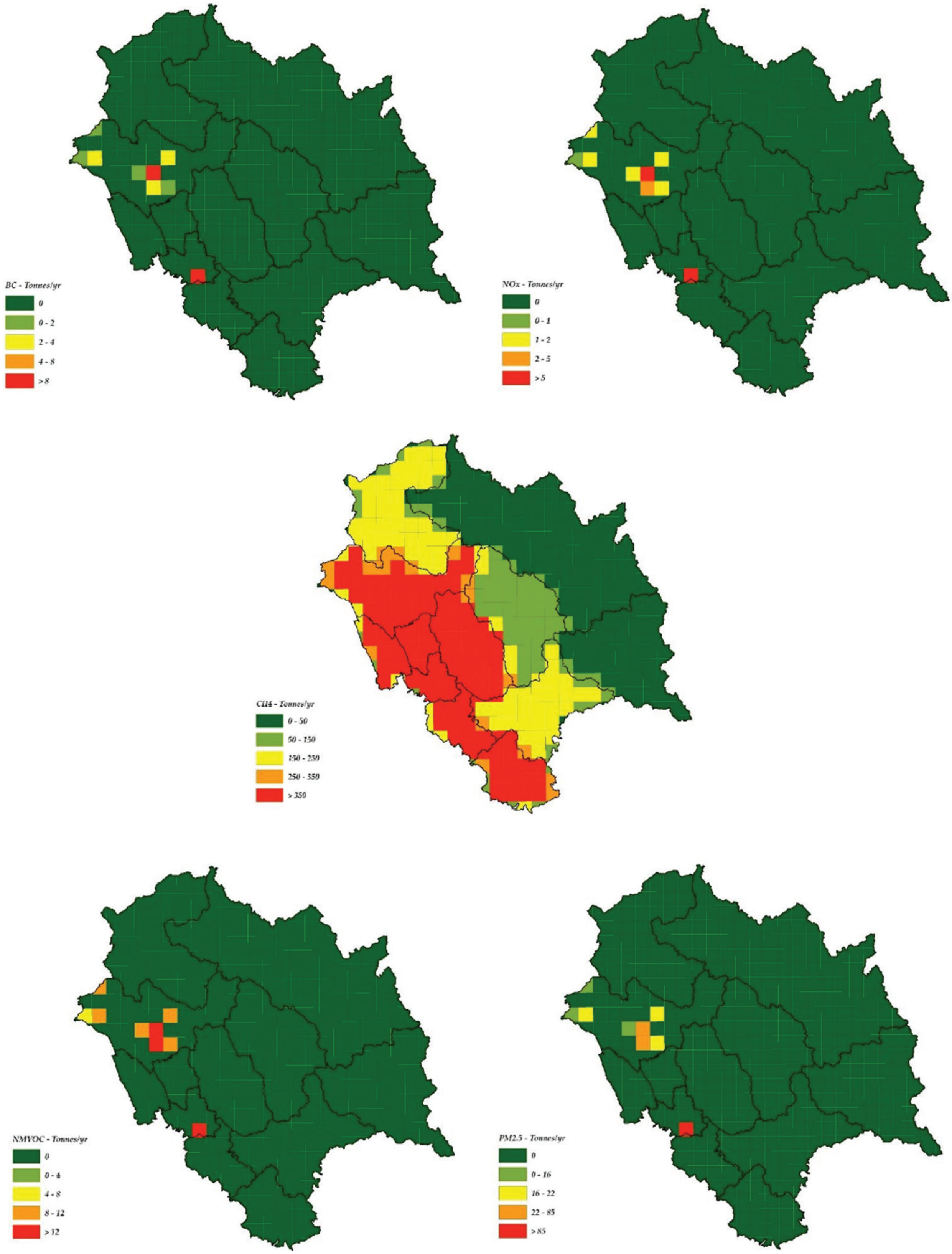


Figure 16: Spatial distribution of estimated annual CH_4 emissions from the Livestock sector

Considering a very small amount of CH_4 emissions from the rice cultivation and the policies related to natural farming practices, waste related to weeds and tree pruning materials are expected to reduce significantly by 2030, This will reduce the emissions of PM, BC and CH_4 from the agriculture residue burning activities. Considering these the emission reduction potentials from rice cultivation and crop residue burning under different scenarios were not estimated in the state.

Consequently, a detailed assessment of the livestock sector and potential alternatives for emission reduction is provided in the next section.

The BAU scenario of estimated annual CH_4 emissions from Livestock sector in Himachal Pradesh

Cattle and buffalo population in the state increased during last two published livestock census (2012 and 2019) although the total livestock population in the state decreased at CAGR –8.9% during the period. Average milk production in state is increasing 3.5% annually during 2012-2023 period. Based on annual increase in cattle and buffalo population in the state,it was assumed that all types of cattle population e.g. crossbreed, indigenous and buffalo will increase at 0.2% annual growth rate. Thus, under the BAU scenario, CH_4 emissions due to enteric fermentation of cattle populations in the state were estimated as ~95 kt/year, 116 kt/year and 133 kt/year during 2030, 2040 and 2047, respectively.

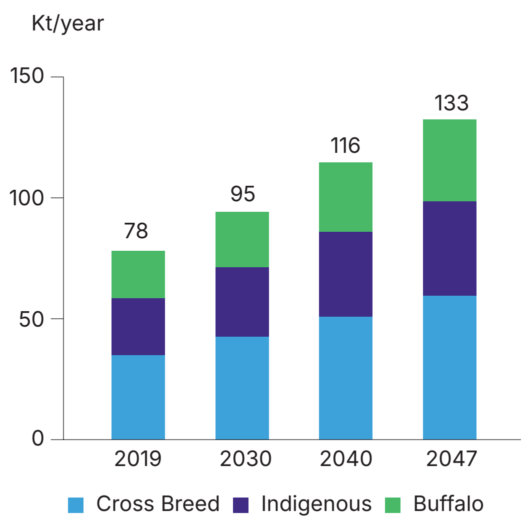


Figure 17: BAU Scenario for the Livestock Sector until 2047

ALT Scenarios for the Livestock Sector

Livestock farming is a cornerstone of rural economy in Himachal Pradesh. In recent years, the state government has emphasised indigenous cattle breed promotion and improved feeding practices as part of its efforts to enhance livestock productivity, ensure rural income stability, and reduce GHG emissions. Table 22 gives details of three mitigation scenarios – these were evaluated based on environmental impact while addressing growing 3.5% annual milk demand.

In line with the Directorate of Animal Husbandry's ongoing initiatives, methane mitigation in the livestock sector can be pursued through productivity enhancement (AI/ETT and conservation of adapted indigenous breeds), balanced ration feeding and mineral supplementation, improved manure management systems, expansion of household and community biogas plants, strengthened animal health services, and improved pasture and grazing management. These measures are technically feasible, socially acceptable, and aligned with Himachal Pradesh's hill ecology and smallholder farming systems.

Table 23: Descriptions of the Alternative Scenarios Assessed in the Livestock Sector

Scenarios	Assumption
ALT -1	Fodder Management: Balanced feeding reduces CH_4 by 10–15%
ALT -2	Promotion of Indigenous Cattle under Natural Farming: Crossbreed & buffalo reduced 5% annually. Indigenous cattle increased to meet milk demand.
ALT -3	Integrated Strategy: Indigenous Cattle and Nutritional Management. This combines ALT 1 and ALT 2 for enhanced mitigation.

ALT 1: Fodder management

(Based on National Dairy Development Board Initiatives)

Inspired by national efforts like those of the National Dairy Development Board (NDDB), Himachal Pradesh encourages balanced feeding practices for cattle. These programs optimise nutrient intake (energy, protein, and minerals) to improve milk productivity. Tannin rich plants, garlic oil, soyabean oil, coconut oil can be used in the fodder as additives to reduce CH_4 emission from enteric fermentation. Improvements in fodder quality have been shown to reduce enteric fermentation–related CH_4 emissions by approximately 10–15%.

ALT 2: Promotion of the indigenous cattle population

(Based on Rashtriya Gokul Mission and Himachal Pahari Cattle Conservation Project)

The Himachal Pradesh government is promoting the indigenous cattle population in the state as part of a natural farming scheme through financial support to the farmers adopting to indigenous cattle breed. It was assumed that the crossbreed and buffalo population in the state would decrease by 5% annually, and accordingly, the population of indigenous cattle would increase to support the estimated future milk production in the state. It is important to meet the demand for milk while decreasing the population of crossbreed cattle. It was estimated that an additional about 90 dairy indigenous cattle population will be required between 2020 and 2030, about 160 dairy indigenous cattle population between 2030 and 2040 and about 280 indigenous cattle between 2040 and 2050. However, this increases overall methane emissions from enteric fermentation.

ALT 3: Promotion of indigenous cattle vis-à-vis nutritional enrichment

(Based on integrated approach combining Rashtriya Gokul Mission and NDDB initiatives)

The decrease in crossbreed and buffalo population under alternative scenario 2 reduces the CH_4 emission from the enteric fermentation of daily cattle on an overall basis(emissions may increase to meet milk demand); however, when fodder management is also included with the cattle population management, these together further reduce the emission of CH_4 from the enteric fermentation of the cattle. The changes in methane emissions from enteric fermentation of cattle livestock in Himachal Pradesh under different policy scenarios have been illustrated in Figure 18.

The emissions pathways vary significantly under the three alternative scenarios. ALT-1, which emphasizes improved cattle feeding and better nutrient efficiency, achieves slightly lower emissions than BAU despite herd growth. For example, total emissions in 2047 reach 116 kt/yr, compared to 133 kt/yr in BAU, with emission reductions across all livestock types, particularly crossbreds and buffaloes.

ALT-2 prioritizes indigenous breed promotion without decreasing the annual milk production rate. This results in the highest total emissions, rising sharply to 251 kt/yr by 2047. This is driven by a significant expansion in the indigenous cattle population to meet milk production demand, making the livestock sector a dominant source of CH_4. Although emissions from crossbreds and buffaloes

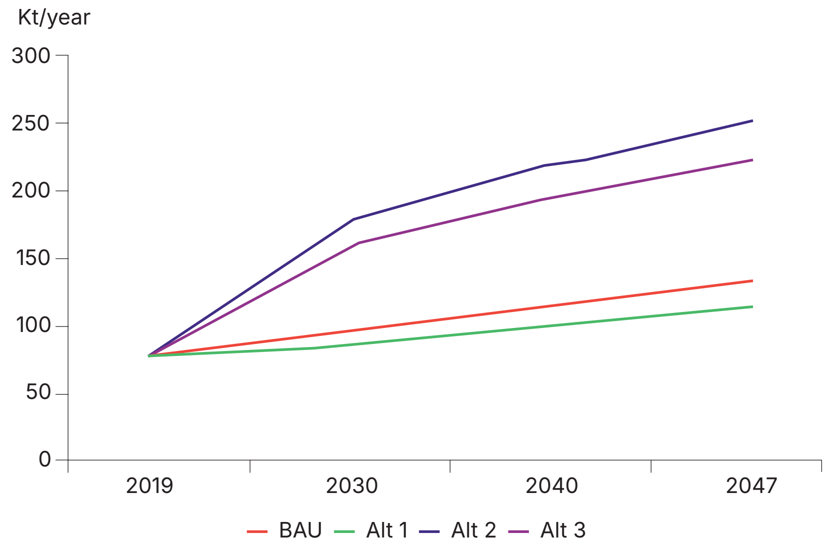


Figure 18: Annual CH_4 emission pathways of Livestock sector in Himachal Pradesh under different ALT scenarios compared to BAU

remain lower due to their decreasing population, the overwhelming growth in indigenous cattle offsets any mitigation gains.

ALT-3, which combines improved feeding with indigenous breed promotion, leads to moderate emissions growth, balancing the trade-offs observed in ALT-1 and ALT-2. Total emissions also reach 225 kt/yr by 2047, but with a slightly lower share from buffaloes and a more efficient emission intensity per animal. Indigenous cattle remain the largest source in this scenario as well, though the integration of feed improvements helps curb emissions compared to ALT-2.

Overall, the table illustrates how different policy strategies influence CH_4 emissions. BAU and ALT-1 reflect more gradual trends, whereas ALT-2 and ALT-3 underscore the implications of breed-focused expansion strategies. While promoting indigenous cattle has cultural and resilience benefits, it can severely increase annual CH_4 emissions to meet milk demands unless combined with parallel nutritional and breed management interventions, as modelled in ALT-3.

Table 24: Change in Livestock Emissions Under Alternative Scenarios, Compared to 2047

Sector	Scenarios	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
Livestock	**ALT 1: Fodder management**	-	-	-	-	-	-	-12%
	ALT 2: Promotion of indigenous cattle under natural farming	-	-	-	-	-	-	43%
	ALT 3: Promotion of indigenous cattle vis-à-vis nutritional enrichment	-	-	-	-	-	-	27%

Key Insights from the Agriculture and Livestock Sector in HP

The agriculture and livestock sector in Himachal Pradesh contributes modestly to overall SLCP emissions, with CH_4 emissions primarily arising from enteric fermentation in livestock and, to a much lesser extent, from rice cultivation. Due to limited crop residue burning, BC and NO_x emissions from the agriculture sector remain minimal. Paddy cultivation contributes less than 2 kt/yr of CH_4 annually, whereas livestock, particularly cattle and buffalo, account for over 77 kt/yr, making them the dominant source of CH_4 emission in the baseline. Annual milk production in 2019–20 stood at approximately 1.57 million tonnes (Mt), representing about 0.86% of national production. District-level emission assessments reveal stark regional contrasts. Mandi and Kangra districts—with high cattle and buffalo populations—are hotspots for livestock emissions, whereas districts such as Lahaul & Spiti and Kinnaur show minimal emissions due to their sparse animal populations.

Given the low CH_4 emissions from paddy fields, mitigation efforts in the state should primarily focus on the livestock sector. This study has explored livestock-related emissions and mitigation pathways of the existing policies. Under a BAU scenario, total livestock emissions from Himachal Pradesh are projected to quadruple by 2050 due to growing demand for milk and livestock products. To address this, three livestock mitigation scenarios were evaluated: ALT1 (Balanced feeding and fodder management), ALT2 (Indigenous cattle promotion), and ALT3 (Integrated approach: Indigenous breeds + Balanced feeding).

ALT1 offers a technically viable and cost-effective strategy for the short term, enabling 10–15% methane reductions by improving feed digestibility and energy conversion, especially in high-emission districts like Kangra and Mandi. However, scaling requires improved supply chains for balanced feed, veterinary services, and farmer training. ALT2 aligns with Himachal's push for natural farming and local breed conservation, especially in hill regions like Kinnaur and Lahaul–Spiti, but leads to increased emissions due to the lower milk yield per indigenous animal and the need for larger herd sizes. Without nutritional interventions, ALT2 will inadvertently result in increased methane emissions. ALT3 offers the most balanced and sustainable pathway, combining indigenous breed promotion with nutritional improvements to enhance productivity while moderating methane intensity. Though absolute emissions still rise by 2050, ALT3 reduces per-animal emissions and supports climate resilience, animal health, and rural livelihoods. It is best suited for mixed farming regions like Chamba and Sirmaur where breed conservation efforts can be paired with fodder interventions.

In summary, an integrated livestock strategy (ALT3) offers Himachal Pradesh the most pragmatic balance between methane mitigation and dairy sector growth, while ALT1 delivers quick gains in high-emission districts. ALT2 should be selectively implemented in tribal and ecologically sensitive hill districts with indigenous breed dominance, but only if paired with fodder improvements. District-wise targeting, alignment with national livestock schemes, and improved extension services will be critical for successful adoption and long-term impact.

Residential Cooking: 100% Target for Clean Fuel

Household air pollution is considered one of the world's major environmental risk factors. It is mainly caused using unprocessed solid fuels for cooking activity, which includes biomass (e.g. wood, crop residues, dung cake), coal and kerosene. There is an increasing number of health issues, such as acute respiratory infections (ARI), chronic pulmonary diseases (COPD), asthma, heart diseases, cataract, pneumonia, low birth weight, and tuberculosis associated with indoor air pollution. In India, the residential sector is the second largest consumer of energy, following the industry sector. People from a low socio-economic background of rural India and urban slums are forced to rely on solid biomass fuels due to their ease of availability. Large amounts of pollutants are released into the atmosphere due to the burning of traditional fuels.

As per the Census (2011), about 68% of rural households and 18% of urban households in Himachal Pradesh were dependent on traditional biomass fuel for cooking activity. However, there is significant growth in household LPG connections after 2011, which altered the biomass and kerosene usage patterns in the residential sector for cooking activity. The district-level LPG consumer and number of cylinders use data from 2015 to 2019, obtained from the Food, Civil Supplies, and Consumer Affairs Department of the Government of Himachal Pradesh, were used to establish the growth trend (vide Annexure for details). The biomass and kerosene consumption in the residential sector in Himachal Pradesh during 2019 were re-estimated by incorporating the state level growth rate (5.9%) of LPG consumers. Although LPG coverage and consumption improved significantly, especially due to policy interventions and the expansion of the LPG distribution network, rural areas continue to show a heavy reliance on traditional biomass fuels. In 2019, approximately 50% of rural households in the state were still dependent on biomass fuels (primarily fuelwood) as their main source of energy for cooking.

The monthly per capita consumption of different fuels in rural and urban Himachal Pradesh was derived from the NSSO (2014) report, which reflects consumption patterns from 2011–2012. Given the considerable increase in LPG adoption post-2011, the biomass and kerosene consumption in the residential sector for 2019 was re-estimated following the LPG consumer growth rate. Electricity used in the residential sector was excluded from the emission inventory as it does not directly contribute to air pollutant emissions from the residential sector. Despite these improvements in clean fuel access, traditional cooking practices using inefficient biomass stoves continue to emit significant amounts of pollutants.

The spatial distribution of estimated emissions reveals significant variation across districts (Figure 19), primarily due to differing reliance on LPG and biomass fuels. Fuelwood remains the dominant source of emissions in the rural areas of most districts, particularly in Mandi, Kangra, Chamba, Bilaspur, and Sirmaur. However, LPG adoption substantially increased in major urban centers in districts like Kangra, Shimla, and Sirmaur. While fuelwood was estimated as the main biomass fuel, certain districts, such as Bilaspur, Kangra, and Mandi, exhibit mixed fuel use patterns, relying on crop residues and kerosene for residential cooking activity. These variations highlight the diverse energy consumption patterns across the state, underscoring the need for localised interventions to reduce residential sector emissions effectively.

The sections below provide an in-depth analysis of emission projections from residential cooking activity in Himachal Pradesh under different scenarios. It highlights the potential emission reductions achievable through varying levels of intervention and technology adoption, offering insights into the most effective strategies for mitigating air pollution and achieving climate co-benefits in the state.

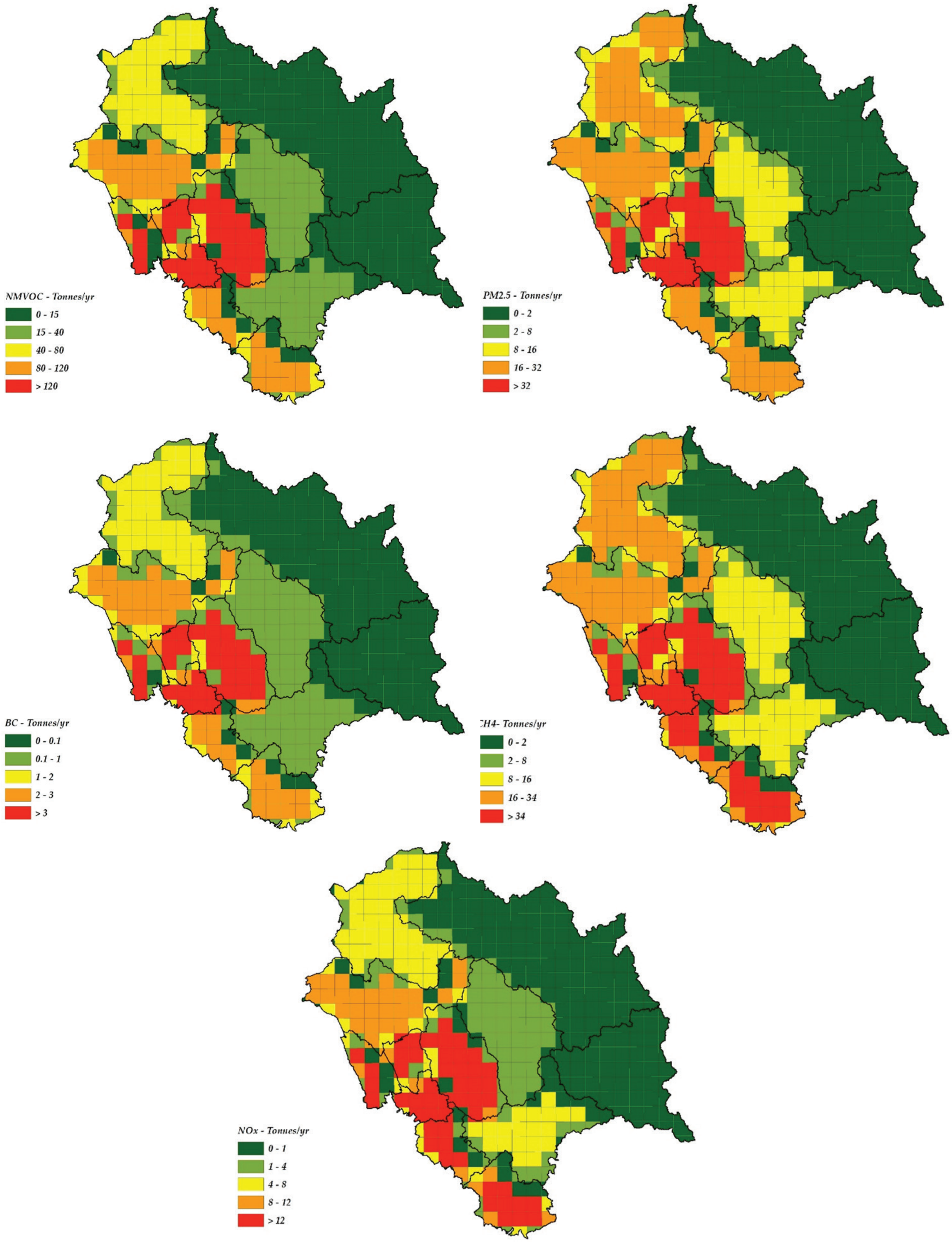


Figure 19: Spatial distribution (12 km X 12 km) of emissions of different pollutants in the residential cooking sector

BAU scenario of the Residential Cooking Sector

Under the BAU scenario, emissions have been projected considering the growth pattern of LPG consumers in residential households of Himachal Pradesh. District-level domestic LPG consumers' (2019-20, 2021-22 and 2022-23) information provided by the Food, Civil Supplies and Consumer Affairs department, Government of Himachal Pradesh, has been used to project the growth trend of LPG usage in the state during future years. Accordingly, household LPG usage was estimated to grow at 5.90% annually in urban and rural areas of Himachal Pradesh during 2030, 2040, and 2047.

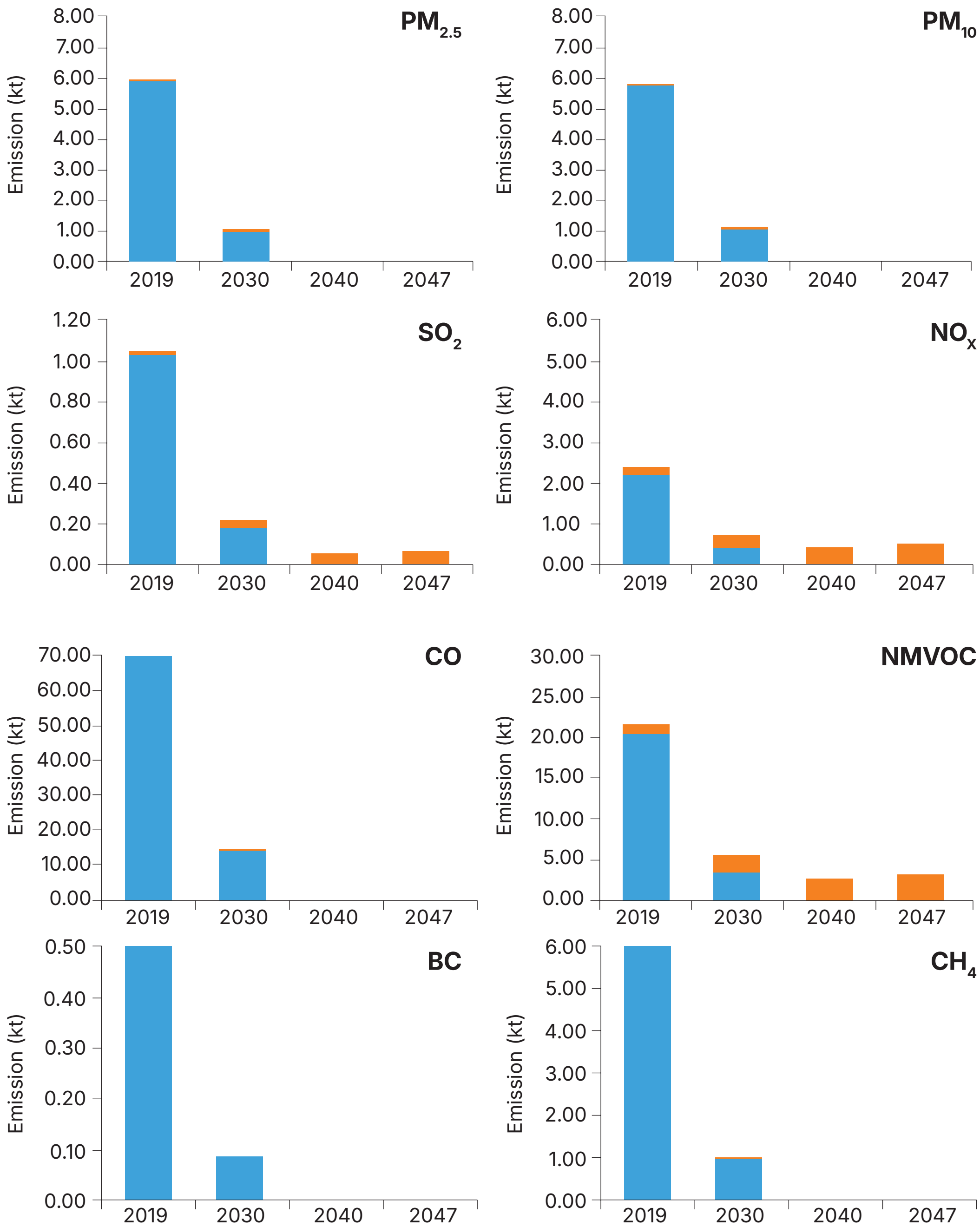


Figure 20: Fuel wise estimated annual emission (kt) of different pollutants from residential cooking activity under BAU scenario

FW: Fuelwood; CR: Crop Residue; DC: Dung Cake; K: Kerosene; LPG: Liquified Petroleum Gas

As it was estimated that with the present CAGR of LPG in the state, all households in the state will have the LPG connection by 2030, no alternative policy scenarios to reduce emissions from residential cooking was analysed.

