IGSD

HARYANA STATE POLLUTION CONTROL BOARD

teri

A DUAL STRATEGY SPRINT TOWARDS SUSTAINABILITY: NON-CO_2 PATHWAYS FOR HARYANA

TERI Project Team

Dr. Suruchi Bhadwal (Advisor), Program Director and Senior Fellow

Dr. Manish Kumar Shrivastava (Co-Principal Investigator), Senior Fellow and Associate Director

Mr. Nimish Singh (Principal Investigator), Fellow

Mr. K Sai Dinesh, Research Associate,

Mr. Uday Veer Singh, Research Associate,

Ms. Shivani Sharma, Associate Fellow

Mr. Justin Jacob, Research Associate

Ms. Shweta Gautam, Research Associate & Area Convenor

Mr. Krishnapriya Nair, Research Associate

Mr. Arindam Datta, Senior Fellow

Md. Hafizur Rahman, Fellow

Mr. Prabhat Sharma, Associate Fellow

Mr. Dheeraj Mehra, Research Associate

Ms. Pooja Sehbag, Research Associate

Ms. Saranya Sircar, Project Associate

Mr. Saptarshi Majumdar, Research Associate

Mr. K. Umamaheshwaran, Consultant

Ms. Jahnavi Sanjay Shah, Intern

IGSD Team

Mr. Akshat Patni, Head of Research

Ms. Zerin Osho, Director

Ms. Yukti Dabas, Project Development Lead

Ms. Pranjali Chowdhary, Research & Policy Associate

Ms. Nehal Sharma, Program Head

Ms. Sunandini Seth, Program Coordinator

Mr. Asad Ali, Communications Manager

Mr. Nikhil Kumar, Head of Communications

Ms. Ravleen Kaur, Government Affairs Manager

Ms. Abir Saraon, Project Manager

Ms. Saloni Srivastava, Research & Policy Associate

Ms. Bhhavya Kapoor, Research & Policy Associate

Mr. Ali Reza, Research & Policy Associate

Mr. Shivang Agarwal, Technical Fellow

Prepared by:

Haryana State Pollution Control Board (HSPCB), Govt. of Haryana, Institute for Governance & Sustainable Development (IGSD) and The Energy and Resources Institute (TERI).

Citation:

Singh, Nimish; Patni, Akshat; Osho, Zerin; et. al. (2025). A Dual Strategy Sprint Towards Sustainability: Non-CO_2 Pathways for Haryana. Haryana State Pollution Control Board (HSPCB), Govt. of Haryana, Institute for Governance & Sustainable Development (IGSD), and The Energy and Resources Institute (TERI).

Shri Nayab Singh Saini
Hon'ble Chief Minister
Government of Haryana

Message

The health of our environment is the very foundation of Haryana's prosperity, with clean air, fresh water, and fertile soil acting as essential resources which drive our economy and sustain our communities. As the growth of our state is continuing and we are facing the urgent challenge of balancing progress with our responsibility to protect these vital resources for future generations. While we must continue to address long-term pollutants like CO_2, it is also crucial to mitigate short-lived climate pollutants (SLCPs) such as black carbon and methane, which are highly potent in the short term and require immediate action to combat the warming climate.

The comprehensive report, **"A Dual Strategy Sprint towards Sustainability: Non-CO_2 Pathways for Haryana,"** is a landmark achievement. I am proud to share that this critical document, authored by the **Institute for Governance & Sustainable Development (IGSD)** and **The Energy and Resources Institute (TERI),** was developed with the valuable support of the **Haryana State Pollution Control Board (HSPCB).**

This report is more than just a study; it is a clear, actionable roadmap for tackling our most pressing environmental issues, particularly the reduction of **short-lived climate pollutants**. By focusing on practical strategies across key sectors like industry, transport, and agriculture, this plan offers a path way to not only mitigate climate change but also to improve public health and ensure food and water security for our citizens.

The success of this mission depends on a collective effort. Our Government is fully committed in implementing the recommendations of this report with transparency and accountability. However, true change requires collaboration from every Government Department, institution and citizen. Let us all work together, with a shared sense of purpose, to build a greener and healthier Haryana. I am confident that by embracing this dual strategy, we will not only protect our natural heritage but also set a leading example for sustainable development across our country. Releasing this report alongside Haryana's State Environment Plan is a strategic move to ensure immediate action towards implementing the outlined initiatives.

Nayab Singh Saini

Shri Rao Narbir Singh
Industries & Commerce, Environment,
Forest and Wild Life, Foreign Cooperation and
Sainik & Ardh Sainik Welfare Minister, Haryana

Message

The environment is not separate from our lives. It is the foundation of our State, economy, and well-being, providing the clean air, pure water, and fertile soil that sustain us. Yet, our rapid development has placed an immense and unsustainable pressure on these vital resources. To secure our future, we must commit to a path of development that's deeply rooted in climate protection. Along with addressing long-term pollutants like CO_2, we must take immediate action on **short-lived climate pollutants (SLCPs),** which are highly potent in the short term. Without a healthy planet, no progress can be truly meaningful or lasting.

I am immensely pleased to present the report, "**A Dual Strategy Sprint towards Sustainability: Non-CO_2 Pathways for Haryana."** This comprehensive document, a result of dedicated research, is a