According to the baseline (2019) situation, 50% of rural households and 93% of urban households have access to LPG connections. With population growth at 0.29% annually and domestic LPG usage growing at 5.90% annually, rural households are bound to achieve 100% LPG connection by 2040. Similarly, with population growth at 4.15% annually and domestic LPG usage growing at 5.90% annually, urban households are expected to achieve 100% LPG connection by 2030. The emission load of various pollutants is expected to reduce due to an increased rate of LPG consumption in residential households in the future. The increased rate of LPG usage would affect rural households using biomass (mostly fuelwood) in Himachal Pradesh. Accordingly, the emission load of various pollutants from residential cooking activity in the state of Himachal Pradesh is expected to reduce between 71% and 99% during 2030, 2040 and 2047 with respect to the baseline emission rate (2019).

Key Insights from the Residential Cooking Sector Analysis

The residential sector is a significant contributor to air pollution and climate change in the state in 2019 due to emissions of $PM_{2.5}$, BC, and NMVOC. While dependence on traditional biomass fuels has remained significant in rural kitchens, reducing their environmental impact is crucial. Following the current policy trends in the residential sector with an aim of ensuring a sustainable supply of LPG can significantly reduce reliance on biomass fuels, reducing emissions, and improving air quality. The Ministry of Petroleum and Natural Gas launched the PMUY to provide a cleaner cooking fuel alternative, LPG, for households relying on traditional fuels like firewood, coal, and cow-dung cakes, targeting both rural and low-income urban households. While the scheme has improved access to LPG as a cleaner cooking fuel but the high initial refill costs, limited subsidy accessibility, fuel stacking practices, and logistical challenges in rural areas contribute to the limited adoption of LPG, leading many rural households to continue relying on biomass and other traditional fuels. However, with the present growth in LPG consumer households in the state, it was estimated that by 2030 there will be complete LPG coverage in the state for household cooking.

Solid Waste Sector

Himachal Pradesh, known for its pristine natural beauty and diverse ecological landscape, faces unique challenges in managing its growing waste burden. The state's mountainous terrain, cold climate, and status as a popular tourist destination contribute to the complexity of waste management. With increasing urbanisation and tourism, Himachal Pradesh generates 1,17,939 tons per annum (TPA) of municipal solid waste (MSW), including biodegradable waste, recyclables such as plastics, glass, paper, and non-biodegradable materials. Managing this waste effectively is essential to safeguard the state's environment, reduce greenhouse gas emissions, and protect the fragile ecosystems that underpin its identity. Despite efforts to establish waste processing infrastructure, challenges persist in achieving sustainable waste management. Inadequate source segregation, underutilised composting and biogas facilities, and reliance on waste combustion contribute to inefficiencies and environmental impacts. Furthermore, the state's cold climate hinders the effectiveness of conventional waste processing technologies such as anaerobic digestion, which requires warmer temperatures for optimal microbial activity. Recognising these challenges, Himachal Pradesh has shifted its focus toward decentralised and sustainable waste management practices. Emphasising source segregation, composting, and recycling, the state aims to align its strategies with regional characteristics and sustainability goals. Although Himachal is working towards achieving zero landfill status, there are many dumpsites that still require attention. This transition not only supports resource recovery but also addresses pressing environmental issues such as methane emissions from waste disposal sites and air pollution from combustion-based solutions.

The state government has also implemented several initiatives to enhance waste management, in accordance with the Solid Waste Management Rules, 2016, including:

- Notification of the Himachal Pradesh State Policy on Solid Waste Management.
- Preparation of the Himachal Pradesh State Solid Waste Management Action Plan.
- Drafting and circulating byelaws on solid waste management (SWM) to urban local bodies (ULBs), aligned with the SWM Rules, 2016.
- Development of a scheme for the registration of rag-pickers and scrap dealers.
- Preparation of ULB-specific action plans.

The success of waste management in Himachal Pradesh hinges on adopting innovative approaches tailored to its unique hilly conditions. By leveraging microbial technologies for composting, expanding recycling infrastructure, and enhancing community participation, the state could transform its waste sector into a model of environmental sustainability.

The waste sector emissions in Himachal Pradesh have been estimated using the SWEET tool and spatially distributed over a 12×12 km resolution grid. This distribution is based on a hybrid methodology combining population density and area ratios, recognising that waste generation is closely linked to population density. As such, more densely populated areas are associated with higher emissions from waste-related activities due to a higher amount of waste generation in those areas.

The solid waste sector in Himachal Pradesh contributes significantly to non-CO_2 pollutants, especially SLCPs like CH_4 and BC, as well as PM ($PM_{2.5}$, PM_{10}) and SO_2. The analysis for 2019 reveals that the total methane emissions from the waste sector in the state amounted to approximately 1.33 kt/year, with Kangra (22%), Mandi (14%), and Shimla (12%) being the top three contributing districts. These districts alone account for nearly half of the state's methane emissions from solid waste.

Kangra, the highest contributor, emitted about 0.27 kt of CH_4, followed by Mandi (0.18 kt) and Shimla (0.15 kt). Other districts like Solan, Sirmaur, Chamba, Una, and Kullu contribute between 6–9% each, while Lahaul & Spiti contributed negligibly (close to zero). Smaller districts such as Kinnaur and Lahaul & Spiti had minimal contributions due to their lower population densities and smaller waste generation volumes.

The distribution of other pollutants mirrors the methane emission trends as can be seen in Figure 16. Kangra again leads in $PM_{2.5}$ and PM_{10} emissions (0.0044 kt and 0.0016 kt, respectively), with Mandi, Shimla, and Solan also showing notable contributions. The total BC emissions from the waste sector are estimated to be approximately 0.01 kt/year, again with the highest emissions from Kangra and Mandi districts.

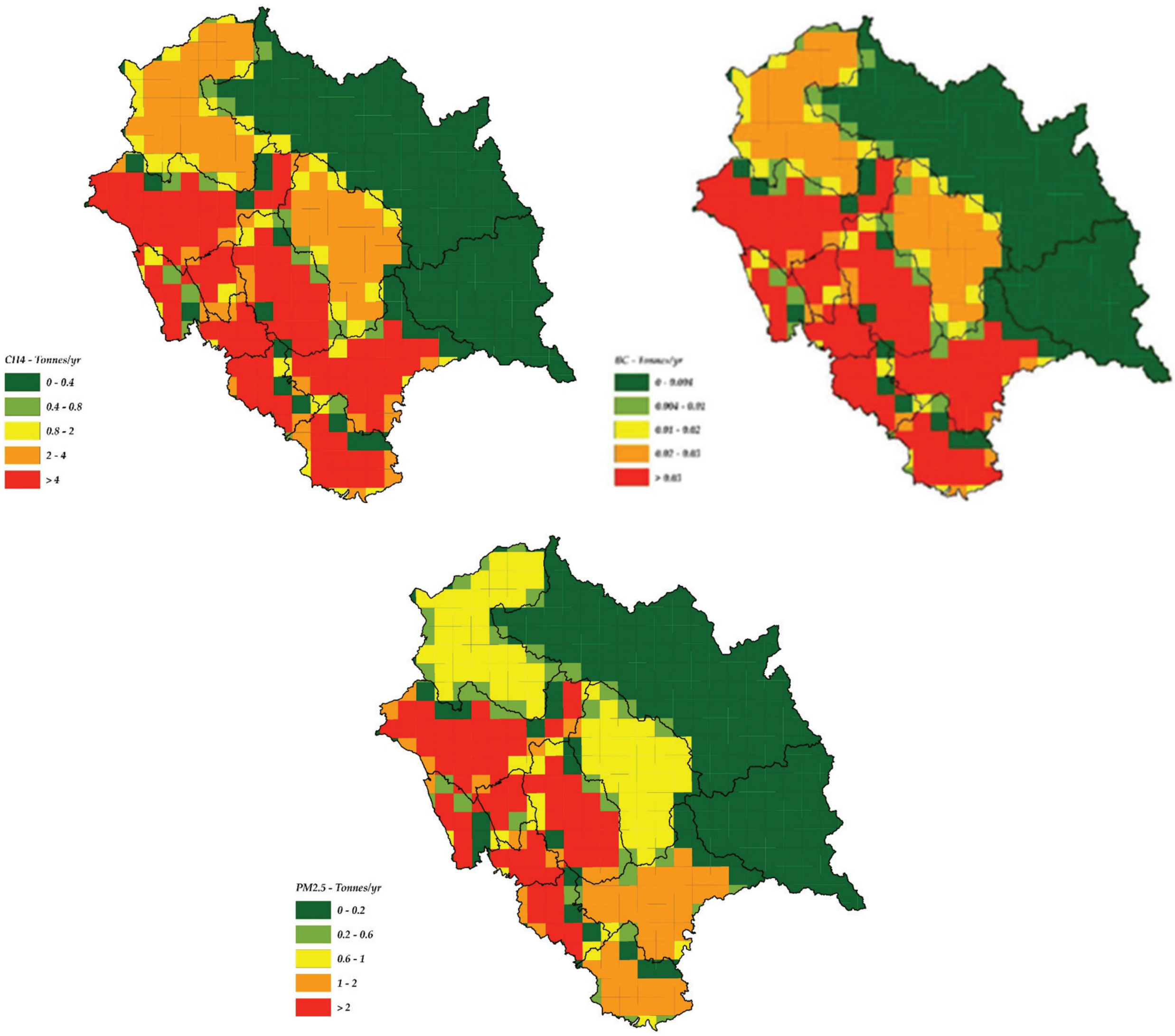


Figure 21: Spatial distribution (12 km x 12 km) of estimated annual emission of pollutants from municipal solid waste sector

This assessment was carried out using the Solid Waste Emissions Estimation Tool (SWEET) developed by the Climate and Clean Air Coalition (CCAC). The tool enables district-level estimation of CH_4, BC, and co-pollutants from municipal solid waste based on waste generation and treatment pathways.

The next section presents the Business-as-Usual (BAU) projections for future years (2030, 2040, and 2047), estimating how emissions from the waste sector may evolve if current practices continue. This is followed by a detailed assessment of an Alternative scenario, incorporating improved waste management interventions aimed at reducing emissions and enhancing co-benefits for air quality and climate.

BAU Scenario of the Solid Waste Sector

A BAU scenario for solid waste sector emissions has been developed using SWEET, projecting emissions till 2047. The BAU scenario represents a scenario where, of the total waste generated, 1,17,939 TPA (with 96% collection efficiency) is being collected, with about 84% of waste being processed. In this baseline scenario, the state primarily focuses on recycling, waste combustion, composting, and anaerobic digestion (AD) as key waste treatment methods. Of the 84% of waste being processed, 55% is recycled, followed by waste combustion (37%), composting (7%), and anaerobic digestion (0.37%). Presently, the state faces challenges due to inadequate source segregation, resulting in mixed and contaminated waste reaching processing plants and thus under-utilising composting and AD facilities.

Despite the ban on open burning in the country in accordance with the MSW Rules, 2016, it continues to occur due to gaps in waste management systems. Based on findings from (Ajay Singh Nagpure, 2015) and TERI's previous studies, this study includes an open waste burning rate in the baseline scenario as 2% of uncollected waste being burnt by residents and 2% being burnt at the landfill. Only municipal solid waste is considered in this analysis, excluding agricultural, construction and demolition waste and other types of waste.

Based on the projected annual growth rates (3.97%) for waste collection in this sector, the BAU scenario has been developed, and emission loads have been estimated. The estimates for the years 2020, 2030, 2040, and 2047 are shown in Figure 22.

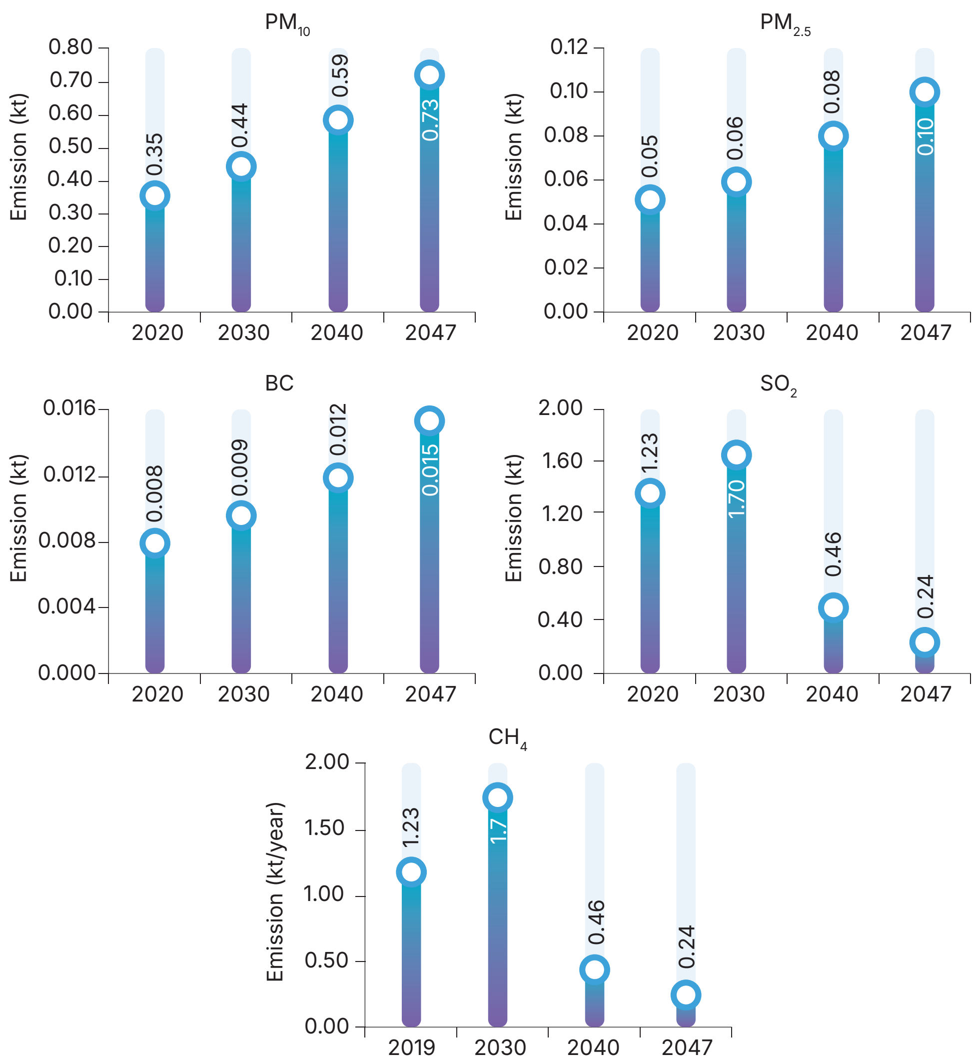


Figure 22: BAU emission projection for the waste sector

Figure 22 outlines the BAU emissions projections for Himachal Pradesh's waste sector, focusing on five key pollutants which include CH_4, BC, SO_2, $PM_{2.5}$, and PM_{10}. The emissions in the baseline primarily result from waste combustion, followed by waste collection and transportation, waste handling equipment, decomposition of waste at landfill sites, and open waste burning. This study documents two landfills (in Shimla and Baddi) and 31 dumpsites of Himachal Pradesh. One landfill site at Shimla and all the dumpsites are assumed to close in 2026, with the second landfill scheduled for closure in 2029, indicating that this site remains open until 2029. During this time, new waste continues to be deposited, leading to CH_4 generation. After the second landfill closes in 2029, no additional fresh organic waste will be deposited. Methane emission peak in 2030 from waste deposited due to anaerobic decomposition of organic waste deposited before landfill closures. CH_4 production begins to decline as the existing organic material in the landfills and dumpsites gradually stabilizes. By 2040 and 2047, the CH_4 emissions decrease significantly due to the reduction in the availability of decomposable organic matter and the stabilising of old/legacy waste over time.

In Himachal Pradesh, waste combustion is the primary source of emissions for $PM_{2.5}$, PM_{10}, and SO_2. For PM_{10} and $PM_{2.5}$, waste combustion is followed by open burning and waste collection & transportation. For SO_2, waste combustion is followed by marginal emissions from waste handling equipment, waste collection & transport, and open burning. BC emissions, however, show a different pattern. These emissions are primarily attributed to the use of diesel-powered vehicles, followed by marginal emissions from waste combustion, handling equipment, and burning. As waste generation in Himachal Pradesh continues to grow over the years, the heavy reliance on waste combustion as a processing method, combined with the increasing use of diesel-powered waste handling equipment and vehicles for waste collection and transportation, will exacerbate emissions. These systems, already under strain, are expected to become increasingly inadequate in managing the escalating waste volumes under the BAU scenario. This inadequacy will lead to a significant rise in pollutants, including $PM_{2.5}$, PM_{10}, SO_2, and BC, further deteriorating air quality and contributing to environmental and health challenges in the state.

To mitigate these impacts, transitioning to more sustainable waste management practices, such as improved waste segregation at the source, enhancing the efficiency of waste processing facilities, and adopting cleaner technologies for waste collection and transportation, will be crucial. Additionally, promoting alternative waste treatment methods that reduce dependency on combustion and encouraging community participation can help address these challenges in the long term.

ALT Scenarios of the Solid Waste Sector

The Alternative scenarios (ALTs) of the waste sector focus on improving waste diversion and aligning waste management strategies with the region's unique climatic and geographical characteristics. This approach aligns better with Himachal Pradesh's sustainability goals while addressing limitations of waste management practices. ALT-1 is based on the proposed plants to be established by the state government. Whereas ALT-2 and ALT-3 scenarios focus on increasing waste diversion to composting and recycling rather than anaerobic digestion and waste combustion. Given its cold mountainous climate, anaerobic digestion is less viable due to the need for warmer temperatures for the bacteria to break down waste to create biogas. Thus, the process slows down or stops, making the biogas plant less cost-effective. Previous efforts to establish composting units faced setbacks, primarily due to the feeding of mixed, unsegregated waste and the challenges posed by low temperatures. However, composting remains a viable option for managing wet waste in cooler climates when combined with cold-tolerant microbial consortia with efficient hydrolytic enzymes, which can break down organic matter into nutrient-rich compost. Additionally, given that waste combustion is the primary source of emissions in BAU and considering HP's status as a popular tourist destination generating significant recyclable materials like plastics, glass, and paper, recycling is a more viable option than waste combustion. The four scenarios, including three Alternative scenarios, begin in the year 2024.

Table 25: ALT Scenarios Descriptions for the Solid Waste Sector

Scenario	Description
ALT-1 Policy Driven Scenario (Balanced Waste Management)	▪ The scenario comprises the plants proposed to be developed by the State govt. which include composting of 81.73 TPD, anaerobic digestion of 54 TPD, waste combustion plant of 94 TPD, and MRFs of 89 TPD. ▪ Within this scenario, out of the total of 363.67 TPD waste collected, 87.6% of the collected waste (318.73 TPD) is diverted to composting, anaerobic digestion, waste combustion, and material recovery facilities (MRFs). ▪ Waste processing includes: 26% composting (81.73 TPD), 17% anaerobic digestion (54 TPD), 29% waste combustion (94 TPD), and 28% MRFs (89 TPD). ▪ Open burning assumes 2% of uncollected waste is burned by residents and 2% at landfills. ▪ There was no significant improvement in treatment efficiency over BAU; open burning rates remain unchanged.
ALT-2 (Composting Driven Scenario)	▪ Within this scenario, out of the total of 363.67 TPD waste collected, 87.6% of the collected waste (318.73 TPD) is diverted, prioritizing composting over anaerobic digestion. ▪ Waste processing includes: 40% composting (127.49 TPD), 3% anaerobic digestion (9.56 TPD), 29% waste combustion (93.99 TPD), and 28% recycling (88.99 TPD). ▪ Open burning assumes 2% of uncollected waste is burned by residents and 2% at landfills. ▪ No significant improvement in treatment efficiency over BAU; open burning rates remain unchanged
ALT-3 (Recycling Driven Scenario)	▪ Within this scenario, out of the total of 363.67 TPD waste collected, 87.6% of collected waste (318.73 TPD) is diverted, prioritizing recycling over waste combustion. ▪ Waste processing includes: 26% composting (81.73 TPD), 17% anaerobic digestion (54.18 TPD), 17% waste combustion (54.18 TPD), and 40% recycling (127.49 TPD). ▪ Open burning assumes 2% of uncollected waste is burned by residents and 2% at landfills. ▪ There was no significant improvement in treatment efficiency over BAU; open burning rates remain unchanged.

ALT-1: Policy Driven Scenario
(Based on HP SWAMP)

The ALT-1 scenario, a policy-driven alternative, emphasizes significant diversion of collected waste to processing facilities, reducing reliance on landfills, and open burning while controlling air pollution emissions. In this scenario, out of the total collected waste, amounting to 363.67 tons per day (TPD), 87.6% is directed towards processing facilities, amounting to 318.73 TPD. Of the total of 87.6%, 81.73 TPD (26%) is treated through composting, 54 TPD (17%) is processed via anaerobic digestion, 94 TPD (29%) is treated in waste combustion plants, and 89 TPD (28%) is directed to MRFs for recycling. These interventions will result in more diversion of waste from landfills and reduction of the burning of waste, which will in turn, control air pollution emissions attributable to this scenario. For instance, in the ALT-1 scenario, $PM_{2.5}$ emissions are projected to decrease by 4.39% in each of the studied years: 2030, 2040, and 2047, in comparison to BAU. Similar diversion and processing targets have been developed for other alternatives (ALT-2 and ALT-3) as depicted in Table 11 below.

ALT-2: Composting Driven Scenario
(Based on HP SWAMP)

The ALT-2 scenario, a composting-driven alternative, emphasizes significant diversion of collected waste to composting facilities, reducing reliance on landfills, and open burning while controlling air pollution emissions. Within this scenario, out of the total of 374.58 TPD waste collected, 85% (318.73 TPD) of the waste is diverted to different diversion facilities. This diversion scenario assumes wet waste is diverted more to composting facilities than AD. Of the 318.73 TPD sent for diversion, 127.49 TPD (40%) is set for composting, 9.56 TPD (3%) is set for anaerobic digestion, 93.99 TPD (29%) is set for waste combustion, and 88.99 TPD (28%) is set for recycling. For open burning, the rate of open burning considers 2% of uncollected waste being burned by residents and 2% being burned at the landfill. Since there is no significant improvement in waste treatment efficiency compared to the BAU scenario, the open burning rates remain unchanged from the BAU levels.

ALT-3: Recycling Driven Scenario
(Based on HP SWAMP)

The ALT-3 scenario, a recycling-driven alternative, emphasizes significant diversion of collected waste to recycling, reducing reliance on landfills and open burning while controlling air pollution emissions. Within this scenario, out of the total of 374.58 TPD waste collected, 85% (318.73 TPD) of the waste is diverted to different diversion facilities. This diversion scenario assumes dry waste is diverted more for recycling than waste combustion. Of the 318.73 TPD sent for diversion, 81.73 TPD (26%) is diverted to composting, anaerobic digestion of 54.18 TPD (17%), 54.18 TPD (17%) is set for waste combustion, and 127.49 TPD (40%) is set for recycling. For open burning, the rate of open burning considers 2% of uncollected waste being burned by residents and 2% being burned at the landfill. Since there is no significant improvement in waste treatment efficiency compared to the BAU scenario, the open burning rates remain unchanged from the BAU levels.

In all the alternative scenarios, the PM_{10}, $PM_{2.5}$, and SO_2 emissions primarily originate from waste combustion. Since ALT 1 and ALT 2 heavily rely on waste combustion, their emissions are significantly higher compared to ALT 3. In contrast, ALT 3, which emphasises a recycling-driven approach with reduced dependence on waste combustion, shows a substantial decline in these emissions. For example, transitioning from ALT 1, a policy-driven scenario, to ALT 3, a recycling-driven scenario, results in a 49.05% reduction in $PM_{2.5}$ emissions across the studied years: 2030, 2040, and 2047.

BC is primarily emitted from waste collection and transportation, followed by waste combustion and marginally from open burning. BC emissions increase across the alternative scenarios over the studied years. However, the difference in emissions among the alternative scenarios and compared to the BAU scenario is not very significant, as a substantial number of diesel-powered vehicles are still assumed to be in operation for waste collection and transportation.

The BAU scenario emphasises strongly on recycling and waste combustion while giving less priority to composting and AD. However, policies of HP suggest a shift towards establishing more composting and AD facilities, as illustrated in ALT 1. This shift is evident in Figure 2, where CH_4 emissions show a significant reduction from the baseline in the subsequent years under consideration. The decrease in methane emissions as compared to BAU is primarily attributed to the diversion of a larger portion of organic waste away from landfills to dedicated processing facilities. Furthermore, ALT 2, which is the composting-driven scenario, demonstrates lower N_2O emissions compared to both ALT 1 and ALT 3. This indicates that composting-driven waste management strategies not only reduce methane emissions but also N_2O emissions more effectively than scenarios with other waste management methods. Overall, the analysis highlights the environmental benefits of integrating composting and AD into the overall waste management system.

The study suggests that it is essential to prioritise methods such as composting, anaerobic digestion, and recycling that minimize greenhouse gas emissions. Each of these processes offers lower emissions compared to waste combustion, which is more carbon intensive. Additionally, replacement of diesel-run vehicles used for transportating by natural gas, EV or even petrol should also be taken care of within the integrated waste facility. From the figure below, the reductions can be interpreted across pollutants through different alternative scenarios.

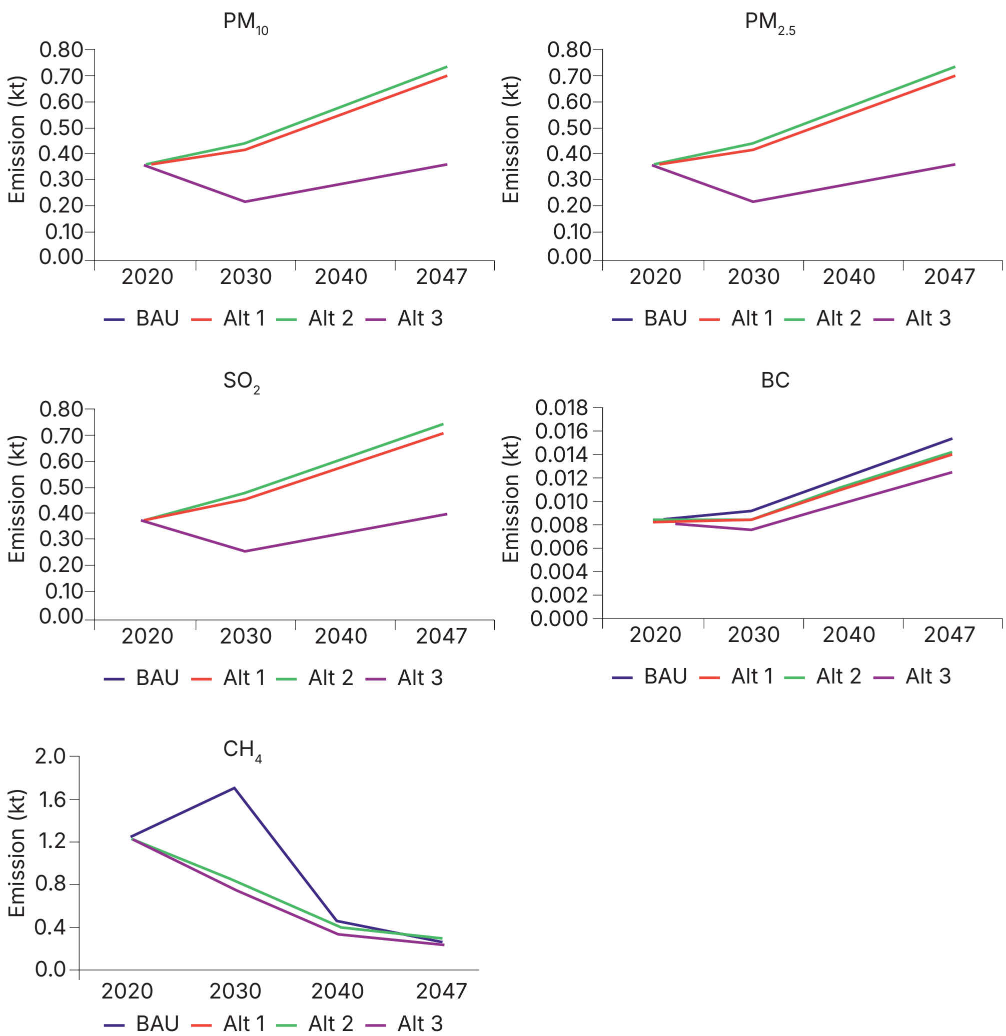


Figure 23: PM_{10}, $PM_{2.5}$, SO_2, BC, and CH_4, emissions during 2020, 2030, 2040 and 2047 from the waste sector under BAU, ALT-1, ALT-2, and ALT-3 scenarios

Table 26: Changes in Annual Emissions from Solid Wate Sector under ALT scenarios Compared to BAU in 2047

Sector	Scenarios	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
Waste	**ALT 1: Balanced Waste Management Scenario**	-4%	-5%	-	-	-	-9%	18%
	ALT 2: Composting-Prioritized Waste Management Scenario	1%	0%	-	-	-	-8%	16%
	ALT 3: Recycling-Prioritized Waste Management Scenario	-51%	-51%	-	-	-	-19%	1%

Key insights from Solid Waste Sector

The waste sector contributes relatively small amounts to total air pollutant emissions, but it remains a critical area for mitigation, particularly in terms of methane emissions. Based on the current emission inventory, the sector emits approximately 0.36 kT/year of PM_{10}, 0.35 kT/year of $PM_{2.5}$, 0.01 kT/year of BC (BC), 0.05 kT/year of SO_2, and 1.33 kT/year of methane. These values correspond to 1% of total PM_{10}, $PM_{2.5}$, and CH_4 emissions, with negligible contributions to other pollutants such as BC and SO_2. While the PM contributions are minor compared to sectors like transport and residential combustion, methane emissions from the waste sector are non-trivial and present an opportunity for targeted reduction through improved waste management practices such as composting, anaerobic digestion, strengthening enforcement mechanisms to eliminate open burning and enhanced diversion strategies suitable for the state.

Spatial analysis indicates that in 2019, the state's waste sector emitted approximately 1.33 kt of CH_4, with the top three districts - Kangra (22%), Mandi (14%), and Shimla (12%)—accounting for nearly half of the total methane emissions. Other contributors include Solan, Sirmaur, Una, Chamba, and Kullu, each responsible for 6–9% of the state's methane load, while remote districts like Lahaul & Spiti and Kinnaur contribute minimally due to low population density and limited waste generation. Emissions are high in densely populated and urbanising areas such as Dharamshala, Palampur, Mandi town, Shimla city, and Baddi-Nalagarh industrial belt, driven by high waste generation. Emissions from waste handling are further exacerbated by the use of diesel-powered vehicles and equipment for waste handling in a major part of the state, contributing to elevated levels of PM_{10}, $PM_{2.5}$ and BC.

While methane emissions from the waste sector are relatively low compared to other sectors, future scenario analysis indicates that even these emissions can be further reduced, contributing meaningfully to the state's broader sustainability and climate goals. Under the BAU scenario, CH_4 emissions are projected to rise to 1.7 kT/year by 2030 before declining in subsequent decades. Among the three alternative scenarios analysed (ALT-1: Policy-Driven, ALT-2: Composting-Driven, and ALT-3: Recycling-Driven), ALT-3 emerges as the most effective in reducing CH_4, CO_2, PM, and SO_2 emissions overall, particularly for Himachal Pradesh's climatic conditions. This scenario assumes 85% of the collected municipal waste (~374.58 TPD) is diverted to processing facilities, with a strong emphasis on recycling (40%), followed by composting (26%), anaerobic digestion (17%), and limited waste combustion (17%).

ALT-3 is particularly suited to districts like Shimla, Manali, Dharamshala, Solan, and Kullu, which experience high tourist influx and generate significant quantities of dry, recyclable waste such as plastics, paper, and glass. Prioritising recycling in these locations not only reduces combustion-based emissions but also supports circular economy goals through resource recovery. Additionally, Mandi, Kangra, and Sirmaur and other high-tourism districts can be targeted for combined composting, Solid Waste Management and recycling strategies to handle both wet and dry waste effectively by preparing a focused action plan .

Implementing ALT-3 in Himachal Pradesh presents several practical and structural challenges. A key issue is inadequate source segregation, with most waste still collected in mixed form, limiting the effectiveness of recycling and composting. Recycling infrastructure, including MRFs, is currently underdeveloped and unevenly distributed, particularly in smaller towns and tourist-heavy districts like Shimla and Manali, where large volumes of recyclables go unprocessed.

The state's cold climate poses an additional barrier, especially in high-altitude districts such as Lahaul & Spiti and Kinnaur, where composting and anaerobic digestion are less effective without adapted microbial solutions. Furthermore, the widespread use of diesel-powered waste collection and handling equipment continues to contribute significantly to PM, SO_2 and BC emissions. Transitioning to electric or CNG-based vehicles will require considerable investment and logistical planning, which the state has already initiated. Institutional capacity remains a constraint. Many Urban Local Bodies (ULBs) lack the technical expertise and trained personnel needed to operate and maintain advanced waste processing systems. Without targeted capacity building, infrastructure upgrades, and behavioural change initiatives, achieving the full benefits of ALT-3 will be challenging. Addressing these issues is essential to realize a low-emission, resource-efficient waste management system in the state.

To effectively operationalize ALT-3, Himachal Pradesh should adopt a district-specific zonal strategy with a dual focus: scaling up recycling infrastructure in urban and tourism-heavy districts and promoting cold-adapted composting solutions in high-altitude and rural areas. Dedicated programs should support:

- Establishing new MRFs and recycling units in Solan, Dharamshala, Kullu, and Manali.
- Introducing decentralized composting in Mandi, Sirmaur, Chamba, and Kangra.
- Launching public awareness campaigns on source segregation and plastic waste management across all districts.
- Transitioning diesel vehicle fleets to EVs or CNG in Shimla, Baddi, and Mandi.

Aligning these actions with national initiatives such as GOBARdhan, Swachh Bharat Mission 2.0, and SATAT will unlock additional financing, technical support, and co-benefits, including rural employment, improved air quality, and reduced environmental health risks. With focused implementation of ALT-3, Himachal Pradesh can transform its waste sector from a source of emissions into a driver of sustainable development, achieving climate, air quality, and socio-economic co-benefits.

Diesel Generator (DG) Set Sector:

Construction, DG Sets and Crematoria: Minor Sources with Localised Impact

The construction sector emits 3.71 kt/year of PM_{10} and 0.61 kt/year of $PM_{2.5}$, while DG sets contribute 0.21 kt/year of $PM_{2.5}$, 0.14 kt/year of BC, 0.23 kt/year of SO_2, 3.48 kt/year of NO_x, 0.28 kt/year of NMVOCs, and 0.01 kt/year of CH_4. Although these emissions are relatively small in magnitude, their impacts are localised yet noticeable, particularly in rapidly urbanising towns and densely populated neighbourhoods. Strict enforcement of dust-control norms at construction sites, proper covering and handling of loose materials, and promotion of cleaner or more efficient backup power options can significantly reduce these localised air quality impacts.

The Diesel Generator (DG) sector in Himachal Pradesh is critical for addressing the gap between electricity supply and demand, particularly as a reliable backup power source across various sectors, including agriculture, industry, commercial activities, mobile towers, and residential use. Despite the state's significant reliance on renewable energy, with over 90% of its power generation from large hydroelectric plants, the increasing electricity demand continues to drive DG set usage. This reliance contributes to air pollution and greenhouse gas emissions, posing environmental and health challenges. This study quantifies the emissions from DG sets, evaluates future scenarios, and proposes strategies to mitigate their environmental impact, focusing on key pollutants such as PM_{10}, $PM_{2.5}$, SO_2, NO_X, CO, NMVOCs, CH_4, and BC.

The spatial distribution of emissions from diesel generator (DG) sets in Himachal Pradesh shows pronounced spatial variability, largely governed by the intensity and type of DG set usage across districts. GIS-based mapping of DG sets at their actual locations highlights that emission hotspots are closely associated with areas having higher concentrations of industrial and commercial DG installations.

Solan district emerges as the most prominent hotspot, contributing the highest emissions across all major pollutants, including PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, NMVOCs, and BC. This reflects the dense concentration of industrial DG installations in the southern industrial belt of the state. Kangra and Bilaspur also show relatively elevated emissions, particularly for NO_x and PM, indicating significant DG usage linked to industrial and commercial activities. Moderate emission levels are observed in districts such as Kullu, Shimla, and Kinnaur, while lower emissions are recorded in districts like Chamba, Hamirpur, Una, and Sirmaur. Lahaul and Spiti show negligible emissions due to minimal DG deployment and limited industrial presence.

Overall, the spatial emission pattern clearly demonstrates that DG set emissions in Himachal Pradesh are dominated by industrial sources, with localized hotspots corresponding to major industrial and commercial zones. The resulting spatial emission maps (Figure 24) provide a realistic representation of DG-related emission loads across the state.

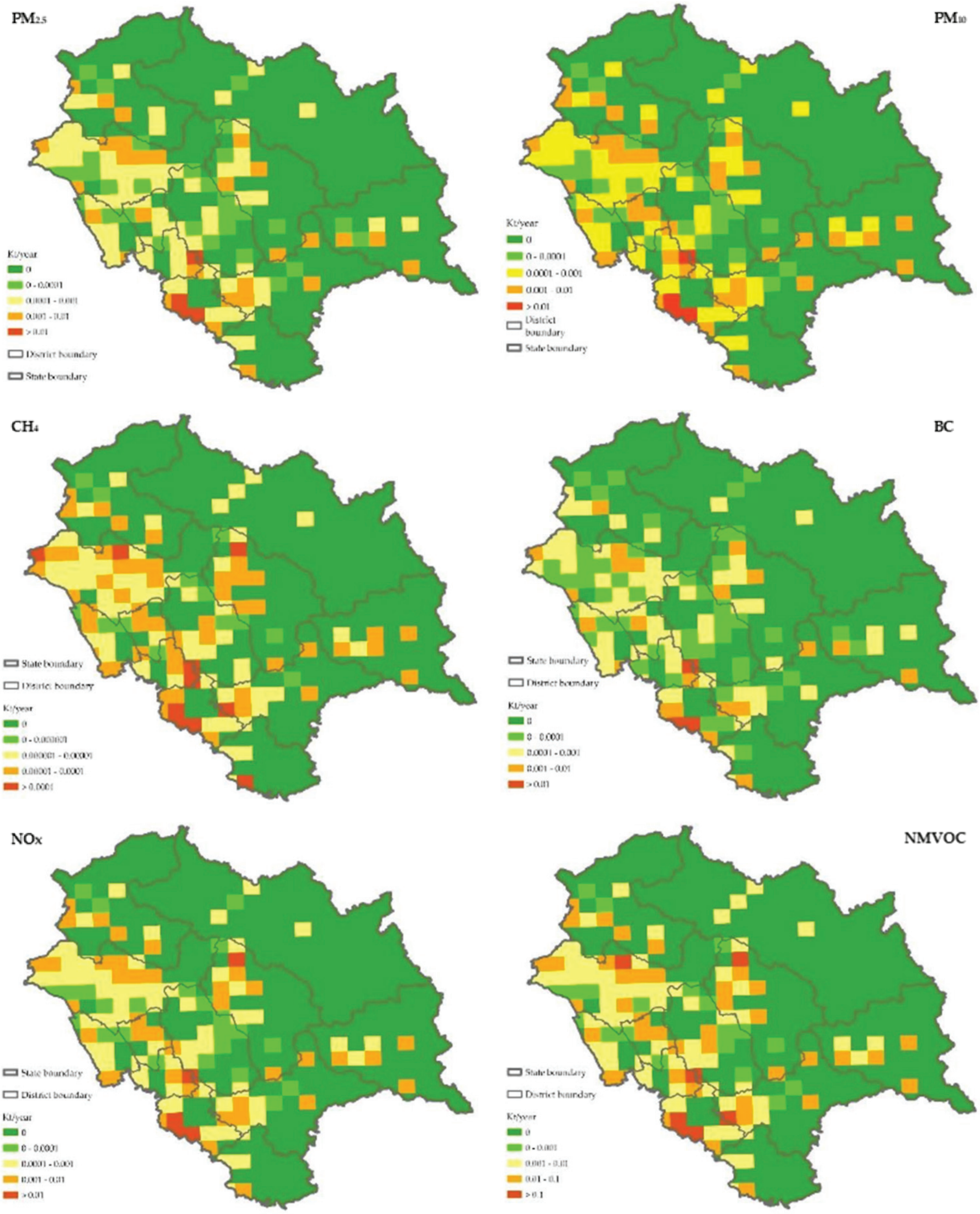


Figure 24: Spatial distribution of pollutants emission from DG sector

According to the Ministry of Petroleum and Natural Gas (MoPNG), diesel consumption in Himachal Pradesh increased at a compound annual growth rate (CAGR) of 5.45% during 2008–2019. This growth rate has been adopted as a proxy for the business-as-usual (BAU) projection of DG set usage in the state, assuming that DG operation scales proportionally with overall diesel consumption trends.

For the base year assessment, emissions from DG sets were estimated using detailed activity data received from different Regional Offices across Himachal Pradesh. The inventory was developed based on actual DG set information, including location and usage characteristics, and emissions were quantified using established emission factors from AP-42 (USEPA), Bond et al. (2004) for BC, and AR6 values for methane.

The total DG set emissions for Himachal Pradesh are estimated at 3.48 kt/year of NO_x, making NO_x the dominant pollutant emitted from DG operations. This is followed by CO at 0.75 kt/year and NMVOC at 0.28 kt/year. PM emissions are also substantial, with PM_{10} and $PM_{2.5}$ estimated at 0.24 kt/year and 0.21 kt/year, respectively, both of which have significant implications for ambient air quality and public health. SO_2 emissions from DG sets are estimated at 0.23 kt/year, while BC, a pollutant of concern due to its combined climate and health impacts, is estimated at 0.14 kt/year. CH_4 emissions from DG sets are negligible at 0.01 kt/year.

Table 27: Sector-wise emissions from diesel generator (DG) sets in Himachal Pradesh (kt/year)

	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NMVOC	CH_4	BC
Commercial	0.01	0.01	0.01	0.18	0.04	0.02	0.00	0.01
Construction (Stone crushers +Hot mix plants)	0.01	0.01	0.01	0.20	0.04	0.02	0.00	0.01
Hotels	0.03	0.03	0.03	0.50	0.11	0.04	0.00	0.02
Hydro Power Plant	0.03	0.02	0.03	0.40	0.09	0.03	0.00	0.02
Industry	0.15	0.13	0.14	2.19	0.47	0.18	0.00	0.09
Mobile Towers	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	**0.24**	**0.21**	**0.23**	**3.48**	**0.75**	**0.28**	**0.01**	**0.14**

Table 27 presents the sector-wise distribution of emissions from DG sets in Himachal Pradesh. The results indicate that the industrial sector is the dominant contributor across all pollutants, accounting for the highest emissions of PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, NMVOCs, and BC, reflecting intensive DG usage in industrial operations. This is followed by hotels and hydro power plants, which show notable contributions, particularly for NO_x and PM, due to sustained DG operation for backup power. Commercial establishments and construction activities (stone crushers and hot mix plants) contribute comparatively lower but non-negligible emissions, while emissions from mobile towers are minimal across all pollutants.

BAU Scenario for the Diesel Generator Sector

Under the Business-as-Usual (BAU) scenario, diesel consumption for DG sets is projected to continue increasing at a compound annual growth rate (CAGR) of 5.45%, consistent with historical trends reported by the Ministry of Petroleum and Natural Gas. Sectoral diesel consumption shares are assumed to remain constant in line with estimates reported by Petroleum Planning and Analysis Cell (2021). In the absence of any additional policy measures targeting DG sets beyond existing emission standards, diesel use across all sectors continues to rise, leading to a corresponding increase in pollutant emissions over time.

Based on the BAU assumption, emissions from DG sets increase steadily across all pollutants over time. For example, PM_{10} rises from 0.24 kt in 2019 to 1.07 kt by 2047, while NO_x increases from 3.48 kt to 15.24 kt over the same period. Similar upward trends are observed for $PM_{2.5}$, SO_x, CO, NMVOCs, CH_4, and BC, reflecting continued growth in diesel use for backup power in the absence of additional policy interventions.

Relative to the 2019 baseline, this translates to an approximate 79% increase by 2030, 203% increase by 2040, and 338% increase by 2047 across all major pollutants, including PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, NMVOC, CH_4, and BC. The uniform growth pattern reflects the direct dependence of emissions on diesel consumption under BAU conditions and underscores that, without targeted interventions such as fuel substitution, demand-side management, or stricter emission controls for DG sets, emissions are likely to rise sharply over the long term.

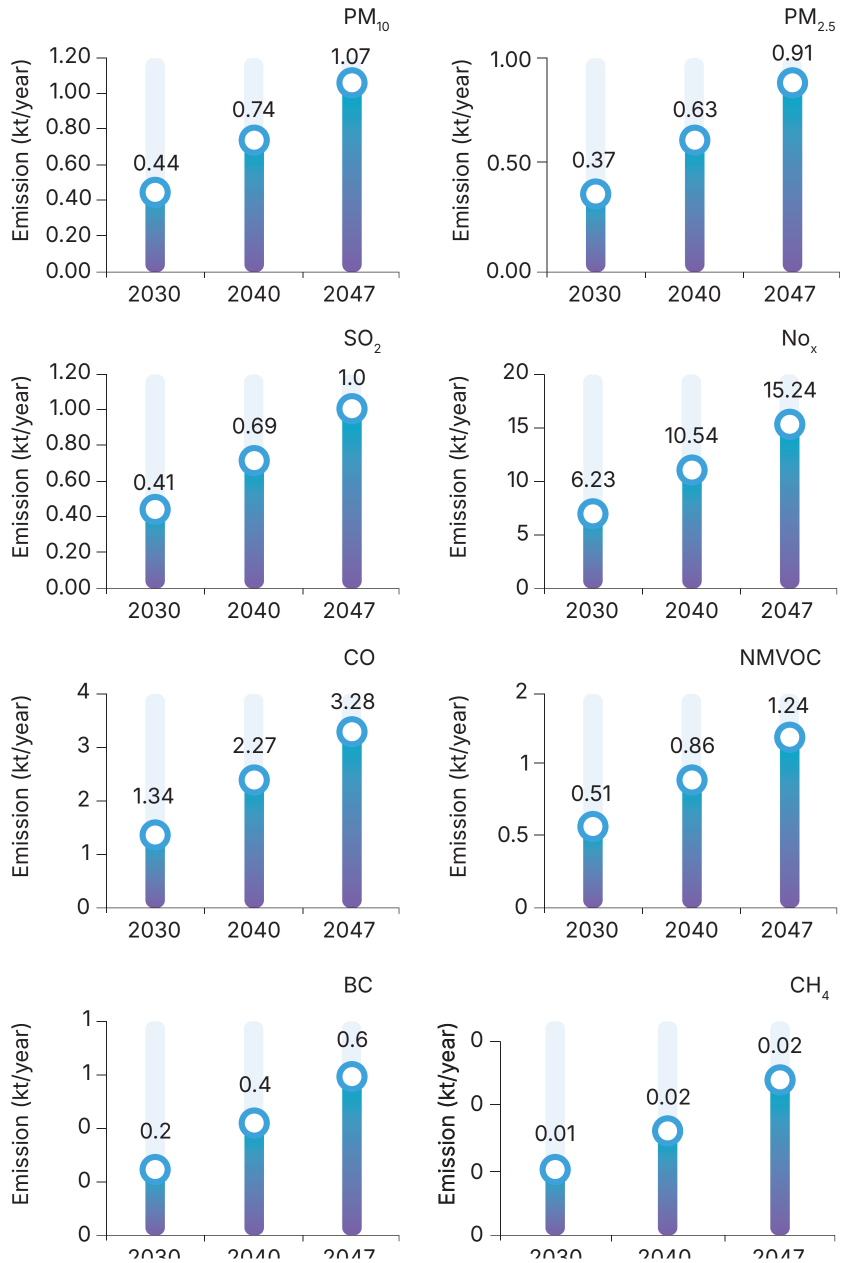


Figure 25: BAU emission projection for the DG set sector

ALT Scenarios for the Diesel Generator Sector

Under the alternative scenario (ALT), emissions from DG sets are moderated through the assumed large-scale adoption of Retrofit Emission Control Devices (RECDs), supported by stronger regulatory enforcement and increased compliance. Unlike the BAU case, this scenario assumes no change in activity growth or sectoral structure; instead, emission reductions are achieved primarily through end-of-pipe controls on existing DG sets. RECD penetration is assumed to increase progressively over time, resulting in measurable reductions for particulate and incomplete-combustion-related pollutants, while offering only marginal benefits for sulphur and nitrogen-based emissions.

Under the ALT scenario, total emissions in 2030 are estimated at 0.35 kt PM_{10}, 0.29 kt $PM_{2.5}$, 0.41 kt SO_2, 6.23 kt NO_x, 1.06 kt CO, 0.40 kt NMVOC, 0.01 kt CH_4, and 0.19 kt BC, compared to substantially higher levels under BAU. By 2040, emissions increase to 0.43 kt PM_{10}, 0.37 kt $PM_{2.5}$, 0.70 kt SO_x, 10.59 kt NO_x, 1.32 kt CO, 0.50 kt NMVOC, 0.01 kt CH_4, and 0.24 kt BC, reflecting continued growth in diesel consumption but moderated by higher RECD coverage. By 2047, emissions stabilize or slightly decline for several pollutants despite increasing activity, reaching 0.40 kt PM_{10}, 0.34 kt $PM_{2.5}$, 1.01 kt SO_x, 15.36 kt NO_x, 1.23 kt CO, 0.47 kt NMVOC, 0.01 kt CH_4, and 0.23 kt BC.

When compared directly with the BAU scenario, the ALT scenario yields substantial emission reductions for most pollutants. Relative to BAU levels, PM_{10}, $PM_{2.5}$, CO, NMVOC, CH_4, and BC emissions are reduced by approximately 21% in 2030, 42% in 2040, and 63% in 2047. These reductions are primarily attributable to the deployment of RECD technologies, which are specifically designed to control PM, unburnt hydrocarbons, and carbon monoxide through improved exhaust filtration and oxidation mechanisms.

In contrast, SO_2 and NO_x emissions show negligible reductions, limited to about 0–1% across the same periods, reflecting the inherent limitations of RECDs for these pollutants. SO_2 emissions remain closely linked to the sulphur content of diesel fuel, while NO_x formation is governed by high-temperature combustion chemistry.

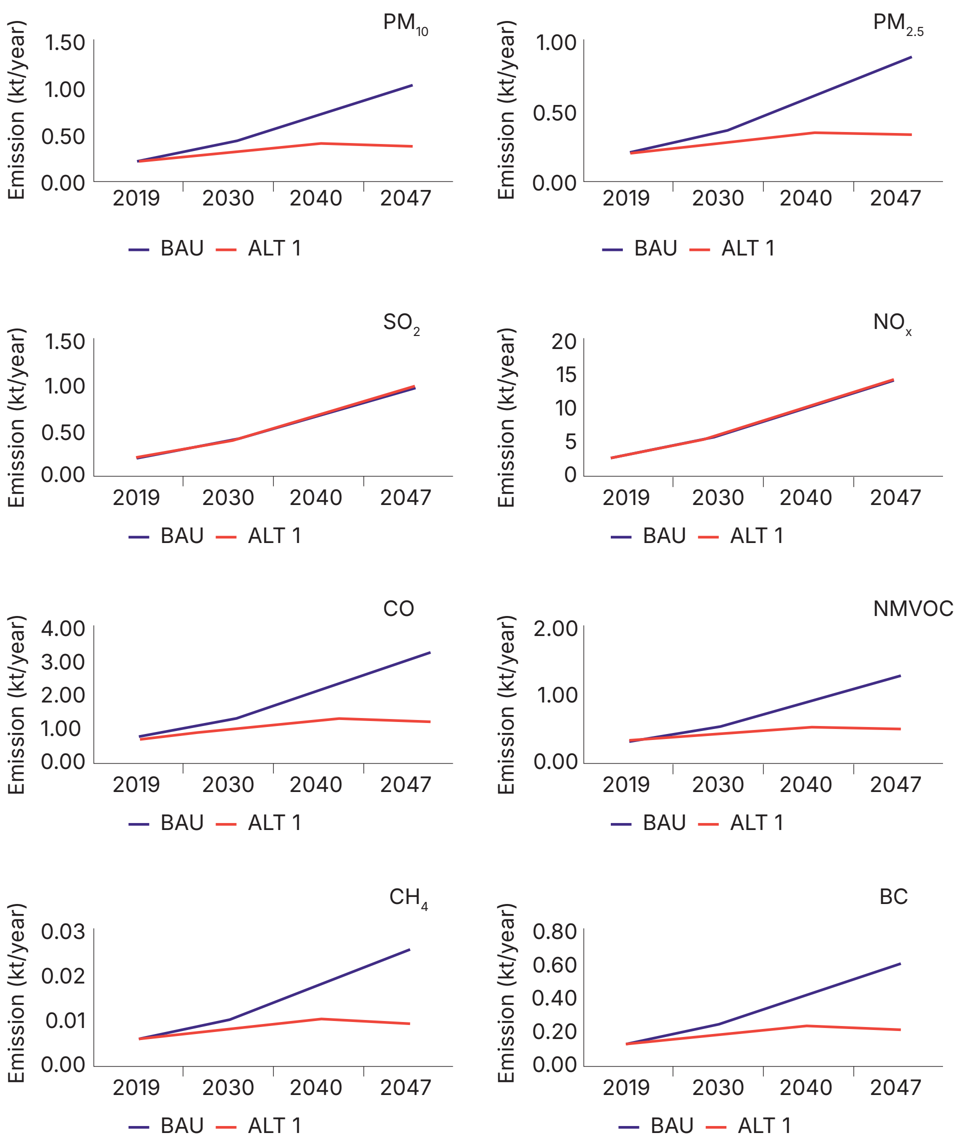


Figure 26: Emission reduction potential of alternative in DG set sector

Key Insights from the Diesel Generator Sector Analysis

The diesel generator (DG) sector in Himachal Pradesh represents a significant and growing source of air pollutant emissions, particularly from industrial and commercial DG sets.

Under the Business-as-Usual (BAU) scenario, diesel consumption from DG sets is projected to increase steadily at a CAGR of 5.45%, with no additional policy interventions beyond existing emission standards. As a result, emissions from all pollutants rise sharply over time. Relative to 2019 levels, emissions increase by approximately 79% by 2030, 203% by 2040, and 338% by 2047. By 2047, NO_x emissions alone increase from 3.48 kt to over 15 kt, while BC emissions rise from about 0.14 kt to around 0.60 kt, indicating a strong deterioration in air quality and an escalation of climate-relevant short-lived pollutants if current trends persist.

The alternative scenario (ALT) evaluates the impact of large-scale adoption of Retrofit Emission Control Devices (RECDs) on DG sets, without altering overall activity levels or sectoral growth. RECDs are assumed to be progressively implemented through stronger enforcement, regulatory push, and improved compliance. Under this scenario, emissions of PM_{10}, $PM_{2.5}$, CO, NMVOC, CH_4, and BC are substantially moderated compared to BAU. By 2030, these pollutants are reduced by about 21% relative to BAU, increasing to 42% by 2040 and 63% by 2047.

These reductions are consistent with the technical performance of RECDs, which are primarily designed to control PM, hydrocarbons, and carbon monoxide through filtration and oxidation processes. In contrast, SO_2 and NO_x emissions show negligible reductions (0–1%) under the ALT scenario, as these pollutants are largely governed by fuel sulphur content and high-temperature combustion chemistry, which are not significantly influenced by RECD technologies. This highlights a clear limitation of end-of-pipe controls when deployed in isolation.

Despite the clear benefits demonstrated under the ALT scenario, several challenges remain. The widespread deployment of RECDs is constrained by high upfront costs, limited market penetration, and the absence of mandatory, DG-specific emission regulations. In addition, continued reliance on DG sets driven by power supply constraints and reliability issues sustains high diesel consumption, thereby offsetting some of the gains achievable through emission controls alone.

To effectively curb emissions from the DG sector, a multi-pronged strategy is required. Strengthening the reliability and resilience of the electricity grid is essential to reduce baseline dependence on DG sets. Simultaneously, introducing DG-specific emission standards, supported by fiscal incentives and compliance monitoring, can accelerate RECD adoption. Based on ALT results, such measures could reduce BC, $PM_{2.5}$, CO, NMVOC, and CH_4 emissions by up to 63% by 2047 relative to BAU, delivering substantial air quality and climate benefits.

The co-benefits of these interventions are significant. Reductions in PM and BC will lower the burden of respiratory and cardiovascular diseases, while decreases in short-lived climate pollutants contribute to regional climate mitigation. Improved power reliability can also reduce fuel expenditure for users and lower long-term operating costs, while RECD deployment enhances environmental resilience despite its initial capital requirement.

In conclusion, emissions from DG sets in Himachal Pradesh pose a growing environmental and public health risk under BAU conditions. While RECD-based mitigation alone cannot address all pollutants particularly SO_2 and NO_x it offers a highly effective pathway for controlling particulate and carbonaceous emissions. Coupled with power sector improvements and a robust regulatory framework, these measures can substantially alter the sector's emission trajectory and align the state's development pathway with broader air quality and climate objectives.

Recommended Pathways for Himachal Pradesh

Based on the analysis conducted in this study, Himachal Pradesh demonstrates substantial potential for reducing SLCP emissions and other non-CO_2 pollutants across multiple sectors. Achieving these reductions would support India's national climate commitments and enhance the long-term sustainability of the state's economy. However, effective mitigation requires the establishment of well-defined policy targets, which a comprehensive understanding of sector-specific emission profiles must inform. Table 31summarises key policy measures that, while ambitious, can be implemented by the state through appropriate incentives and prioritisation to support the mitigation of SLCPs and non-CO_2 pollutants across relevant sectors. These interventions have been identified based on the assessment carried out in this study to evaluate their emission reduction potential.

Building on this, we assessed the projected reductions in emission loads of SLCPs and other non-CO_2 pollutants across various sectors in Himachal Pradesh that could be achieved through the implementation of these selected interventions. The study identifies a Recommended Pathway that incorporates feasible and policy-aligned interventions across key sectors, transport, industry, residential energy use, waste, and livestock.

Figures below illustrate the results of this analysis, which compares emissions from all major sectors under the baseline scenario with those under the intervention scenarios, highlighting the potential impact of alternative sectoral strategies.

Table 28: High-impact high-feasibility policies for optimal emission reduction (Recommended Pathway)

Sector	Scenario	Policy Basis / Strategy	Description
Transport	Combined Strategy of ALT-1, ALT-2	Himachal Pradesh Electric Vehicle (EV) Policy, 2022 National Vehicle Scrappage Policy, 2024	**By 2030,** 100% of state transport buses and government fleets will shift to EVs. Additionally, 30% of 20-year-old petrol and 15-year-old diesel vehicles will be scrapped, By **2040,** 50% of all vehicle fleets will convert to EVs; 60% of 20-year-old petrol and 15-year-old diesel vehicles will be scrapped, . **By 2047,** 70% of vehicle fleets in all districts will be converted to EVs; 80% of 20-year-old petrol and 15-year-old diesel vehicles will be scrapped
Industry	ALT-2	NCAP Industrial Emission Guidelines (MoEFCC)	Implementation of Wet Scrubbers (WSC) will be enforced by 25%, 50%, and 100% in industries for the years 2030, 2040, and 2047, respectively, to reduce PM and gaseous emissions.
Livestock	ALT-3	National Dairy Development Board (NDDB) Guidelines	Combines balanced feeding (ALT-1) with the promotion of indigenous cattle (ALT-2). It focuses on optimising energy, protein, and minerals in cattle diets while increasing the indigenous cattle population by +500 (2020-30), +900 (2030-40), and +1,600 (2040-50).
Solid Waste	ALT-3	Himachal Pradesh State Policy on Solid Waste Management (Urban)	96% waste collection assumed; 85% of collected waste treated, 40% recycled, 26% composted, 17% via anaerobic digestion, and 17% through waste combustion. Composting and AD increase from BAU levels. Open burning is minimised, with 2% of uncollected waste burned by residents and 2% at landfills.
DG Set	ALT-1	Installation of Retrofit Emission Control Devices (RECDs)	**2030:** 30% of DG sets fitted with RECDs; **2040:** 60% fitted with RECDs; **2047:** 90% fitted with RECDs

Table 29: Summary of emission reduction under different alternative scenarios compared to BAU in 2047

Sector	Strategies	$PM_{2.5}$	SO_2	NO_x	CO	NMVOCs	BC	CH_4
Transport	ALT 1	-25%	-33%	-13%	-20%	-16%	-19%	-46%
	ALT 2	-29%	-33%	-23%	-24%	-23%	-20%	-60%
Industry	ALT 1	-8%	-8%	-8%	-8%	-8%	-9%	-8%
	ALT 2	-82%	-88%	-91%	-80%	-85%	-86%	-87%
Livestock	ALT 1	-	-	-	-	-	-	-12%
	ALT 2	-	-	-	-	-	-	43%
	ALT 3	-	-	-	-	-	-	27%
Solid Waste	ALT 1	-4%	-5%	-	-	-	-9%	18%
	ALT 2	1%	0%	-	-	-	-8%	16%
	ALT 3	-51%	-51%	-	-	-	-19%	1%
DG Set	ALT 1	-63%	1%	1%	-63%	-63%	-63%	-63%

Note: Increase in emissions of $PM_{2.5}$, BC and SO_2 for waste sector are marginal in absolute terms, * Residential Sector: LPG penetration already achieved in BAU

$PM_{2.5}$ emission pathway of Himachal Pradesh

In 2019, the transport sector represented the largest share of $PM_{2.5}$ emissions in 2019, accounting for approximately 55% of the total. Under the BAU scenario, this share is projected to increase to 61% by 2030, followed by a marked decline to 44.17% by 2047. The initial rise reflects continued vehicle activity, while the subsequent decline is driven by the full adoption of Bharat Stage VI (BS-VI) emission standards by 2030, which is expected to significantly reduce per-vehicle emissions.

The residential sector was the second-largest source of $PM_{2.5}$ emissions in Himachal Pradesh, contributing approximately 26% of the total emissions. Under the Business-as-Usual (BAU) scenario, this contribution is projected to decline significantly, reaching 5% by 2030 and further decreasing to just 0.2% by 2047. This downward trend is primarily attributed to increased penetration of liquefied petroleum gas (LPG) and the associated reduction in biomass usage.

The industrial sector was the third-largest contributor in 2019, with an estimated share of 16%. Under the BAU trajectory, the sector's contribution is expected to increase substantially, rising to 32% by 2030 and further to 52% by 2047. This increase is likely linked to projected industrial growth in the absence of additional emission control interventions.

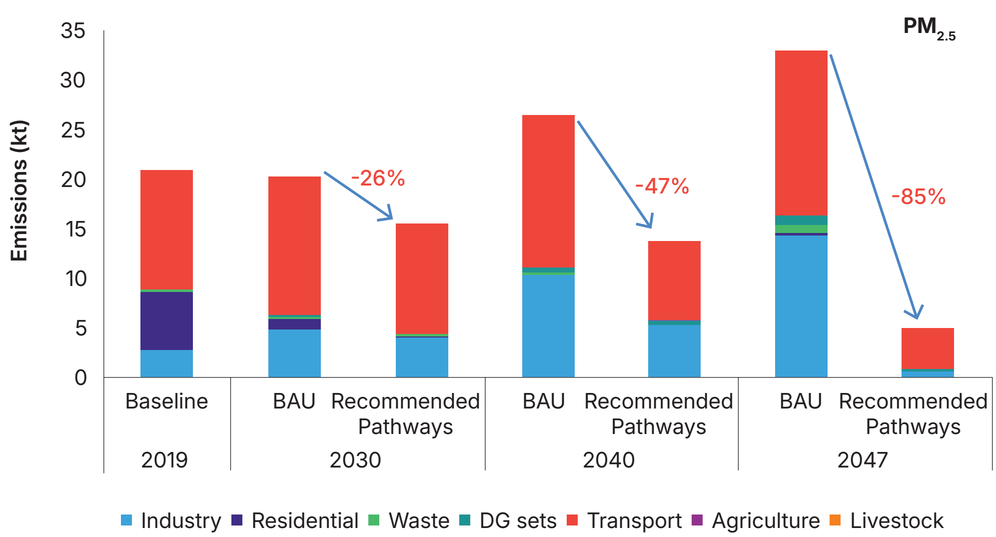


Figure 27: Annual changes in $PM_{2.5}$ emission under recommended pathways w.r.t BAU scenario

The recommended pathways for $PM_{2.5}$ emission reduction in Himachal Pradesh outline a multi-sectoral strategy aimed at achieving substantial improvements in air quality.

In the residential sector, the continuation of LPG uptake by itself will reduce emissions even in BAU. Hence no ALTs are needed

In the transport sector, the recommended pathway integrates the Himachal Pradesh Electric Vehicle (EV) Policy and the National Vehicle Scrappage Policy. This comprehensive approach promotes EV adoption, accelerates the retirement of older high-emitting vehicles. Collectively, these measures are expected to reduce $PM_{2.5}$ emissions from 12 kt/yr in 2019 to 4 kt/yr by 2047.

The industrial sector's strategy involves the mandatory installation of Air Pollution Control Devices (APCDs), specifically wet scrubbers (WSCs), across industrial units. A phased implementation plan ensures progressive coverage. Despite expected growth in industrial activity, these measures are projected to reduce $PM_{2.5}$ emissions from 2.8 kt/yr in 2019 to 1 kt/yr by 2047.

For the waste sector, the proposed pathway prioritises a recycling-centric management system, significantly diverting waste from landfills and open burning practices. This transition is expected to reduce $PM_{2.5}$ emissions from 1 kt/yr under the BAU scenario in 2047 to 0.4 kt/yr under the recommended alternative (ALT3) scenario for the same year.

In the agriculture sector, a transition to natural, low-input farming practices, as promoted by the National Mission on Natural Farming, is expected to eliminate $PM_{2.5}$ emissions. Similarly, emissions from the livestock sector are projected to remain negligible, supported by integrated strategies that also aim to reduce the SLCPs.

Overall, the implementation of these recommended pathways is expected to lead to substantial reductions in $PM_{2.5}$ emissions across all major sectors, thereby contributing significantly to improved air quality and public health outcomes in Himachal Pradesh.

NO_x emission pathway of Himachal Pradesh

NO_x are key precursors to ground-level ozone and secondary $PM_{2.5}$ formation, both of which have significant implications for air quality and public health. In Himachal Pradesh, NO_x emissions in the base year 2019 were predominantly driven by fuel combustion in the transport and industrial sectors. The transport sector alone accounted for 187 kt, or approximately 94.4% of total NO_x emissions, while industrial activities contributed 7 kt (3.3%). Together, these two sectors comprised 98% of the total NO_x emissions in the state.

Under the BAU scenario, emissions from both sectors are projected to increase substantially by 2047. Industrial NO_x emissions are expected to rise fivefold to 35 kt, largely due to increased coal consumption in response to growing production demands. In the transport sector, emissions are projected to grow more gradually, reaching 270 kt by 2047, primarily due to the expanding vehicle fleet.

In contrast, the recommended pathway scenario, anchored in emission controlling technology adoption and policy enforcement, projects a markedly different emissions trajectory. In the industrial sector, the implementation of APCDs, particularly wet WSCs, is expected to reduce NO_x emissions from 35 kt in BAU 2047 to just 7 kt in the recommended (ALT) 2047 scenario—an 80% reduction.

In the transport sector, the adoption of BS-VI emission standards and the promotion of electric vehicles under the Himachal Pradesh EV Policy significantly curb emissions growth. Consequently, NO_x emissions from transport are projected to decline from 270 kt in BAU 2047 to 112 kt in ALT 2047, representing a reduction of nearly 59% compared to the BAU scenario, despite continued growth in vehicle numbers.

Other sectors also contribute to the overall decline in NO_x emissions. In the residential sector, the widespread adoption of cleaner cooking fuels and technologies—including LPG, solar cookstoves, and improved biomass stoves—is expected to reduce NO_x emissions from 2.36 kt in 2019 to 0.5 kt in 2047 under the recommended pathway. However, emissions from diesel generator (DG) sets remain a concern. Even under the recommended scenario, emissions from DG sets are projected to increase from 2 kt in 2019 to 9 kt in 2047, underscoring the need for additional targeted interventions in this area.

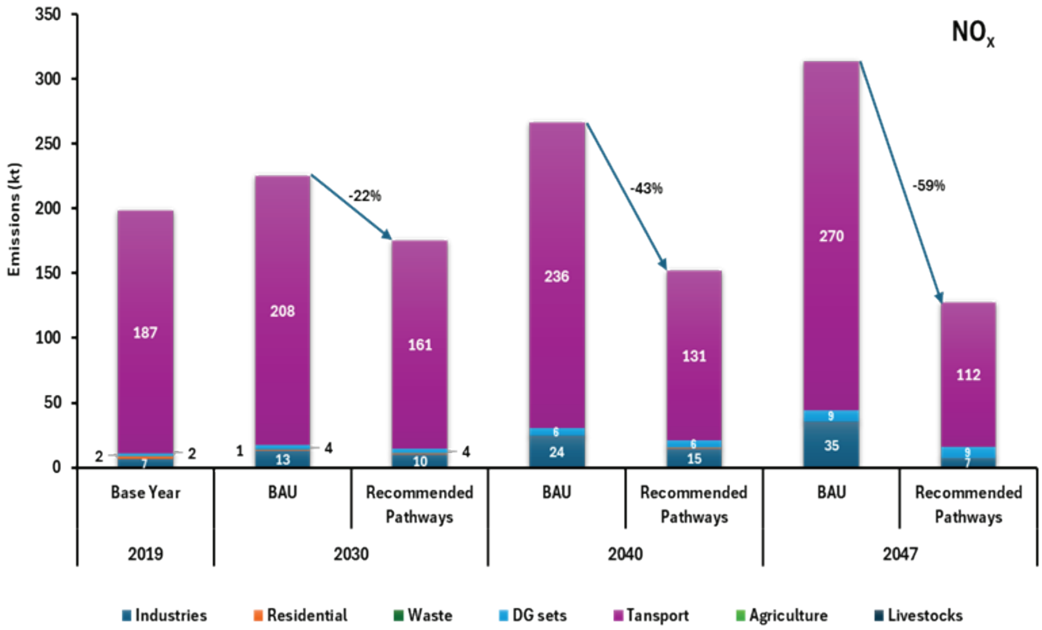


Figure 28: Annual changes in NO_x emission under recommended pathways w.r.t the BAU scenario

Overall, the implementation of recommended sectoral interventions is expected to result in significant reductions in total NO_x emissions: 22% by 2030, 43% by 2040, and 59% by 2047, relative to the BAU scenario (see Figure XX). These results underscore the importance of coordinated, cross-sectoral action, particularly in the industrial and transport sectors, and demonstrate the potential of climate-aligned policies to deliver substantial co-benefits in terms of air quality improvement and public health protection. Furthermore, sustained reductions in NO_x emissions will play a critical role in mitigating the formation of both ozone and secondary $PM_{2.5}$, contributing to the achievement of the state's near- and long-term clean air objectives.

NMVOCs emission pathway of Himachal Pradesh

NMVOCs are critical precursors to ground-level ozone and secondary organic aerosols, contributing significantly to ambient air pollution and associated public health risks. In Himachal Pradesh, NMVOC emissions in the base year 2019 were primarily attributed to the transport sector, which accounted for 116 kt or 84% of total emissions, followed by the residential sector at 22 kt (16%). Emissions from the residential sector predominantly arose from the combustion of solid biomass fuels used for cooking, which release unburnt hydrocarbons and other volatile species. In the transport sector, NMVOCs were primarily emitted due to incomplete combustion in petrol- and diesel-powered vehicles.

Under the BAU scenario, emissions from the residential sector are projected to decline significantly, reaching 3 kt by 2047 and constituting only 2% of total NMVOC emissions. This decline is driven by the increased uptake of LPG. In contrast, emissions from the transport sector are expected to rise to 149 kt by 2047, representing 96% of total NMVOC emissions, primarily due to increased vehicular demand, despite ongoing improvements in fuel standards and vehicle technologies.

The recommended pathway introduces a series of sector-specific interventions that markedly reduce NMVOC emissions. In the residential sector, the provision of LPG across HP results in an 86% reduction in emissions, from 22 kt in 2019 to 3 kt in 2047. In the transport sector, the implementation of BS-VI emission norms and the accelerated adoption of EVs substantially reduce emissions from 149 kt under BAU 2047 to 38 kt under the recommended scenario for the same year. These measures highlight the effectiveness of fuel-switching strategies and advanced emission controls in mitigating hydrocarbon emissions.

Other sectors contribute marginally but demonstrate important trends. Industrial NMVOC emissions increase modestly from 0.5 kt in 2019 to 3 kt in 2047 under BAU but are limited to 1 kt in the recommended scenario through the adoption of emission control technologies. Emissions from DG sets remain relatively low across scenarios, increasing from 0.2 kt in 2019 to 1 kt under BAU by 2047, but are constrained to 0.2 kt under the recommended pathway.

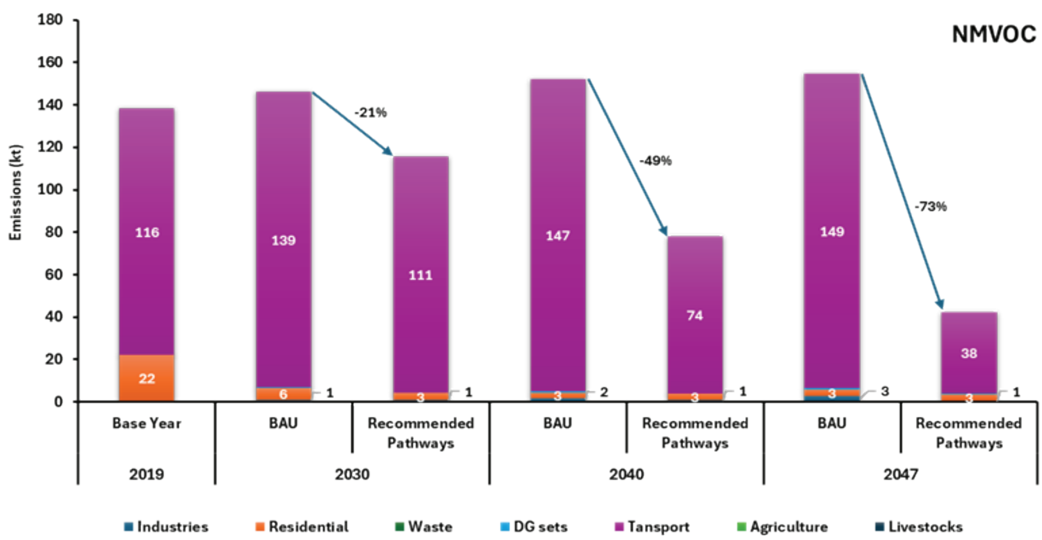


Figure 29: Annual changes in NMVOC emission under recommended pathways w.r.t the BAU scenario

Collectively, the recommended interventions are projected to reduce total NMVOC emissions by 21% in 2030, 49% in 2040, and 73% in 2047 relative to the BAU scenario. These reductions are primarily driven by structural transformations in the residential and transport sectors, supported by emissions abatement in industry. The expected co-benefits include reductions in ground-level ozone formation and improved public health outcomes, positioning NMVOC mitigation as a critical component of Himachal Pradesh's broader air quality and climate policy framework.

BC emission pathway of Himachal Pradesh

In 2019, BC, a major component of $PM_{2.5}$ and a potent SLCP, was primarily emitted from the transport sector (92%) and, to a lesser extent, the residential sector (5%) in Himachal Pradesh. Transport-related BC emissions were predominantly associated with diesel combustion in heavy-duty vehicles, while emissions from the residential sector originated largely from biomass burning. Industrial contributions to BC emissions were relatively minor. Mitigation efforts have therefore been strategically focused on the transport and residential sectors to maximise benefits for both air quality and climate.

Under the BAU scenario, this sectoral distribution remains broadly consistent over time. The transport sector's share of BC emissions is projected to decline slightly from 95% in 2030 to 90% by 2047, owing to the progressive implementation of Bharat Stage VI (BS-VI) emission standards. Concurrently, the residential sector's contribution is projected to diminish substantially, approaching zero by 2047, driven by the widespread adoption of cleaner cooking fuels, particularly LPG. Despite these shifts, absolute BC emissions from the transport sector are expected to increase from 9 kt in 2019 to 12 kt by 2047, while residential emissions decrease from 1 kt to effectively zero.

The recommended pathway scenario envisions substantial reductions in BC emissions across all major sectors. In the transport sector, the combined effects of vehicle electrification, and the accelerated retirement of older diesel vehicles, reduce BC emissions to 3 kt by 2047—a 74% reduction relative to the BAU scenario. In the residential sector, near-complete transitions to LPG result in emissions declining to just 0.001 kt by 2047. These two sectors together contribute to the majority of the reductions in total BC emissions under the recommended pathway.

Although smaller in magnitude, notable reductions are also achieved in the industrial sector. Through the implementation of wet scrubbers (WSCs) and other emission control technologies, industrial BC emissions decreased from 1 kt in 2019 to 0.1 kt by 2047.

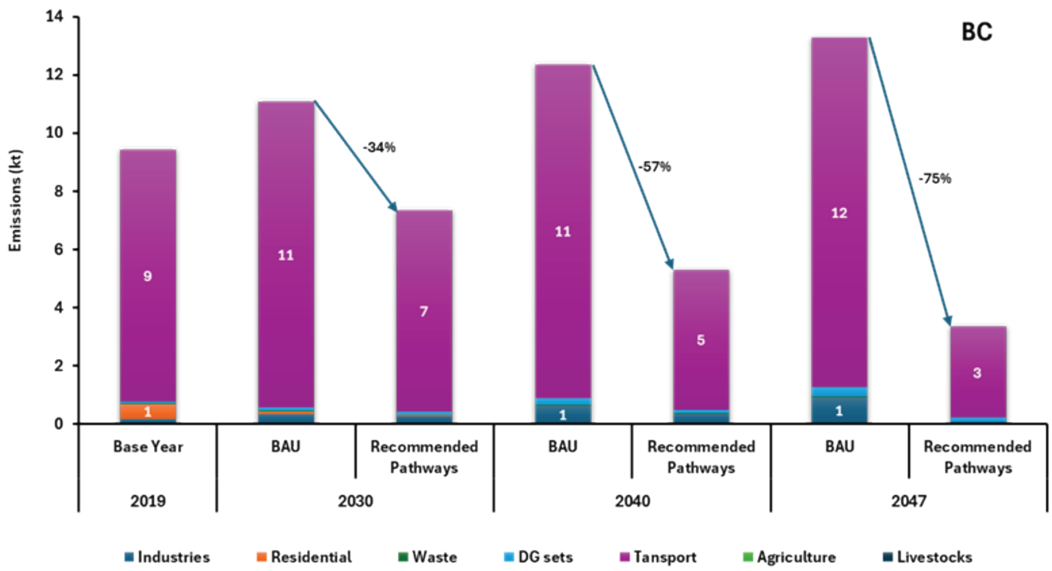


Figure 30: Annual changes in BC emissions under recommended pathways w.r.t the BAU scenario

Overall, the implementation of recommended interventions results in a 34% reduction in total BC emissions by 2030, a 57% reduction by 2040, and a 75% reduction by 2047, compared to the BAU trajectory. These reductions offer dual benefits: improving air quality and associated health outcomes, while simultaneously delivering immediate climate co-benefits due to the high radiative forcing potential of BC. Consequently, BC mitigation emerges as a critical component of Himachal Pradesh's integrated air quality and climate action strategy.

CH_4 emission pathway of Himachal Pradesh

In the base year 2019, CH_4 emissions in Himachal Pradesh were estimated at approximately 91 kt, with the livestock sector being the overwhelming contributor, accounting for 78 kt, or 86% of total emissions. This dominance continues and intensifies over time under both the BAU and Recommended Pathways scenarios. By 2047, livestock-related CH_4 emissions are projected to reach 447 kt under BAU and 568 kt under the Recommended Pathways, reinforcing its position as the most significant and steadily growing source of methane in the state.

Despite the implementation of improved livestock management measures under the Recommended Pathways scenario, such as balanced feeding and promotion of indigenous breeds as guided by NDDB recommendations, the growth in livestock numbers and associated emissions outpace mitigation impacts. The lack of aggressive methane-reducing technologies like anaerobic digesters or feed additives results in sustained emissions growth. By 2047, the livestock sector alone contributes ~99% of total methane emissions in the state.

The residential sector, once responsible for 7 kt of CH_4 emissions in 2019, shows a dramatic decline across all future years. Under the Recommended Pathways, emissions fall to 0 kt by 2030, driven by widespread adoption of clean cooking solutions. The strategy includes significant expansion of LPG access.

The waste sector also demonstrates consistent emissions reductions, falling from 1 kt in 2019 to 0 kt by 2040 under the Recommended Pathways. This reflects the implementation of the Himachal Pradesh State Policy on Solid Waste Management, which emphasizes high collection efficiency (96%), substantial treatment coverage (85%), and the promotion of composting, anaerobic digestion, and recycling. Open burning is nearly eliminated, with only minimal leakage contributing to methane output.

Emissions from the transport sector grow moderately under BAU, from 3 kt in 2019 to 9 kt in 2047, owing to increased vehicular activity. However, under the Recommended Pathways, they rise only slightly to 3 kt, supported by an integrated approach combining the Himachal Pradesh EV Policy, the National Vehicle Scrappage Policy, and the National Biofuel Policy. These measures aim for widespread adoption of EVs (up to 70% by 2047), aggressive vehicle retirement, and biodiesel blending of up to 20%.

Other sectors such as industry, DG sets, and agriculture show negligible or zero methane emissions throughout the period. Emissions from industries rise slightly to 1 kt by 2040 under BAU but remain 0 kt under the Recommended Pathways due to enforcement of emission controls like wet scrubbers under NCAP guidelines. Similarly, DG sets remain negligible across all years under both scenarios, benefiting from solarisation initiatives like PM-KUSUM and stricter emission norms.

Notably, agriculture-related methane emissions fall to zero after 2019, reflecting minimal paddy cultivation in the state and absence of other significant CH_4-producing agricultural practices.

Despite marked reductions in emissions from residential, waste, and transport sectors under the Recommended Pathways, overall methane emissions still rise—from 91 kt in 2019 to 571 kt in 2047, even exceeding the 458 kt projected under BAU. This counterintuitive increase is entirely driven by the livestock sector, whose emissions grow faster under the Recommended Pathways than under BAU due to population expansion and promotion of indigenous breeds, despite some diet optimization efforts.

This trend underscores a critical limitation in the state's current methane mitigation trajectory: the absence of deep, targeted interventions in the livestock sector, which accounts for over 99% of CH_4 emissions by 2047. Without aggressive strategies—such as enteric fermentation inhibitors, manure management systems, or methane capture from dairy farms—the potential for meaningful CH_4 reductions remains extremely limited.

To align with SLCP reduction goals and near-term climate targets, Himachal Pradesh must prioritise high-impact interventions in the livestock sector, alongside continuing the successful transition in residential and waste domains.

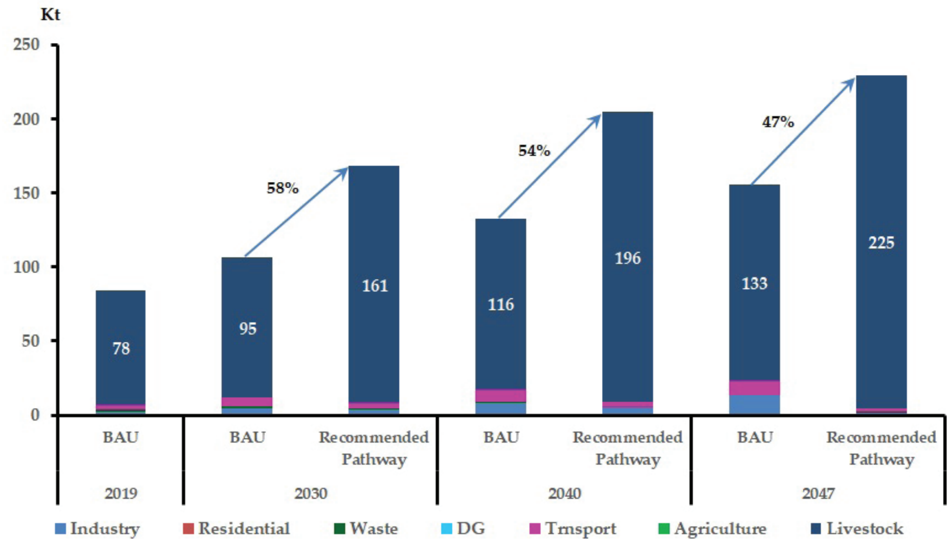


Figure 31: Annual changes in CH_4 emission under recommended pathways w.r.t BAU scenario

Notably, NO_x emissions are projected to decline by up to 59%, NMVOCs by 73%, and BC by 75% by 2047 under this scenario. These reductions are primarily driven by the implementation of clean transport policies (e.g., EV adoption, scrappage of old vehicles), industrial emission controls, and universal transition to clean cooking fuels in the residential sector.

BC, a major SLCP, sees a dramatic decline, largely due to the electrification of transport and the phasing out of biomass use in homes. Emissions drop from 10 kt in 2019 to just 3.1 kt by 2047, delivering major climate and air quality co-benefits. Likewise, NMVOC emissions, which contribute to ground-level ozone and secondary organic aerosol formation, fell from 139 kt in 2019 to 42 kt by 2047, led by LPG penetration and vehicle electrification.

Transport-related $PM_{2.5}$ emissions also fall , supported by the Himachal Pradesh EV Policy

Despite these successes, CH_4 emissions rise sharply under both BAU and Recommended Pathways. CH_4 emissions grow from 93 kt in 2019 to 230 kt by 2047 under the Recommended Pathway, even exceeding the BAU projection of 156 kt. This paradoxical trend is entirely driven by the livestock sector, which, despite incorporating balanced feeding and promotion of indigenous cattle as per NDDB guidelines, remains the dominant source, accounting for over 98% of CH_4 emissions by 2047.

The study finds that while the residential and waste sectors demonstrate near-complete elimination of CH_4 emissions by 2040 due to clean energy transitions and efficient solid waste management, these gains are offset by continued livestock emissions growth. The lack of deeper, more targeted methane abatement technologies—such as enteric fermentation inhibitors, anaerobic digesters, or improved manure management systems—limits the overall mitigation potential.

This presents a critical policy and implementation gap in Himachal Pradesh's emission landscape. Without a sector-specific roadmap for livestock methane reduction, the state risks missing a key opportunity to address a high-impact SLCP source.

Emission Scope and Policy Alignment

The emissions analysis in this study includes eight major pollutants—PM_{10}, $PM_{2.5}$, SO_2, NO_x, CO, NMVOCs, BC, and CH_4—with a focus on five key pollutants: $PM_{2.5}$, NO_x, NMVOCs, BC, and CH_4. These pollutants are central to air quality management, health impact assessments, and climate strategy. For instance:

- $PM_{2.5}$ reflects fine particulate exposure and trends in broader combustion emissions.
- NO_x and NMVOCs are precursors to ozone, a major health risk and SLCP.
- BC and CH_4 are critical SLCPs with immediate climate and air quality co-benefits.

The Recommended Pathway aligns with key national and state policy frameworks, including the NCAP, State EV Policy (2021), National Policy on Biofuels, PM-KUSUM, and Swachh Bharat Mission. However, achieving these targets at scale will require addressing persistent challenges such as inter-departmental coordination, financing of clean technology infrastructure, and strengthening of institutional monitoring and enforcement capabilities.

Strategic Recommendations for Implementation

To operationalise the Recommended Pathway and accelerate emissions reductions across sectors, the following strategic actions are proposed:

- **Establish a State Clean Air and Climate Action Cell** to lead multi-sector coordination and integrate SLCP strategies with state climate goals.
- **Develop sectoral roadmaps,** especially for high-emission sectors like livestock and transport, with time-bound methane and particulate reduction targets.
- **Introduce dedicated methane mitigation measures,** including:
  - **In livestock:** Pilot community-scale biogas plants, promote manure management, and test enteric methane inhibitors such as 3-NOP and seaweed-based additives.
- **Leverage climate finance and CSR investments** to expand electric mobility, off-grid renewables, and waste management infrastructure.
- **Build robust Monitoring & Evaluation (M&E) systems,** including real-time emission tracking, remote sensing for crop residue burning, and enforcement audits.

This assessment shows that Himachal Pradesh is well-positioned to become a sub-national leader in clean air and climate action. The recommended pathways provides a viable roadmap to reduce air pollutant and SLCP emissions substantially. However, addressing the livestock sector's growing methane footprint is essential to achieving deeper climate gains.

By embedding methane mitigation in the broader air quality and climate strategy—and by investing in institutional capacity, innovation, and inclusive implementation—the state can set a national precedent for integrated, science-based environmental governance.

The Way Forward - Sectoral Recommendations & Policy Pathways

Himachal Pradesh, with its pristine yet fragile Himalayan ecosystem and abundant hydropower, is at the forefront of India's climate action efforts. The state faces pressing challenges in managing air quality and mitigating SLCPs such as BC, CH_4, O_3 and HFCs. As discussed in the previous sections, addressing these pollutants offers substantial co-benefits, including improved public health, enhanced agricultural productivity, and greater food security, crucial for a state where the average Respirable Suspended PM (RSPM=PM_{10}) concentration (~78 µg/m3) already exceeds the national ambient air quality standard (NAAQS).

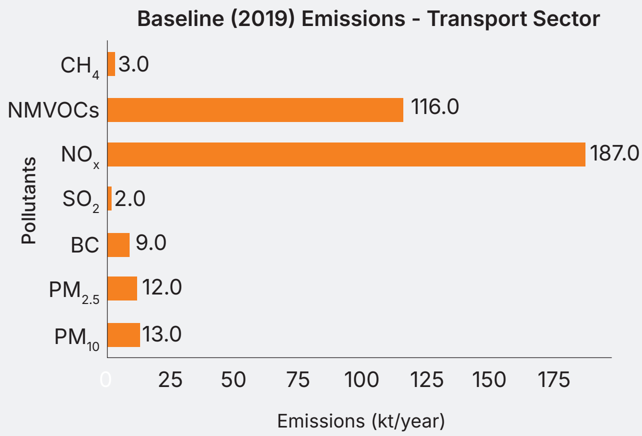
The state's commitment to a sustainable future is enshrined in its overarching climate initiatives, including the State Strategy and Action Plan on Climate Change (SAPCC) (2021–2030) and the State Action Plan on Climate Change and Human Health (SAPCCHH) (2022–2027). These plans guide comprehensive climate action and integrate climate-sensitive health planning. Furthermore, the State Environment Plan (2024) explains the state's role in protecting the climate while specifically addressing CH_4 and N_2O emissions too, and the Heat Wave Action Plan (2020) acts as a guide towards monitoring air quality and reducing heat stress in the state. It highlights the long-term goal of creating a comprehensive inventory of air pollutants and emissions, which will also focus on SLCPs. Abating these SLCPs will therefore act as a key strategy for mitigating heat stress in the state. The Drishti Himachal 2030 integrates UN Sustainable Development Goals (SDGs) into state planning, balancing growth and environmental protection. Building on its foundational policy framework, Himachal Pradesh is also concurrently introducing new schemes in key sectors to address growth more sustainably.

Against this backdrop, we have developed a comprehensive set of detailed policy recommendations. These recommendations have been drawn from our alternative scenarios, carefully integrating a multifaceted approach. We have considered existing policies, identifying specific modifications that promise to enhance their implementation. Furthermore, our recommendations account for newly introduced schemes and draw valuable insights from best practices observed in other states, offering actionable models for Himachal Pradesh to replicate. Our overarching goal is to transform these strategic frameworks into tangible, real-time policy solutions that not only contribute to the state's economic growth but also ensure this progress is achieved in a more sustainable manner, by significantly reducing emissions and simultaneously considering their broader impact on the public.

The sections below further highlight specific sectoral strategies which can be integrated with existing interventions for a comprehensive approach towards mitigation of non-CO_2 emissions.

Transport Sector

The transport sector represents an escalating threatii and an average RSPM concentration (~78 /m3) already exceeding NAAQS. Diesel combustion from commercial vehicles is a primary and rapidly growing source of NO_X (187kt/yr) and NMVOCs (116 kt/yr), particularly in urban centres and popular tourist destinations such as Shimla, Manali, and Dharamshala. Despite the implementation of the Vehicle Scrappage Policy, older vehicles, over 10 years old, still disproportionately contribute to total vehicular pollution iii. EV uptake, while significant in popular destinations, still remains lower in challenging terrains such as Lahaul and Spiti.iv This necessitates immediate, robust, and comprehensive intervention to avert severe health and environmental consequences.



EXISTING POLICIES

- **State Transport Policy:** Promotes efficient public transport systems and gradual adoption of electric vehicles (EVs), particularly for urban and intercity mobility.
- **EV Promotion in Non-Attainment Cities:** Focuses on accelerating EV uptake in identified pollution hotspots such as Parwanoo and Baddi, where transport emissions significantly contribute to local air quality deterioration.
- **Fuel Quality Regulations:** Enforcement of Bharat Stage-VI (BS-VI) emission standards across the state to reduce PM, NO_X, and other transport-related pollutants.

RECOMMENDATIONS

To **accelerate EV adoption,** Himachal Pradesh can adopt a dual strategy approach similar to Delhi's vehicle scrappage-linked EV incentive model, that offers targeted incentives for EV purchases and incentives for scrapping older vehicles. For HP too, such a strategy can include an amalgamation of reduced registration fees/exemptions, scrappage bonuses, or purchase subsidies, enabling the phased replacement of ICE vehicles in urban towns with higher vehicular density such as Shimla, Hamirpur, Solan, Manali, etc.

To expand charging infrastructure in difficult terrain, HPSEBL should be empowered with **single-window clearances, streamlined land acquisition, and assured financing,** drawing from Himachal Pradesh's Green Corridor approach on major highways. Fast-charging stations should be installed at **regular intervals** along identified corridors and integrated with the **Himachal Pradesh Solar Power Policy (2023),** using distributed solar generation to ensure grid resilience and year-round charging access in remote and tourist-heavy locations such as Shimla, Kangra, Kullu etc.

To strengthen vehicle scrappage implementation, the state should follow Delhi's digitally enforced scrappage incentive framework, integrating state and central vehicle databases to automatically flag end-of-life and high-emitting vehicles. Freight corridors can introduce targeted levies on older diesel trucks, while authorised scrappage centres can be established through public-private partnerships, supported by NCAP and central transport funds.

To reduce emissions from the existing diesel fleet, Himachal Pradesh can expand its regulatory toolkit to include Diesel Particulate Filter (DPF) retrofit programmes, aligned with practices emerging in urban low-emission zones. Financial incentives—covering up to 50% of retrofit costs or ₹50,000 per vehicle—can be offered to commercial fleet operators, ensuring immediate reductions in PM and BC emissions.

POTENTIAL HURDLES

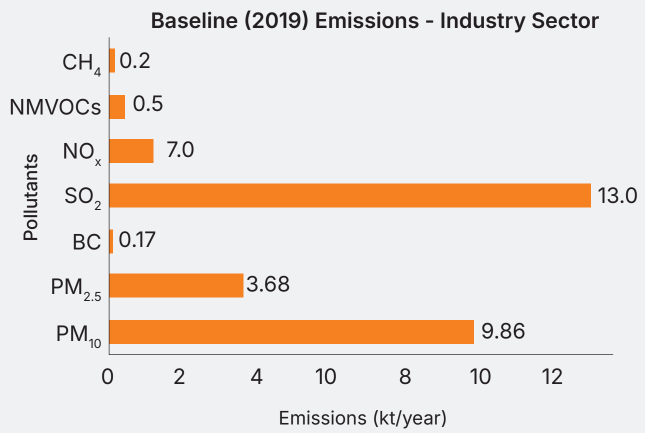
- **Fiscal and financing constraints:** Sustained EV incentives, charging infrastructure expansion, scrappage support, and retrofit programmes will require predictable and long-term financing. Budget limitations and dependence on central schemes may affect continuity and scale.
- **Institutional coordination challenges:** Successful implementation depends on close coordination between Transport, Power (HPSEBL), Urban Development, Pollution Control Board, and local bodies. Fragmented mandates or delays in inter-departmental approvals could slow rollout.
- **Terrain-driven implementation complexity:** Himachal Pradesh's hilly geography increases infrastructure costs, complicates land acquisition, and affects grid reliability, making EV charging deployment and vehicle retrofits more challenging than in plains states.
- **Market readiness and industry response:** EV availability, charging equipment supply chains, scrappage operators, and certified retrofit providers may not scale at the pace required, especially outside major towns.
- **Behavioural and acceptance barriers:** Vehicle owners and fleet operators may be hesitant to transition due to concerns around upfront costs, vehicle range, resale value, and operational reliability in hill conditions, even when incentives are available.
- **Monitoring and enforcement capacity:** Digitally enforcing scrappage, ensuring DPF performance, and monitoring charging and incentive misuse will place additional administrative and technical demands on state agencies.

Way Forward:

Himachal Pradesh's transport transition should be guided by a phased, terrain-sensitive clean mobility strategy that simultaneously accelerates fleet turnover, expands charging infrastructure, and reduces emissions from existing vehicles. Building on state EV policies, NCAP funding, and national scrappage frameworks, the state can adopt a scrappage-linked EV incentive approach, combining purchase incentives, registration fee exemptions, and scrappage bonuses to accelerate replacement of older ICE vehicles in urban and tourist-intensive towns such as Shimla, Solan, Manali, and Hamirpur. Charging deployment must be treated as critical infrastructure, with HPSEBL empowered through single-window clearances, assured financing, and integration with the Solar Power Policy (2023) to ensure reliable charging along highways and hill corridors. To deliver near-term air-quality benefits, regulatory tools such as DPF retrofit programmes for commercial diesel fleets should complement electrification. Key cross-cutting hurdles—high capital costs, grid constraints, behavioural resistance, and enforcement capacity—can be addressed through predictable incentive frameworks, digital enforcement of scrappage and retrofit compliance, and corridor-based infrastructure planning, ensuring that clean transport adoption remains practical in Himachal's mountainous context.

Industry Sector:

Critically polluted industrial zones like Baddi, Kala Amb, and Parwanoo in Himachal Pradesh are major contributors to SO_2, PM, NO_x, and SLCPs, primarily due to fossil fuel combustion (coal, pet coke) in MSMEs. Industrial emissions are projected to increase fivefold by 2047 without interventions, reflecting broader industrial pollution issues in India. Below are the suggested recommendations that take into account existing norms and how certain modifications can help improve emission reductions from the sector.



EXISTING POLICIES

- **Industrial Emission Norms & CTO Conditions:** Stack emission standards and consent-to-operate requirements applicable across industrial units.
- **CEMS Requirements & Polluted Area Notifications:** Mandatory continuous monitoring in critically polluted industrial clusters such as BBN.
- **Draft State Fuel Policy**: Allows limited biomass co-firing and regulates industrial fuel use.
- **Boiler Regulations:** Standards governing installation and operation of industrial boilers.
- **HP Energy Policy (2021):** Supports cleaner industrial energy transitions.
- **HP Green Hydrogen Policy (2023) & National Green Hydrogen Mission:** Focus on hydrogen production, incentives, and early adoption.

RECOMMENDATIONS

Himachal Pradesh's industrial sector—particularly MSME-dominated clusters such as Baddi-Barotiwala-Nalagarh (BBN), Kala Amb, and Parwanoo—continues to rely heavily on coal and petcoke, with widespread use of inefficient standalone boilers and uneven compliance with emission norms. While existing policies address fuel standards and monitoring, enforcement remains largely reactive, fuel switching is fragmented, and adoption of advanced clean technologies is limited.

The state can shift toward a **performance-driven compliance framework** by strengthening the linkage between Consent-to-Operate (CTO) conditions and real-time Continuous Emission Monitoring System (CEMS) performance, drawing from Haryana's CEMS-linked enforcement model in critically polluted areas. Under this approach, industries in high-pollution clusters would be required to install or upgrade process-appropriate emission-abatement technologies (e.g., wet scrubbers, bag filters) based on repeated exceedances captured through CEMS data, rather than through blanket mandates. This introduces a transparent, data-triggered enforcement layer that improves regulatory credibility, focuses compliance where it is most needed, and reduces discretionary decision-making.

To address fuel-related emissions, the Draft State Fuel Policy can be amended to explicitly **promote shared boiler and steam-supply infrastructure in industrial clusters,** building on existing provisions that allow biomass fuels such as pine-needle pellets and lantana. This recommendation draws directly from BBN's own pilots of common boiler and steam-generation facilities, where shared utilities replaced multiple inefficient boilers, reduced coal use, improved combustion efficiency, and enabled centralized pollution monitoring. Scaling this model through cluster-level boiler parks operated by common utility providers can significantly lower unit-level capital costs while enabling phased fuel-switching targets—such as a 30% reduction in high-sulphur fuels (coal and petcoke)—with a transition toward biomass pellets, cleaner fuels, and gas where feasible.

Fuel switching can be further accelerated by **replicating lessons from Punjab's biomass pellet transition programme for MSMEs,** which combined cleaner-boiler demonstrations with assured pellet procurement networks. Himachal Pradesh can adapt this approach by developing local pellet supply chains using pine needles and forest residues, coupled with demonstration boilers in BBN and Kala Amb, ensuring that biomass fuels are reliable, affordable, and technically viable for small and medium industries.

Looking ahead, Himachal Pradesh can complement its **Green Hydrogen Policy (2023) by introducing a Green Hydrogen Consumption and Demand-Guarantee mechanism,** shifting the focus from production incentives alone to assured local industrial off-take. Adoption barriers can be lowered through usage-linked subsidies, preferential electricity tariffs, and tradable green-hydrogen credits for verified consumption, ensuring that hydrogen actually substitutes fossil fuels in high-emission clusters.

Over the longer term, the state may introduce a graduated green hydrogen consumption mandate—for example, 5% by 2040 and 8% by 2047 for energy-intensive sectors—supported by a **credit-trading system** that allows over-compliance to offset under-compliance. Together, CEMS-linked enforcement (Haryana model), shared clean-energy infrastructure (BBN experience), biomass fuel transition (Punjab model), and demand-side hydrogen incentives form a coherent industrial decarbonisation and air-quality pathway tailored to Himachal Pradesh's clustered industrial geography.

POTENTIAL HURDLES

- **Industry resistance to data-triggered enforcement,** as real-time CEMS may expose frequent exceedances and force unplanned investments.
- **Limited technical and financial capacity of MSMEs,** particularly in clusters like BBN and Kala Amb, to rapidly install abatement technologies or shift fuels.
- **High upfront costs and coordination challenges** for shared boiler parks, including land availability, demand aggregation, and fuel logistics in hilly terrain.
- **Supply uncertainty and infrastructure gaps for green hydrogen,** especially in early years, affecting industry confidence.
- **Administrative and regulatory burden on pollution control boards** to monitor, verify, and enforce CEMS-linked and fuel-switching requirements.
- **Perceived cost competitiveness risks,** leading to pushback if cleaner fuels or hydrogen are seen as affecting industrial viability.

Way Forward:

Himachal Pradesh's industrial decarbonisation pathway should move from fragmented, input-based regulation to a **performance-driven, cluster-level compliance framework,** anchored in existing emission norms, CTO conditions, and the State Fuel and Green Hydrogen Policies. Strengthening the linkage between **real-time CEMS data and regulatory action**—drawing from Haryana's CEMS-linked enforcement experience—can ensure that pollution-control investments are triggered by verified exceedances rather than blanket mandates, improving regulatory credibility while limiting unnecessary compliance costs. At the same time, **cluster-based shared infrastructure,** such as common boiler and steam-supply facilities piloted in the **Baddi–Barotiwala–Nalagarh (BBN) cluster,** should be scaled to reduce dependence on coal and petcoke and enable phased fuel switching toward biomass, gas, and cleaner alternatives. Over the medium term, **demand-side green hydrogen incentives and credit-based consumption mandates** can complement supply-focused national schemes, ensuring real fossil-fuel substitution in high-pollution belts. Key implementation hurdles—MSME financing constraints, technical capacity gaps, and inter-agency coordination—can be addressed through pooled infrastructure models, targeted capital support, and strengthened SPCB–industry digital monitoring systems, creating an industrial transition pathway that is both enforceable and economically viable in Himachal's clustered industrial geography.

Livestock:

The livestock sector is a major contributor to CH_4 emissions in HP, primarily through enteric fermentation, accounting for roughly **86% of the state's total CH_4 emissions in 2019. The report identifies Kangra, Mandi, and Chamba as the highest-emitting districts,** driven by large cattle populations, extensive dairy activity, and sheep and goat rearing. Methane emissions from this sector are projected to rise substantially by 2047 with increasing livestock numbers. While policies such as the Himachal Pradesh Cattle Breeding Policy (2018), the Bovine Breeding Act (2019), and the Gau Vansh Sanrakshan and Samvardhan Act (2018) focus on improving productivity and reducing emissions intensity, **deployment of direct methane-mitigation measures—such as feed additives, Ration Balancing Programmes (RBP), and decentralised anaerobic digesters—remains limited.** Persistent challenges include inconsistent availability of quality fodder, low farmer awareness and technical capacity, and difficulties in adapting feed and biogas interventions to cold, high-altitude conditions. As a result, despite national initiatives such as GOBARdhan and SATAT, enteric fermentation and unmanaged manure continue to be dominant methane sources in Himachal Pradesh.

EXISTING POLICIES

- **Himachal Pradesh Cattle Breeding Policy (2018):** Focuses on productivity enhancement and reduced methane intensity per unit of output.
- **Bovine Breeding Act (2019):** Promotes genetic improvement and herd efficiency.
- **Gau Vansh Sanrakshan and Samvardhan Act (2018):** Supports indigenous breeds and sustainable herd management.
- **National GOBARdhan Programme:** Enables manure management and biogas-based methane capture.
- **SMAM Mechanization Scheme:** Supports mechanised livestock and dairy management systems.
- **ICAR / NDDB Extension Platforms:** Provide tested tools for ration balancing and feed-based mitigation.

RECOMMENDATIONS

Himachal Pradesh's livestock sector is characterised by smallholder, low-input dairy systems, reliance on open grazing and low-quality roughage, and sub-optimal feed management, resulting in high enteric methane emissions per unit of milk. While existing policies focus on breed improvement, productivity enhancement, and manure management, gaps in feed optimisation, adoption of methane-reducing practices, and climate-suitable infrastructure persist.

A high-impact, near-term mitigation pathway is the **state-wide scaling of the Ration Balancing Programme (RBP)** by directly integrating NDDB and IRVI digital RBP tools into Himachal's livestock extension system. Using dairy cooperatives and veterinary networks, customised ration advice and fodder planning can be delivered at the household level, supported by fodder hubs at Taal, Jeori, Palampur, and Bagnath. This approach enables immediate feed optimisation, improving milk yields while delivering **10–15% methane reduction per litre of milk**.

Complementing RBP, the state can **promote anti-methanogenic feed additives by embedding ICAR–NIANP's Harit Dhara dissemination toolkit** into Livestock Development Programmes and providing targeted subsidies for commercial production and farmer adoption. This intervention can deliver an additional 17–20% reduction in enteric methane per animal, particularly effective in Himachal's roughage-dominated feeding systems.

For manure-related methane, Himachal Pradesh can expand decentralised biogas systems by deploying MNRE-approved polyethylene (flexi) digesters, bundled with GOBARdhan capital support and SMAM mechanisation incentives. These digesters can be integrated into dairy farms and gaushalas, enabling year-round methane capture from manure while providing clean energy for households and institutions. Proven cold-climate adaptations from Himalayan states can be incorporated to improve performance in mid- and high-altitude districts.

Together, feed optimisation, methane-inhibiting additives, and decentralised manure management create a mutually reinforcing pathway that links productivity gains with methane mitigation, making climate action economically attractive for smallholder farmers.

POTENTIAL HURDLES

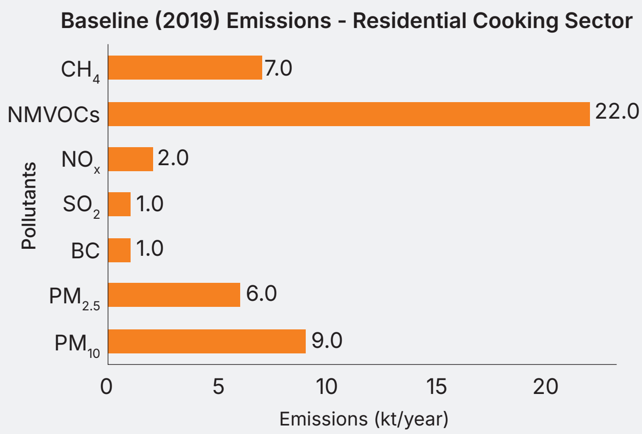
- **Limited availability of trained nutritionists and extension workers** at the field level to deliver RBP at scale.
- **Seasonal fodder availability gaps,** particularly in high-altitude districts, constraining ration optimisation.
- **Low farmer awareness and behavioural resistance,** especially where cattle are traditionally left to graze without monitoring.
- **Supply-chain and cost barriers for anti-methanogenic feed additives,** including uncertainty on dosage under varied hill agro-climatic conditions.
- **Reduced biogas digester efficiency in cold climates** without insulation or microbial adaptation.
- **Upfront costs, land constraints, and limited technical servicing capacity** for decentralised biogas systems.

Way Forward:

Reducing methane from Himachal Pradesh's livestock sector requires integrating **productivity-oriented breeding policies with proven feed, manure, and energy interventions,** while aligning national programmes such as **GOBARdhan, SMAM, and NDDB-led initiatives** with state implementation. Scaling up the **Ration Balancing Programme (RBP)** through digital tools and cooperative networks can deliver immediate methane-intensity reductions while improving farmer incomes, as demonstrated by Punjab's dairy cooperatives. Parallel promotion of **anti-methanogenic feed additives such as Harit Dhara,** supported by targeted subsidies and extension services, can provide low-cost emission reductions suitable for smallholder systems dominant in hill regions. Manure-related methane should be addressed through **decentralised biogas systems,** using MNRE-approved PE digesters adapted for cold climates, integrated into dairy farms and gaushalas to ensure year-round energy access. Challenges related to fodder availability, cold-climate performance, and farmer adoption can be mitigated through district-level fodder hubs, demonstration pilots, and bundling climate mitigation with productivity and energy-security benefits—ensuring that methane reduction aligns with livelihood enhancement rather than imposing additional burdens on smallholders.

Residential Cooking Sector:

The residential sector is a significant contributor to air pollution and climate change in Himachal Pradesh due to emissions of NMVOCs (22kt/yr), PM_{10} (9kt/yr). Fuelwood remains the dominant source of emissions in most districts, particularly in regions like Mandi, Kangra, Chamba, Bilaspur, and Sirmaur, where it is almost exclusively used. This is primarily due to the inefficient combustion of biomass for cooking and heating. While the Ministry of Petroleum and Natural Gas launched the PMUY to provide LPG as a cleaner cooking fuel alternative for households relying on traditional fuels, a considerable disparity exists between LPG connection rates and its consistent, exclusive use. This gap is largely attributed to "fuel stacking"—the simultaneous use of LPG with traditional solid fuels like firewood.



EXISTING POLICIES

- **PMUY:** A central scheme providing subsidised LPG connections and refills to promote clean cooking among poor households.
- **Himachal Pradesh Energy Policy (2021):** A state policy guiding the transition to clean and renewable energy across sectors.
- **National Bioenergy Programme / SATAT:** Central programmes supporting biogas and compressed biogas deployment through financial incentives and offtake support.
- **MNRE Solar Initiatives & PM Surya Ghar:** National programmes promoting rooftop solar and decentralised clean energy for households.
- **SHG & Livelihood Platforms (DAY-NRLM, HIMIRA Rasoi, CIF):** Community institutions enabling livelihood support and last-mile service delivery.
- **Smoke-Free Himachal Declaration:** A state commitment to eliminate household air pollution through clean energy adoption.

RECOMMENDATIONS

Himachal Pradesh's residential sector continues to exhibit high dependence on biomass and persistent fuel stacking, driven by seasonal heating requirements, higher winter energy demand, and affordability constraints—particularly in colder and high-altitude districts. While policy efforts have substantially expanded access to LPG connections, sustained usage remains uneven, limiting reductions in household air pollution and associated BC emissions.

In this context, the Pradhan Mantri Ujjwala Yojana (PMUY), which is currently structured largely around a connection-based access model, can be recalibrated for Himachal Pradesh into a usage- and climate-sensitive LPG promotion framework. Introducing targeted LPG refill support in colder and high-altitude districts such as Lahaul and Spiti can directly address seasonal affordability barriers and reduce wintertime reversion to biomass fuels.

To strengthen sustained adoption, the state can institutionalise LPG refill-based monitoring, using secure data-sharing arrangements with Oil Marketing Companies to track refill frequency and seasonal consumption patterns. These data can inform targeted IEC campaigns, behavioural nudges, and district-specific interventions, enabling a shift from access-oriented metrics to outcome-based clean cooking indicators.

This approach can directly support the state's Smoke-Free Himachal Declaration by enabling identification and certification of smoke-free households based on demonstrated LPG usage outcomes rather than connection status alone. Recognition of smoke-free villages or panchayats—anchored in verified refill data—can reinforce positive social norms while strengthening local accountability.

To enhance transparency and adaptive policy design, Himachal Pradesh can introduce independent third-party verification in select districts, using findings as a feedback loop to refine PMUY targeting, prioritise cold-climate geographies, and calibrate refill-linked incentives over time.

Complementing LPG promotion, Himachal Pradesh's special-category CFA advantage, as reflected in its financial allocation and human development framework, can be strategically leveraged to scale household- and community-level biogas systems, particularly in livestock-rich districts. This can help partially offset long-term dependence on LPG refills and traditional biomass, while improving energy access and resilience in remote areas. Converging the SATAT programme with the Himachal Pradesh Rural Livelihood Mission (HP-RLM) / DAY-NRLM can enable biogas units to function as SHG-financed and SHG-managed livelihood assets, supporting local income generation alongside clean-energy delivery. Prioritising deployment in districts identified under the state's clean-energy and climate-vulnerability targeting framework can enhance operational viability and sustained usage.

Potential implementation challenges—including refill affordability, supply constraints in remote and snowbound regions, and entrenched cooking practices—can be addressed through winter-specific IEC campaigns, last-mile delivery strengthening, and sustained community engagement through Panchayats and self-help groups.

Evidence from other states supports this pathway. Gujarat has improved sustained LPG usage by pairing district-specific refill incentives with community-level behavioural nudges delivered through anganwadis and SHGs, resulting in higher refill frequency and reduced fuel stacking. These lessons are directly relevant for Himachal Pradesh, where climatic variability and remoteness necessitate a climate-responsive, usage-focused clean cooking strategy.

POTENTIAL HURDLES

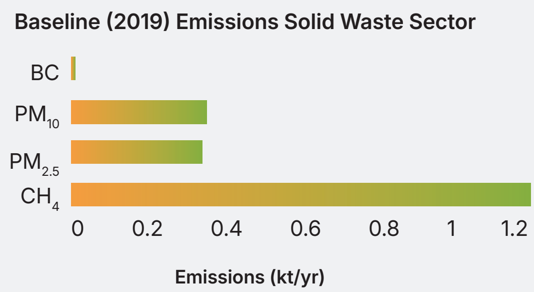
- **Fiscal and political sensitivity** around differentiated, district-specific LPG refill support and geographic prioritisation, particularly in the absence of established usage-based subsidy frameworks.
- **Household hesitation and behavioural inertia,** including concerns related to refill affordability, seasonal availability, and apprehension around increased monitoring linked to usage-based targeting.
- **Institutional capacity gaps at the level of Panchayats,** self-help groups, and frontline workers, limiting their ability to support outreach, monitoring, verification, and sustained behaviour-change communication.
- **Data governance and privacy concerns,** alongside uneven digital literacy, which may affect the effectiveness of LPG refill tracking and the deployment of targeted behavioural nudges based on consumption data.
- **Inter-departmental coordination challenges,** given the need for alignment across petroleum and energy agencies, rural livelihoods missions, Panchayati Raj institutions, and district administrations—potentially increasing administrative and implementation burdens.

Way Forward:

Himachal Pradesh's residential clean-cooking transition should shift from access-based metrics to **sustained, climate-appropriate LPG usage,** aligned with PMUY and the state's Smoke-Free Himachal vision. Despite high LPG coverage, low refill rates and continued fuel stacking—especially in cold and high-altitude districts—necessitate **usage- and climate-sensitive PMUY reforms,** including targeted winter refill support and refill-based monitoring to enable better district prioritisation, behavioural nudges, and credible smoke-free verification based on actual usage outcomes. Complementing LPG promotion, **strategically deployed household- and community-level biogas systems,** supported by the state's special-category CFA advantage and convergence with HP-RLM / DAY–NRLM, can enhance energy resilience in livestock-rich and remote districts while moderating long-term dependence on LPG. Addressing adoption barriers related to affordability, behavioural inertia, and seasonal access through **SHG- and Panchayat-led outreach, winter-specific IEC, and strengthened last-mile delivery** can ensure that clean-cooking gains translate into durable usage shifts and sustained reductions in household air pollution and BC emissions across Himachal Pradesh.

Solid Waste Management Sector:

The **solid waste management sector** is a growing contributor to climate and air pollution in Himachal Pradesh, driven primarily by rising **methane (CH_4)** emissions from unmanaged municipal solid waste (MSW) and legacy dumpsites, alongside **N_2O** emissions from wastewater systems. Kangra, Mandi, and Shimla together account for nearly half of MSW-related methane emissions in the state. With most towns and rural blocks still dependent on **open dumping,** waste undergoes uncontrolled anaerobic decomposition, resulting in elevated methane generation—an issue that is worsening as waste volumes increase annually. The challenge is compounded by Himachal's **mountainous terrain and cold climatic conditions,** which hinder efficient collection, reduce processing efficiency for organic waste, and make sanitary landfill development technically and financially demanding. Although the state has a strong policy framework aligned with the **SWM Rules, PWM Rules, and EPR Guidelines,** implementation on the ground remains uneven. Urban areas have approximately **50 Material Recovery Facilities (MRFs)** across 68 ULBs, but the **3,708 Panchayati Raj Institutions (PRIs)** that generate a significant share of the state's waste lack comparable processing infrastructure. This urban–rural infrastructure gap—combined with limited source segregation, constrained institutional capacity, and weak financial incentives—continues to drive high methane emissions and hinders Himachal's transition to a scientifically managed, low-emission waste system.



EXISTING POLICIES

- **State Solid Waste Management Strategy (2019):** Provides guidance on segregation, processing, sanitary landfills, and cluster-based infrastructure.
- **SWM Rules (2016) & PWM Rules:** Mandate segregation, processing of organic waste, landfill gas (LFG) capture, and extended producer responsibility.
- **Environmental Cell for Urban Waste Management (2024):** Institutional mechanism for coordination, planning, and monitoring of urban waste systems.
- **Door-to-door Collection & Cluster Sanitary Landfill Guidance:** Policy emphasis on decentralized collection and scientific disposal.
- **State Energy Policy (2021):** Enables waste-to-energy, biogas, and renewable energy offtake.
- **EPR Framework for Plastics:** Supports material recovery through producer responsibility, though rural coverage remains limited.

RECOMMENDATIONS

Himachal Pradesh's waste sector continues to face challenges of uneven source segregation, limited rural material recovery, open dumping at legacy sites, and underperforming methane controls—particularly in hill towns and peri-urban areas. While the State Solid Waste Management Strategy (2019), SWM Rules, Plastic Waste Rules, and the recently created Environmental Cell for Urban Waste Management (2024) provide a strong policy foundation, implementation remains fragmented, technology choices are often not climate-optimised, and investments are not always prioritised based on methane-reduction potential.

To optimise public investment and maximise methane abatement, the state should institutionalise dumpsite- and landfill-wise Life-Cycle Assessments (LCAs) for all major disposal sites, and use these assessments to prioritise the **ALT Scenario 4 pathway (MRF + decentralised composting + sanitary landfill) where it demonstrates the lowest lifecycle emissions per rupee invested.** A state-led LCA exercise, starting with large sites such as Baddi, would allow Himachal Pradesh to rank sites based on climate and environmental impact and direct limited capital toward the most effective diversion pathways. This approach aligns with national and international evidence that decentralised treatment of organics combined with controlled disposal significantly reduces methane compared to transport-heavy or landfill-dependent systems.

To strengthen front-end waste management, the state should move from a compliance-only approach on source segregation to an operational performance model, linking segregation outcomes to tiered user charges or incentives, and institutionalising decentralised door-to-door collection managed by SHGs or Gram Panchayats. Financing village-level collection points and providing sustained capacity-building for local community groups will ensure that segregated waste is reliably collected and delivered to downstream facilities. This recommendation draws from the **Nathuwala (Dehradun) integrated decentralised sanitation park model,** which demonstrated that ward-level MRFs combined with local composting can achieve near-zero-waste outcomes at low cost while creating local livelihoods—an approach highly suited to Himachal's hill towns and peri-urban settlements.

For organic waste, Himachal Pradesh should adopt a climate-adapted processing strategy, scaling cold-adapted aerobic composting in high-altitude districts and biomethanation in larger urban centres such as Shimla, Kangra, and Mandi, with clear diversion targets of 50% by 2030 and 80% by 2047. Support mechanisms should include capital subsidies, R&D funding for cold-adapted microbial consortia, and assured energy or Bio-CNG off-take through RPOs and SATAT-linked mechanisms.

To address legacy methane emissions, the state should strengthen enforcement of Landfill Gas (LFG) capture mandates under the SWM Rules by introducing capacity thresholds, targeted capital support, and assured power or gas off-take for LFG-to-energy projects. Drawing on national and international assessments—including IEA-supported evaluations of landfill methane potential in India—Himachal can prioritise LFG capture at larger, stabilised dumpsites where gas yields justify investment, translating regulatory mandates into real climate and renewable energy outcomes.

Rural material recovery remains a critical gap. While urban areas are served by approximately 50 MRFs, PRIs lack systematic access to recovery infrastructure or data visibility. Himachal Pradesh should strengthen Extended Producer Responsibility (EPR) implementation by linking village-level collection points to existing cluster MRFs, formalising the role of informal waste collectors and SHGs, and introducing producer-funded incentive mechanisms for verified recyclable collection. This recommendation responds directly to evidence that rural waste in Himachal is often uncollected or dumped due to weak integration with formal systems. Improved material flows will reduce landfill volumes, lower methane generation, and create rural livelihoods.

Best practices within the state further reinforce this pathway. **Shimla Municipal Corporation's planned transition toward decentralised composting, local MRFs, and staged transport to sanitary facilities** demonstrates how hill cities can manage waste within terrain constraints while minimising methane and transport impacts. Similarly, regional experiences such as **Punjab's biomass and pellet value chains** show how organic and residual waste streams can be converted into usable fuels, offering Himachal a complementary pathway for managing forest residues and certain organic fractions while reducing open burning and fossil fuel use.

Taken together, LCA-based investment prioritisation, decentralised segregation and processing, climate-adapted organic waste technologies, strengthened LFG capture, and rural MRF integration form a coherent waste-sector pathway that is both methane-focused and implementation-ready for Himachal Pradesh's hill-state context.

POTENTIAL HURDLES

- **High technical and financial requirements** for conducting robust LCAs and climate-informed modelling.
- **Political and institutional resistance** to ranking or deprioritising certain dumpsites or districts.
- **Public compliance fatigue with segregation enforcement:** penalties may face local resistance.
- **Capacity constraints among ULBs, PRIs, and SHGs** to monitor segregation, operate facilities, and maintain systems.
- **Operational risks in cold climates,** including slower composting and reduced biogas yields.
- **Market and offtake uncertainty** for compost, biogas, Bio-CNG, and LFG electricity, affecting financial sustainability.
- **Land availability, rights issues, and community opposition** to new processing or LFG infrastructure.
- **Higher rural logistics costs and challenges** in formalising informal waste workers under EPR systems.

Way Forward:

The waste sector in Himachal Pradesh requires a shift from compliance-oriented planning to a **methane-first, lifecycle-optimised implementation approach,** building on the State SWM Strategy (2019), national waste rules, and the Environmental Cell for Urban Waste Management. Institutionalising **site-specific Life-Cycle Assessments (LCAs)** for dumpsites and landfills can guide investments toward pathways that deliver the highest methane reductions per rupee—particularly decentralised combinations of **MRFs, composting, and sanitary landfilling,** as demonstrated in models such as **Nathuawala (Dehradun)** and emerging practices in Shimla. Strengthening front-end segregation through community-led door-to-door systems, performance-linked user charges, and SHG engagement can ensure that downstream infrastructure functions effectively, while **climate-adapted organic waste technologies—**cold-adapted composting in high-altitude areas and biomethanation in larger towns—can address Himachal's terrain and temperature constraints. Legacy methane emissions must be tackled through targeted **landfill-gas capture with assured energy off-take,** while rural waste gaps can be bridged by linking village-level collection to cluster MRFs under EPR-backed financing. Implementation risks—such as technical capacity gaps, financing constraints, and public acceptance—can be mitigated through phased targets, demonstration projects, and convergence of climate, urban, and renewable-energy funding, ensuring a resilient and context-appropriate waste transition.

Diesel Generator Set Sector:

Diesel generator (DG) sets are a significant source of local air pollution and BC emissions in Himachal Pradesh, particularly in urban centres, commercial establishments, telecom infrastructure, healthcare facilities, construction sites, and tourism-intensive districts. DG usage is driven less by lack of grid access and more by **precautionary backup during outages, peak demand periods, and extreme weather events,** with higher runtime observed in urban and high-growth districts such as Shimla, Kangra, Solan, and Kullu. While the electricity grid has expanded substantially, seasonal supply disruptions and reliability concerns—especially during winter months and monsoon-related events—continue to sustain DG dependence.

Existing regulatory frameworks, including CPCB emission and noise standards (TREM-IV+), focus primarily on **certifying new DG sets and enforcing emission limits,** rather than addressing emissions from the large stock of in-use and legacy generators or reducing overall runtime. State-level energy and climate policies emphasise clean energy transition and efficiency but do not explicitly integrate DG usage as a priority source of short-lived climate pollutants. As a result, **deployment of mitigation measures such as Retrofit Emission Control Devices (RECDs)** and systematic DG runtime reduction strategies remains limited, fragmented, and largely compliance-driven.

Persistent challenges include limited monitoring of DG runtime and fuel consumption, weak enforcement capacity for in-use emissions, high costs and low awareness of RECD retrofitting options, and coordination gaps across power utilities, pollution control authorities, urban local bodies, and tourism departments. Consequently, despite improved grid coverage and national emission norms, DG sets continue to contribute disproportionately to particulate and BC emissions in Himachal Pradesh, underscoring the need for an integrated DG mitigation and transition pathway aligned with the state's air-quality, heat-risk, and SLCP objectives.

EXISTING POLICIES

- **CPCB DG Set Emission & Noise Standards (TREM-IV+)** – National standards regulating PM, NO_x, and noise emissions from diesel generator sets.
- **Himachal Pradesh Energy Policy (2021)** – State policy guiding the transition toward cleaner energy systems and reduced fossil-fuel dependence.
- **HPSEBL Grid Reliability & Distribution Strengthening Measures** – Ongoing initiatives to improve electricity supply stability and reduce outage frequency.
- **BEE Energy Efficiency Programmes (ECBC, UJALA, etc.)** – National schemes aimed at reducing electricity demand through efficient appliances and building standards.
- **Urban Local Body, Tourism & Construction Guidelines** – Local regulations governing power use, DG operation, and temporary energy needs in urban and tourist areas.

RECOMMENDATIONS

Himachal Pradesh should adopt a DG emissions mitigation and transition pathway that combines strict enforcement of emission standards with accelerated deployment of Retrofit Emission Control Devices (RECDs) for in-use DG sets, particularly in urban areas, commercial establishments, telecom infrastructure, hotels, hospitals, and tourist hubs. RECD retrofitting should be prioritised for high-runtime and legacy DG sets, alongside DG runtime reduction measures enabled through grid reliability improvements and demand-side energy efficiency. Embedding DG runtime and RECD penetration as measurable indicators within the state's air-quality, heatwave, and SLCP frameworks can directly link power-backup management to reductions in BC and particulate emissions. Over time, this approach can enable a phased transition where DG sets move toward last-resort usage, with RECDs serving as an interim mitigation tool where immediate displacement is not feasible.

POTENTIAL HURDLES

- **High upfront and recurring costs associated with RECD installation, operation, and maintenance, particularly for small commercial users**
- **Limited awareness and confidence in RECD performance and durability under diverse operating conditions**
- **Monitoring and verification challenges related to DG runtime, fuel use, and post-retrofit emission reductions**
- **Capacity constraints within Pollution Control Boards and urban local bodies for enforcement and compliance tracking**
- **Coordination challenges across power utilities, pollution control authorities, urban development agencies, and tourism departments**

Way Forward:

Himachal Pradesh's DG set mitigation strategy should move beyond compliance-based emission standards toward an **integrated emissions management and transition pathway** that prioritises reductions in BC and particulate emissions from in-use generators. This requires **targeted retrofitting of high-runtime and legacy DG sets with Retrofit Emission Control Devices (RECDs)** in urban centres, commercial establishments, telecom infrastructure, healthcare facilities, and tourism hubs, alongside measures to **progressively reduce DG runtime** through improved grid reliability and demand-side energy efficiency. Embedding DG runtime reduction and RECD penetration as measurable indicators within the state's SAPCC, HWAP, and SLCP action frameworks can strengthen accountability and align backup power management with climate and air-quality goals. Phased implementation—supported by prioritised enforcement, streamlined compliance mechanisms, and capacity-building for regulators and local bodies—can address monitoring and institutional constraints, ensuring that DG sets are progressively relegated to last-resort use while delivering near-term reductions in BC emissions across Himachal Pradesh.

Cross-Sectoral Interventions

Building on the sectoral recommendations, Himachal Pradesh has an opportunity to adopt integrated, cross-sectoral strategies that leverage synergies across livestock, waste, transport, residential energy, and industry. The state's unique geography, dispersed settlements, biomass dependence, and livestock-dominated districts call for solutions that are locally adapted and mutually reinforcing.

Dry biomass and crop residues, which contribute to BC and methane emissions when burned, can be aggregated for decentralized biogas, compressed biogas (CBG) production, or biomass energy generation. Districts such as Mandi, Kangra, and Chamba—with high livestock populations and crop residue availability—offer strong potential for these transitions. Biogas slurry and compost generated from such systems can be reused in agriculture, creating a circular model that enhances soil health, reduces synthetic fertilizer use, and improves rural livelihoods.

Urban and peri-urban waste streams present another integration opportunity. Cities like Shimla, Solan, and Dharamshala can scale up material recovery facilities (MRFs), decentralized composting, and cold-adapted digestion technologies for high-altitude areas like Lahaul-Spiti and Kinnaur. Dry waste fractions can be converted into refuse-derived fuel (RDF) for co-firing in local industries, reducing both methane from landfills and BC from fossil fuel substitution. Integration of decentralized energy generation with EV charging infrastructure—particularly in tourist hubs such as Manali and Dharamshala—can further link waste management, clean transport, and energy efficiency.

Industrial clusters in Sundernagar, Baddi, and Kala Amb can adopt complementary mitigation pathways: fuel switching to green hydrogen, waste heat recovery, and biofuel co-firing alongside emission controls like wet scrubbers. These interventions can be coordinated with transport and energy measures to maximize co-benefits, including reduced air pollution and enhanced climate resilience.

Residential energy use also offers cross-sectoral synergies. Promotion of solar cookstoves and continued LPG access in biomass-reliant districts such as Kangra, Bilaspur, and Chamba can reduce indoor air pollution and deforestation pressures. Bundling clean energy solutions with natural farming or waste-to-compost initiatives can further strengthen adoption while generating local employment.

Institutional Capacity and Financing

Effective SLCP mitigation in Himachal Pradesh can be advanced by leveraging existing institutional systems while mobilising targeted new climate finance. The Department of Environment, Science, Technology & Climate Change (DESTCC), as the state's nodal climate agency, can anchor SLCP integration within departmental plans and district processes, building on cross-sectoral planning and capacity-building approaches already operationalised under initiatives such as the Himachal Pradesh Integrated Development Project (HPIDP). Strengthening planning and implementation through ULBs, Panchayati Raj Institutions, and line departments—supported by standardised toolkits, digital decision-support systems, and training—aligns with the state's established environmental governance frameworks, including the Environmental Assessment and Management Framework. Financing for SLCP actions can combine centrally sponsored schemes with new investments through multilateral and climate finance, drawing on lessons from ADB-supported institutional strengthening initiatives ADB Project Documentation and the World Bank–supported Himachal Pradesh Public Financial Management Capacity Building Programme. Complemented by climate budget tagging and public–private partnerships, this approach can ensure SLCP interventions are scalable, well-tracked, and sustained beyond individual project cycles.

Community Engagement and Innovation

Behavioral change will be central to achieving SLCP reduction. Himachal's network of self-help groups, eco-clubs, and women's collectives can lead campaigns on waste segregation, adoption of clean cooking technologies, and discouraging open burning. Multilingual, culturally sensitive awareness campaigns, combined with demonstration projects and district champions, can accelerate adoption and scale impact.

Technology innovation should be localized and cold-climate appropriate. Collaborations with IIT Mandi, CSKHPKV Palampur, Dr. YSPUHF, and startups can advance solutions such as compact digesters, biochar units, cold-region composting, and wildfire-resilient land management technologies. Pilot demonstration zones can serve as testing grounds, catalyzing replication across districts.

Monitoring and Governance

A robust Monitoring, Reporting, and Verification (MRV) system for methane, BC, and HFCs will be essential. Expanding the role of the State Pollution Control Board (SPCB) to include SLCP-specific tracking, hotspot mapping, and integration of data into climate dashboards can strengthen accountability. Formal inter-departmental mechanisms—spanning DESTCC, Forest, Rural & Urban Development, Transport, Animal Husbandry, and Energy—will ensure coordinated planning, resource alignment, and capture of cross-sectoral co-benefits.

By pursuing district-focused, capacity-driven, and innovation-enabled strategies, Himachal Pradesh can emerge as a model hill state for integrated SLCP mitigation. Coordinated governance, cross-sectoral collaboration, and community engagement will enable the state to deliver cleaner air, resilient ecosystems, and sustainable development—benefiting both urban centers and remote rural communities.

Annexure

Residential

The basic equation employed for emission estimation from the residential sector is,

$$E_p = \sum_{a=1}^{n}\sum_{f=1}^{6} Pop_{(a,f)} \times C_{(a,f)} \times EF_{(f,p)}$$

Where, $[E_p]_R$ is the emission of a particular pollutant (p) from the residential sector, $Pop_{(s,f)}$ is the population using a particular fuel (f), $C_{(s,f)}$ = State specific per capita consumption of a particular fuel for cooking activity, $EF_{(f,p)}$ = Emission factor of the particular pollutant (p) of the particular fuel type (f). Six major fuels that are used in residential households for cooking purposes are included in this emission inventory preparation – a) Fuel wood, b) dung cake, c) crop residue, d) coal, e) kerosene and f) LPG. Population of Himachal Pradesh during 2019 were estimated based on district level registered birth and death data during 2013 to 2019 provided by the state government of Himachal Pradesh.

State specific monthly per capita consumption of different fuels (Cs,f) in the rural and urban areas of Himachal Pradesh is taken from NSSO (2014) report. Electricity used in the residential sector has no reported emission of air pollutants, so it is not considered during the preparation of present emission inventory.

NSSO (2014) reports household consumption of various amenities during 2011-2012. However, there is significant growth in household LPG usages after 2011, these affects the biomass, and kerosene uses pattern in the residential sector. The biomass and kerosene consumption and use in the residential sector in 2019 were re-estimated by incorporating the growth rate of LPG consumers.

District level LPG consumers **(2015 to 2019)** information provided by Food, Civil Supplies and Consumer Affairs department, Government of Himachal Pradesh were used to estimate the growth trend of LPG usage in the state. Accordingly, an annual LPG consumer growth of 5.90% has been considered for Himachal Pradesh. The increase in the number of households using LPG is then uniformly distributed to adjust the amount of fuelwood, crop residue, dung cake and kerosene using households during 2019. Fuel specific emission factors of different pollutants (EF(f,p)) are taken from Datta and Sharma (2014) and Pandey et al. (2014). Despite significant improvement in LPG connection, about 50% of rural households in Himachal Pradesh were still dependent on traditional biomass fuel (majorly fuelwood) as primary energy source to meet the cooking needs.

Table 30: Emission factors (g/kg) of different pollutants from different fuel types used in the residential sector

Pollutant	Fuelwood	Crop Residue	Dung Cake	Coal	Kerosene	LPG
$PM_{2.5}$	4.6	5.7	4.4	4.04	3	0.35
PM_{10}	6.77	8.6	10.5	8.26	3.6	0.35
SO_2	0.8	0.7	0.6	15.33	0.4	0.4
NO_x	1.7	1.8	1	2.16	1.3	2.9
CO	66.5	64	78.6	59.46	43	2
NMVOC	15.89	8.5	24.1	10.5	17	19*
BC	0.4	0.3	0.4	0.00826	0.6	
CH_4**	5.16	4.32	6.65	4.4	0.56	0.28

** Pandey et al. (2014); others were adopted from Datta and Sharma (2014)*

*NA: Not available; ** Danish Emission inventories for stationary combustion plants 2018, Danish Centre of Environment and Energy*

Estimated Fuel consumption

Annual consumption of different types of fuels for cooking activity in the residential households of Himachal Pradesh during 2019 is illustrated in Figure 1. Fuel specific consumption pattern revealed that fuel wood is majorly used as an energy source in residential households for cooking activity followed by LPG. Annual consumption of fuel wood and LPG was estimated as 1299.88 kt and 60.53 kt respectively. While annual consumption of crop residue and kerosene were estimated as 0.13 kt and 0.20 kt respectively.

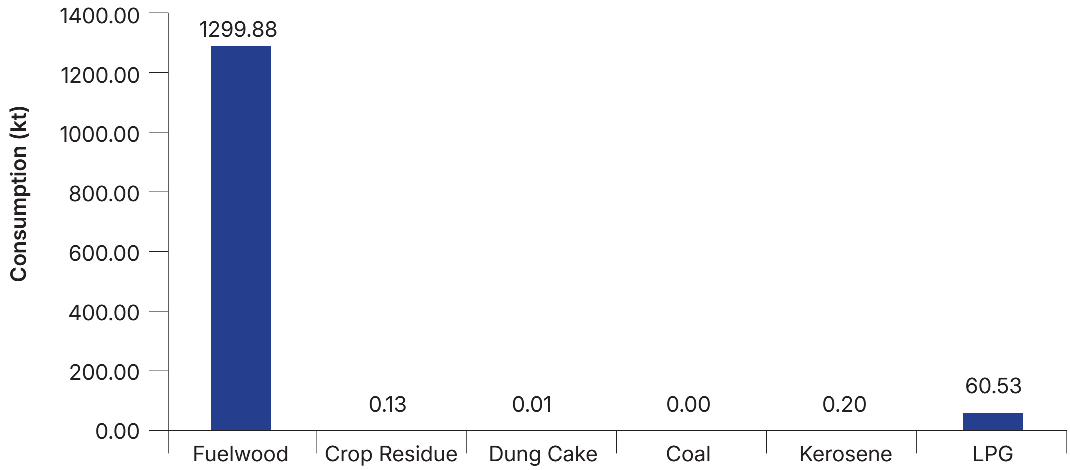


Figure 32: Estimated annual consumption of different types of fuel for cooking activity in the residential households of Himachal Pradesh during 2019

Estimated emission of different pollutants

The activity data of different fuels is fed into the above equation along with the fuel specific emission factors of different pollutants ($EF_{(f,p)}$) (**Table 30**) to calculate the emission (kt) of different pollutants from the use of different fuel types in residential households of Himachal Pradesh during 2019.

Table 31: Emission (kt) of different pollutants from the residential cooking activity in Himachal Pradesh

Pollutant	Fuelwood	Crop Residue	Dung Cake	Coal	Kerosene	LPG
$PM_{2.5}$	5.98	0.00	0.00	0.00	0.00	0.02
PM_{10}	8.80	0.00	0.00	0.00	0.00	0.02
SO_2	1.04	0.00	0.00	0.00	0.00	0.02
NO_x	2.21	0.00	0.00	0.00	0.00	0.18
CO	86.44	0.01	0.00	0.00	0.01	0.12
NMVOCS	20.66	0.00	0.00	0.00	0.00	1.15
BC	0.52	0.00	0.00	0.00	0.00	0.00
CH_4	6.71	0.00	0.00	0.00	0.00	0.02

Transport Sector

The equation to estimate vehicular tailpipe emission in the transport sector is,

Where, Ep is the total emission of a pollutant (p); c is the type of vehicle; s is the emission control norm (BSI to BSIV); VKT is the daily Vehicle Kilometre travelled by vehicle type c; *EF* is the emission factor of pollutant p and ε is the percentage of vehicle under an emission control norm (s) and n is the total number of vehicles in vehicle type c. The methodology of calculating emissions from the sector is explained in **figure**

$$E_p = \sum_{c=1}^{n}\sum_{s=1}^{4} VKT_{c,s} \times EF_{c,s,p} \times \varepsilon_{c,s} \times n_c$$

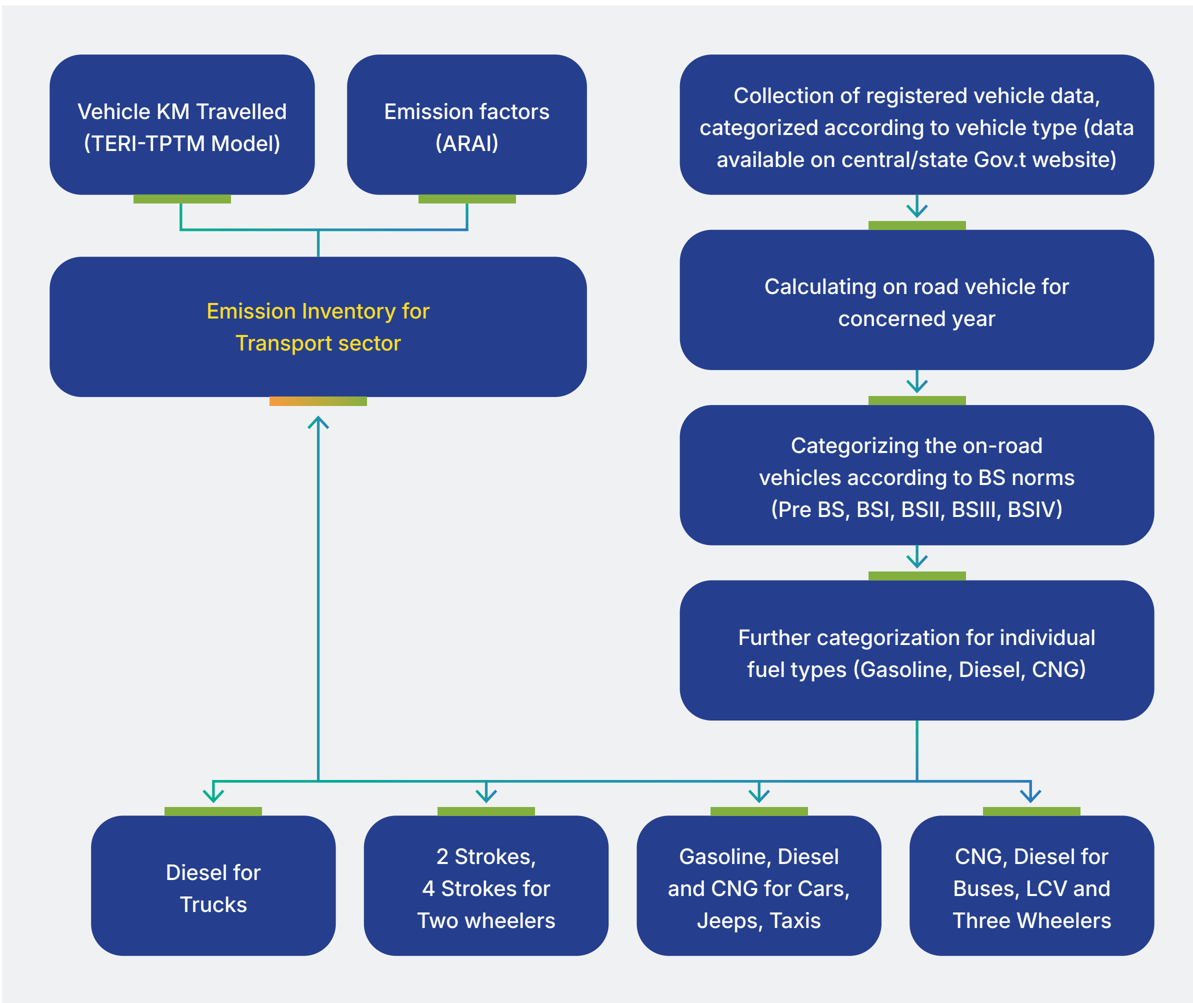


Figure 33: Methodology for estimating emissions from the transport sector

The estimated state level annual Vehicle Kilometre Travelled (VKT) of different categories of vehicle during 2019 was adopted from the TERI-Transport Model (TERI-TPTM) (Table 19). The model first estimates the total transport demand in Himachal Pradesh, which is an aggregation of the projected passenger and freight demand, defined as the annual Billion Passenger Kilometres (BPKM) and Billion Tonne Kilometres (BTKM) respectively.

Passenger Demand (BPKM): For arriving at the total passenger demand a multi- step approach is followed. Firstly, the vehicle ownership is projected based on socio-economic variables such as GDP and population. The vehicle ownership is then disaggregated for urban and rural areas. Further, based on the assumptions of fuel type, fleet utilisation and vehicle occupancy for different vehicle segments (two wheelers, three wheelers, four wheelers, buses and rail) the annual BPKM is calculated for both urban and rural areas separately. Lastly, the total annual BPKM at pan India level is arrived at by the summation of urban and rural BPKM.

Freight Demand (BTKM): For arriving at the total freight demand, a similar approach is followed with the differentiating factor being the consideration of sectorial GDP in the estimation of commercial vehicle ownership. The total annual BTKM is computed as an aggregation of BTKMs of LCVs and HCVs.

Table 32: TERI-TPTM Model Simulated Daily VKT of Different Types of Vehicles

VKT (Km/day)	2W	3W	Car	LDV	HDT	HDB
2019	23	135	61	81	237	191

2W: 2-wheeler; 3W: 3-wheeler; LDV: Light Duty Vehicle; HDB: Heavy Duty Bus; HDT: Heavy Duty Truck.

It was assumed that, after introduction of one BS emission norm, the vehicles under lower BS emission norm were not sold in the market. The lifespan for private (2W, 3W, Cars) and commercial (Trucks, Buses, LMV, Tractors) vehicles was assumed as 15 and 20 years, respectively. This was used to estimate the total number (n) of different types of vehicles under different emission norms during a particular year from the cumulative annual registered vehicle data published by the MoRTH (2020) for Himachal Pradesh. The emission factors (EF) of PM_{10}, $PM_{2.5}$, NO_x, SO_2, hydrocarbon, CO, BC, and CH_4 for this exercise were adopted from ARAI (2008) and IPCC (2006).

Table 33: Emission Estimates in kt/year from the Transport Sector in Himachal Pradesh

Vehicle Type	PM_{10}	$PM_{2.5}$	BC	NO_X	SO_2	NMVOCs	CO
Truck	4.03	3.90	2.74	75.61	0.26	37.67	21.27
Tractor/Trailer	0.52	0.50	0.35	9.35	0.02	3.11	2.60
Bus	0.41	0.40	0.28	8.39	0.44	0.29	3.05
Cars	0.49	0.47	0.33	12.35	0.29	3.50	12.36
MUVs	0.21	0.21	0.15	2.89	0.00	0.46	1.21
2 wheelers	4.52	4.38	3.07	41.49	0.12	61.67	90.80
3 wheelers	0.25	0.23	0.17	1.65	0.18	0.68	1.69
LCVs	2.35	2.27	1.59	35.55	0.40	8.53	16.35
Totals	12.8	12.4	8.7	187.3	1.7	115.9	149.3
	CH_4 (Estimated based on fuel's calorific value)						
Transport	3.2						

Industry Sector

The approach for estimating emissions from the industrial sector used in this study is based on the activity data of fuel consumption in the manufacturing processes and the type of fuel consumed. Emissions of PM_{10} & $PM_{2.5}$, SO_2, NO_x, NMVOCs, BC, and CH_4 into the ambient atmosphere mainly occur during combustion. The data concerning fuel consumption and the APCDs installed is obtained from the MPPCB, providing a comprehensive insight into fuel usage patterns in the industrial sector.

The emissions from the industrial sector are estimated using the fuel consumption data and emission factor; the following is the equation to estimate industrial emissions:

$$E_p = C_f \times_{(f,p)} \times (1-\eta)$$

Where $\mathbf{E_p}$ represents the emission of pollutants **p**, $\mathbf{C_f}$ is the fuel consumption in the industry, **EF** is the emission factor of the pollutant **p** of the fuel consumed **f**, and **η** denotes the efficiency of the APCD deployed in a specific industry. By systematically assessing industrial emissions, this study aims to provide insights into the air pollution challenges in Himachal Pradesh and support the development of effective air quality mitigation strategies.

Estimated Fuel consumption

The industries in Himachal Pradesh primarily rely on coal as the dominant fuel source, indicating a strong dependence on high-carbon energy for industrial operations. Biomass also accounts for a significant share, suggesting the utilization of locally available organic fuel sources. The usage of petroleum-based fuels such as furnace oil, light diesel oil (LDO), and high-speed diesel (HSD) contribute minimally to the overall fuel mix. The use of cleaner alternatives like liquefied petroleum gas (LPG) and piped natural gas (PNG) remains negligible, indicating limited penetration of low-emission fuels in the region. This fuel consumption pattern underscores the need for policy interventions to encourage cleaner energy adoption and reduce industrial emissions in the state.

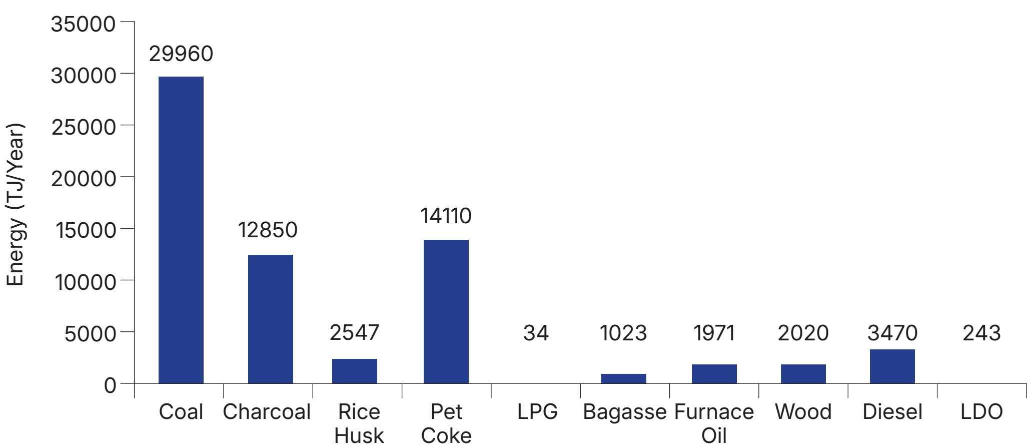


Figure 34: Estimated annual consumption of various types of fuel in the industry sector of Himachal Pradesh during 2019

The manufacturing industries in Himachal Pradesh display a diverse fuel consumption profile, with coal being the dominant energy source, accounting for approximately 44% of the total energy consumption. This significant dependence on coal plays a major role in contributing to air pollution and greenhouse gas emissions in the state. Petroleum coke (pet coke) is the second-largest energy source, contributing 21%, followed by charcoal at 19%, indicating continued reliance on high-emission and biomass-based fuels. Diesel accounts for 5%, while other liquid fuels like furnace oil (3%) and Light Diesel Oil (LDO) (0.4%) are used in smaller quantities for specific industrial processes. Biomass-based fuels, including charcoal (19%), wood (3%), bagasse (1%), and rice husk (4%), together make up approximately 27% of the total energy consumption, reflecting moderate uptake of renewable sources. However, their combustion still poses significant air quality challenges depending on combustion efficiency and emission controls. Other fuels such as LPG (0.05%) make up a negligible share, underscoring limited adoption of cleaner alternatives in the industrial energy mix. The fuel use pattern underscores an urgent need for a transition to cleaner energy options and enhanced fuel efficiency strategies in Himachal Pradesh's industrial sector to mitigate adverse environmental and health impacts.

Estimated emissions of different pollutants

The activity data of different fuels is fed into above equation (1) along with the fuel specific emission factors of different pollutants ($EF_{(f,p)}$) **(Table 33)** to calculate the emission (kt) of different pollutants from the use of different fuel types used in the industries of Himachal Pradesh during 2019.

Table 34: Emission Factors (Kg/t), (Kt/PJ), (T/PJ) of Different Pollutants from Different Fuels Used in Industries in Himachal Pradesh

Emission Factor (Kg/t)	Pet Coke	Charcoal	Wood	Diesel	Furnace Oil	Natural gas	LPG	Coal	LDO	Rice Husk	Bagase
PM_{10}	3.73	200	17.3	0.24	2.592	0.0001216	2.1	187.6	0.24	5.3	8.1
$PM_{2.5}$	2.13	70	15.743	0.216	1.73664	0.0001216	2.1	65.66	0.216	3.445	5.265
SO_2	13.46	9.75	0.2	9.405	37.68	0.0000096	0.4	9.75	33.858	0.11	0.18
NO_X	3.82	12	1.3	1.2	6.6	0.0016	1.8#	4.5	1.2	0.19	0.36
CO	2.73	160	126.3	0.6	0.6	0.001344	0.252#	0.3	0.6	14.05	12.39
VOCs* (kT/PJ)	0.01	0.01	0.015	0.004	0.005	0.003	0.002	0.01	0.004	0.015	0.048
BC* (T/PJ)	0.519	0.519	8	0.11	0.744	0.007	0.013	4	0.11	14.2	14.2
CH_4* (kT/PJ)	0.01	0.01	0.01	0.003	0.003	0.0471	0.001	0.001	0.003	0.003	0.011

Sources: SA Six cities, CPCB, Coal: based on ash content and sulphur content for PM and SO_2, Rice Husk: M Irfan et.al 2014, *Gains Asia, #$Kg/10^6\ m^3$

Emissions (Kt/year) of various pollutants for different fuels from Industries in the state of Himachal Pradesh are shown in **Table 34**

Table 35: Emission Estimates in kt/year from the Industry Sector in Himachal Pradesh

	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	VOC	NMVOC	BC	CH_4
Coke	0.03	0.02	5.34	1.52	1.08	0.25	0.13	0.01	0.13
Charcoal	0.14	0.08	0.03	0.03	0.43	0.00	0.00	0.00	0.00
Wood	0.18	0.20	0.01	0.04	4.07	0.04	0.01	0.01	0.04
HSD	0.00	0.00	0.20	0.03	0.01	0.01	0.00	0.00	0.00
FO	0.02	0.02	1.09	0.19	0.02	0.01	0.01	0.00	0.00
LPG	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Coal	9.44	3.31	7.12	4.75	0.34	0.33	0.30	0.12	0.03
LDO	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Rice husk	0.01	0.02	0.02	0.04	2.61	0.04	0.03	0.03	0.01
Bagasse	0.03	0.02	0.00	0.01	0.20	0.02	0.01	0.00	0.00

Diesel Generator Set Sector

According to the Ministry of Petroleum and Natural Gas report 2021, diesel consumption in Himachal Pradesh increased at a compound annual growth rate (CAGR) of 5.45% during 2008 to 2019. Estimates from the Petroleum Planning and Analysis Cell (2021) indicate that approximately 2.5% of total diesel consumption is attributable to diesel generator (DG) sets, highlighting their role as a key source of backup power across sectors.

To improve the accuracy of activity data, DG set capacity, fuel use, and operating characteristics were compiled directly from Regional Office (RO) records, providing a bottom-up basis for estimating emissions from industrial, commercial, telecom, and residential DG installations. This primary data collection helped address limitations associated with relying solely on secondary statistics and enabled a more realistic representation of DG set usage patterns within the state.

Emission estimates for the 2019 baseline year were developed using RO-based diesel consumption data in combination with pollutant-specific emission factors from established literature, including AP-42 (USEPA), Bond et al. (2004) for BC (BC), and the IPCC AR6 guidelines for methane (CH_4).

Further, emissions are estimated using equations X and Y.

$$E_d = F_d \times Cal_d \quad \text{eq. X}$$

$$E_{DG} = E_d \times EF \quad \text{eq. Y}$$

Where, E_d is the total energy equivalent of the diesel fuel consumed by DG sets annually, F_d is total fuel consumed by DG sets annually, Cal_d is the calorific value of diesel which is 45.5 MJ/Kg.

Tailpipe emission control devices and technologies are not included in current emission estimates. According to expert interviews and literature reviews, there is limited data on the number of diesel generator sets equipped with these devices. But better devices to control emissions from exhaust pipes have been made and are expected to be used more in the future and accounted in Alternative scenario for all the sectors except agriculture pumps. Pollutant-wise emission factors represented in Table 35

Table 36: Emission factor for DG sets as per AP-42, USEPA, Bond et al. 2004 and AR6 report

Pollutants	Emission Factor (g/Joule of energy)
PM_{10}	133.3
$PM_{2.5}$	113.31
SO_2	124.7
NO_x	1896.3
CO	408.5
NMVOCs	154.8
CH_4	3
BC	74.8

*Conversion of ng/J → g/Kg = 0.0036

Emissions for various pollutants in the state of Himachal Pradesh are shown in Table 36.

Table 37: Emissions (Kt/year) from the operation of diesel generators in different sectors in Himachal Pradesh state during the year 2019.

	PM_{10}	$PM_{2.5}$	SO_2	NO_x	CO	NMVOC	CH_4	BC
Commercial	0.01	0.01	0.01	0.18	0.04	0.02	0.00	0.01
Construction (Stone crushers +Hot mix plants)	0.01	0.01	0.01	0.20	0.04	0.02	0.00	0.01
Hotels	0.03	0.03	0.03	0.50	0.11	0.04	0.00	0.02
Hydro Power Plant	0.03	0.02	0.03	0.40	0.09	0.03	0.00	0.02
Industry	0.15	0.13	0.14	2.19	0.47	0.18	0.00	0.09
Mobile Towers	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00
Total	**0.24**	**0.21**	**0.23**	**3.48**	**0.75**	**0.28**	**0.01**	**0.14**

Construction and demolition sector

The construction sector acts as a fundamental driver of economic expansion in India, contributing significantly to employment generation and infrastructure development. However, in urban and peri-urban regions, particularly in hilly terrains such as Himachal Pradesh, construction and demolition (C&D) activities significantly degrade air quality at multiple operational stages. A multitude of emission sources contribute to the release of airborne PM, predominantly PM_{10} and $PM_{2.5}$, from processes including site clearance, land excavation, earthwork compaction, and bulk material handling. Additionally, the transportation of construction materials, coupled with the movement of heavy machinery—such as cranes, excavators, dumpers, and bulldozers—further exacerbates ambient PM concentrations.

In hilly terrains like Himachal Pradesh, the dispersion characteristics of PM are modulated by factors such as altitude, wind patterns, and valley inversion effects. The mechanical fragmentation and resuspension of deposited dust on paved roads, induced by vehicular motion and construction logistics, serve as secondary sources of pollution. Notably, the adherence of soil and debris to construction vehicle tires results in significant translocation of sediments onto public roadways, where vehicular turbulence leads to persistent dust resuspension. Furthermore, on-site mechanical operations—including fixture installation, metal fabrication, hammering, grinding, drilling, and grit blasting—substantially elevate localized PM concentrations. The situation is further compounded by the absence of grid electricity at numerous remote construction sites, necessitating an increased reliance on diesel-powered generators (DG sets). The combustion of diesel fuel releases a spectrum of atmospheric pollutants, including carbon dioxide (CO_2), carbon monoxide (CO), sulfur oxides (SO_x), nitrogen oxides (NO_x), and volatile organic compounds (VOCs), aggravating both particulate and gaseous emissions.

Given the fragile ecosystem of Himachal Pradesh, construction activity not only deteriorates air quality but also accelerates soil erosion and destabilizes slopes. Additionally, regions undergoing large-scale infrastructure development, such as hydroelectric power projects and road expansions, exhibit persistent air quality challenges due to sustained emissions from construction-related activities. To mitigate these environmental impacts, stringent regulatory enforcement—such as mandatory dust suppression systems, controlled demolition protocols, and mechanized material handling—must be integrated into project execution strategies. Furthermore, adopting sustainable construction methodologies, including prefabrication techniques and alternative energy sources, could substantially reduce the pollutant load associated with C&D activities in this ecologically sensitive region.

Methodology

The estimation of emissions from the construction sector is based on the total area allocated for construction and demolition activities. For this analysis, the Gross State Value Added (GSVA) of the construction sector in Himachal Pradesh, as reported in the RBI Handbook (2023), is utilized along with the per-acre cost of land to approximate the total area under development. Based on expert consultations, the average construction cost per acre in 2016 was Rs. 984 lakhs. To adjust for inflation, the Construction Cost Index (CCI) obtained from the Construction Industry Development Council (CIDC), India is applied. The CCI uses 2007 as the base year with a reference value of 100 Rupees. This index is employed to derive the inflation adjusted cost per acre for 2019, which is subsequently used to estimate the total area undergoing construction activities and its associated emissions.

After estimating the construction cost per acre, the GSVA for the construction sector is divided by this cost to quantify the total developed area for the base year. The mathematical expression used for the area calculation is described below:

$$A_{ST} = \frac{GSVA_{ST}}{C_a}$$

Where, A_{ST} represents the total area under construction during a year, $GSVA_{ST}$ denotes the Gross State Value Added from construction activities for that year and Ca refers to the construction cost per acre of land for the respective year.

Below mentioned equation is used for emission estimation for construction or demolition sector.

$$E_p = Ac \times T \times Ef$$

Where, E_p signifies the suspended particulate emissions.

Ac = Activity data or total area under construction or demolition

T= Activity duration for construction or demolition for a site

*Rainy months (RM) are not considered in activity duration

Ef = Emission Factor (tons/acre/month)

The emissions of Suspended PM (SPM) from construction activities are estimated using an emission factor of 1.2 tons/acre/month (Source: EPA). As per USBR (2002), PM_{10} emissions resulting from overburden removal and bulldozing during construction account for 35% of the total PM emissions, while $PM_{2.5}$ constitutes 6% of the total SPM (Ahuja et al., 1989; Houck et al., 1989, 1990). The respective emission factors and estimated emissions are detailed in the table below (Table 37).

Table 38: Emission factors and estimated emissions for 2019 for C&D

Year	2019	Emission Factor	SPM	PM_{10}	$PM_{2.5}$
Construction cost (INR Lakhs)	1000	1.2 tons/acre/month	10.61	3.71	0.64
Estimated area under construction (Acre)	884				

Crematoria

Emissions from the cremation sector are estimated based on the total amount of wood used during cremation rituals. Wood consumption is calculated using key demographic factors, including the total population of Himachal Pradesh, the crude death rate, and the proportion of Hindus, Jains, and Sikhs in the state. For the baseline inventory year 2019, population data was taken from the projected population report of the Census, while the religious composition was sourced from Census 2011. The crude death rate (6.5) was obtained from the Sample Registration System (SRS) Bulletin 2020.

The wood consumption per cremation was taken from the NEERI report 2019 (Short Term and Localized Air Pollution Control System). By combining these parameters, the total wood burned was estimated, serving as the foundation for calculating emissions from the cremation sector. Emissions were quantified using equations_X.

Ep = (P2019 X F X DR X 350) X EF

Where P2019 is the total population of Himachal Pradesh, F is the fraction of Hindus, Sikhs and Jains, DR is the crude death rate i.e. 6.5 (per thousand population), EF is the emission factor and 350 is average wood consumption in KG for one cremation.

The emission factors were adopted from Akagi et al. (2011) and the Scientific Report from DCE ***(Danish Centre for Environment and Energy (2018))***. The compiled emission estimates (Kt/year) and emission factors are presented in the following table 37.

Table 39: Emission factor used & Estimated Emissions from Crematoria Sector

Pollutant	Emission factor (G/Kg)	Emissions (Kt/year)
PM_{10}	18.5	3.18
$PM_{2.5}$	9.1	1.56
SO_2	0.4	0.07
No_x	2.55	0.44
CO	93	15.97
NMVOCs	51.9	8.91
BC	0.52	0.07
CH_4	5.16	0.89

Agricultural Residue Burning

Emission inventory of different pollutants from the burning of different crop residues in the cropland has been developed by following the IPCC (2006) inventory preparation guideline. The primary crops considered for inventory preparation are rice, wheat, maize, sugarcane and cotton. These crops have been selected as they are prone to burning across the country, as mentioned in different published literature along with National Policy for Management for Crop Residues (NPMCR). Emission from the in-situ burning of crop residue is calculated using the equation below,

$$\text{Epol} = \sum_{S=1}^{35} \sum_{D=1}^{n} \sum_{C=a}^{n} Pa \times Ra \times fDa \times fBa \times EFpol \times \boldsymbol{Bf}$$

Where, Epol = Emission of a particular pollutant (pol) (g); Pa is the total production of a particular crop (C) in a particular district (D) of the state (S) in kilogram (here only Himachal Pradesh has been taken); Ra is the fraction of residue generated for the production (Pa) of the particular crop (a); fDa is the fraction of dry matter in the residue of the particular crop (a); fBa is the combustion efficiency of crop residue that is burnt, Bf is the burning fraction of the crop estimated based on MODIS FRP data, and EFpol is the emission factor of the particular pollutant (g/Kg). Emission estimation equation does not show controls as there are no direct emission control measures for control of agricultural burning emissions at the fields. However, burning fractions are to be reduced by implementing in-situ and ex-situ measures.

The seasonal district-wise production data (Pa) of different crops was collected from the Department of Agriculture Cooperation and Farmers' Welfare (DAC&FW), Ministry of Agriculture, and Government of India for the year 2019. Different crops' residue to crop fractions (Ra) has been replicated as in

Datta and Sharma (2014). The dry matter fraction in different crop residues replicates as reported by Aerosol and Air Quality Research. The combustion efficiency (fBa) of different crop residues is used as reported in Turn et al. (1997) (Table 27).

Table 40: Coefficients of Different Crop Residues to Estimate the Emissions of Different Pollutants

Co-efficient	Rice	Wheat	Cotton	Maize	Sugarcane
Residue to Crop ratio (Ra)a	1.59	1.70	3.00	2.00	0.40
Dry fraction of residue (fDa)b	0.86	0.88	0.80	0.90	0.90
Combustion efficiency (fBa)c	0.89	0.86	0.90	0.92	0.68

[a] Datta and Sharma (2014); b Jain et al. (2014); c Turn et al. (1997)

The burning fraction (Bf) has been calculated from the MODIS Fire Radiative Power (FRP) data. The FRP dataset of the NASA's MODIS (aqua and tera) satellites is also used to identify the crop residue burning locations at grids over the state boundary during crop harvesting seasons of 2019. This is further employed to spatially allocate the emissions. The MODIS active fire products provide fire detections at the satellite overpass times. Terra and Aqua respectively cross the equator at approximately 10:30 a.m. and 1:30 p.m. local time during daytime and 10:30 p.m. and 1:30 a.m. during nighttime. The MODIS Level 2 active fire products (abbreviated MOD14 for Terra and MYD14 for Aqua) contain for each fire pixel the detection time, geographical coordinate, confidence (low, nominal, and high), fire radiative power (units: MW per pixel), brightness temperature at the MODIS band 21 (3.660–3.840 µm) and band 31 (10.780–11.280 µm), and average brightness temperature of the surrounding non-fire pixels at bands 21 and 31. The FRP estimates in MODIS Collection 6 (C6) active fire product are retrieved following the method developed by Wooster et al. (2003). The FRP products retrieved from MODIS C6 datasets were plotted on GIS along with LULC (land use and land cover) MODIS products for the study year. The FRP's detected over agricultural land use area were extracted for further analysis, as it is assumed that rest of the FRP's being detected may represent some other form of burning. This extracted data has been used to estimate yearly FRP detected in each district of the country. The maximum FRP value detected in any district of the country since the availability of the data i.e., 2001 has been assumed where almost 70% of the residue is being burnt.

Estimated methane emissions from rice crop land of Himachal Pradesh during 2019-20 were 0.26 kt. During the estimation of methane emission, it was considered that there were no direct methane emissions from other crops like maize, wheat, sugarcane and Cotton as there was no continuous waterlogging condition during cultivation process of these crops.

Livestock and Manure Management

The formula applied to calculate CH_4 emissions from livestock and manure management is as follows:

$$\textbf{Emissions} = N_{(T)} * EF_{(T)} * 10^3$$

Where, Emissions = methane emissions (kg/year),

$EF_{(T)}$ = emission factor for the defined livestock population, kg CH_4/head/year

$N_{(T)}$ = the number of head of livestock species

T = species/category of livestock

For estimating emissions from livestock and manure management, default IPCC emission factors were applied (Table 39).

Table 41: Emission Factors used for Estimating Emissions from Livestock and Manure Management

Category	Sub-Category	Age Group	Methane Emission Factor	
			Enteric Fermentation (kg CH_4/head/year)	Manure Management (kg CH_4/head/year)
Indigenous Cattle	Dairy Cattle	Indigenous	28.00	3.50
	Non-Dairy Cattle (indigenous)	0–1 year	9.00	1.20
		1–3 years	23.00	2.80
		Adult	32.00	2.90
Crossbred Cattle	Dairy Cattle	Cross-bred	43.00	3.80
	Non-Dairy Cattle (cross-bred)	0–1 year	11.00	1.10
		1–3 years	26.00	2.30
		Adult	33.00	2.50
Buffalo	Dairy Buffalo		50.00	4.40
	Non-Dairy Buffalo	0–1 year	8.00	1.80
		1–3 years	22.00	3.40
		Adult	44.00	4.00
Sheep	Non-Dairy		5.00	0.20
Goat	Non-Dairy		5.00	0.22
Horses and Ponies	Non-Dairy		18.00	2.19
Donkeys	Non-Dairy		10.00	0.90
Camels	Non-Dairy		46.00	2.56
Pigs	Non-Dairy		1.00	4.00
Poultry	Non-Dairy		0.00	0.00

Table 42: Total Agriculture and livestock related Methane Emissions in Himachal Pradesh in 2019 (kt/yr)

District	Cattle Emissions (kt)	Buffalo Emissions (kt)	Paddy Emissions (kt)
Bilaspur	1.42	3.05	0.04
Chamba	8.31	0.76	0.08
Hamirpur	0.63	2.98	0.05
Kangra	9.38	4.10	0.86
Kinnaur	0.71	0.00	0.00
Kullu	4.92	0.04	0.03
Lahul And Spiti	0.37	0.00	0.00
Mandi	11.39	1.96	0.45

District	Cattle Emissions (kt)	Buffalo Emissions (kt)	Paddy Emissions (kt)
Shimla	6.98	0.17	0.02
Sirmaur	7.79	1.13	0.17
Solan	4.15	2.17	0.10
Una	1.91	3.46	0.04

Solid Waste Sector

The waste sector is recognized as a significant source of both greenhouse gases (GHGs) and short-lived climate pollutants (SLCPs). Throughout the municipal solid waste management value chain, SLCPs such as CH_4 and BC are emitted from the point of waste generation to its final disposal. The rate of waste generation is influenced by multiple socioeconomic and demographic parameters, including population density, industrial activity and consumption behavior.

Uncontrolled disposal and open burning of mixed waste leads to the release of PM, BC, SO_x, NO_x, CO, CH_4, and CO_2, which contribute to local air pollution, odor nuisance, leachate contamination, and environmental and public health concerns.

To quantify emissions from the waste sector for the state of Himachal Pradesh, the Solid Waste Emission Estimation Tool (SWEET Version 5.0) developed by the USEPA and the Climate and Clean Air Coalition (CCAC) was utilized. The tool follows the methodological framework outlined in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories (Volume 5 – Waste), tools developed by Environmental Protection Agency (EPA) and Global Methane Initiative (GMI) and provides a standardized framework to estimate both GHGs and SLCPs across the waste management chain.

The tool internally uses emission coefficients from IPCC, EPA, and other peer-reviewed studies to evaluate emissions arising from a) anaerobic decomposition of biodegradable waste in dumpsites and landfills b) open burning of uncollected waste c) combustion in waste-to-energy systems, and d) diesel consumption during collection, transfer, and handling operations.

For landfills and dumpsites, the SWEET model employs an equation derived from the EPA's Landfill Gas Emissions Model (LandGEM) VERSION 3.02. Similarly, emissions from composting and anaerobic digestion are estimated using the default emission parameters embedded within SWEET.

$$Q_{CH4} = \sum_{t=1}^{n} kLo\left(e^{-kt_i}\right)(\mathrm{MCF})$$

Where, a) Q_{CH4}
= maximum expected methane generation flow rate (m^3 /yr), b) i = 1 year time increment, c) n = (year of the calculation) – (initial year of waste acceptance), d) k = methane generation rate (1/yr), e) L0 = potential methane generation capacity (m^3 /Mg), f) M_i = mass of solid waste disposed in the i^{th} year (Mg), g) t_i = age of the waste mass Mi disposed in the i^{th} year, h) MCF = methane correction factor

Emissions from collection and transportation activities are estimated based on vehicle activity data, fuel consumption, and operational characteristics, while open burning emissions are simulated using coefficients integrated within the SWEET tool calibrated for Indian waste compositions.

The tool's emission estimation framework is entirely dependent on its internal database of coefficients, decay constants, and correction factors that are harmonized with IPCC (2006) defaults, EPA tools, and other peer-reviewed studies. Therefore, no external emission factors were applied, and all results presented are derived directly from the SWEET v5.0 model

Emission estimates for the base year 2019, based on the average annual growth rate of 3.97% and SWEET-modeled factors, indicate that the waste sector contributes to non-CO_2 pollutants, especially SLCPs such as CH_4 and BC, as well as PM ($PM_{2.5}$ and PM_{10}) and sulphur oxides (SO_x). The Business-as-Usual (BAU) emissions scenario for Himachal Pradesh's waste sector focuses on these five key pollutants.

The emissions in the baseline primarily result from waste combustion, followed by waste collection and transportation, handling equipment, decomposition at landfill sites, and open waste burning. The spatial distribution of emissions corresponds to densely populated and rapidly urbanizing areas that generate higher waste volumes.

The emission estimates for the base year 2019 from the waste sector in Himachal Pradesh are presented below. These values are directly obtained from SWEET computations using state-specific inputs and activity data sourced from the State Annual Reports, District Environment Plans, and NMCG Monthly Progress Reports.

Table 43: Emission Estimates for the base year 2019 from the Waste Sector in Himachal Pradesh

Pollutant	Emission (kt/year)
CH_4	1.23
$PM_{2.5}$	0.05
PM_{10}	0.35
SO_x	0.015
BC	0.008

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For more information

IGSD,First Floor, N -122 Panchsheel Park,
Malviya Nagar New Delhi, India-110 017
Web- www.igsd.org | Tel- 011-35062638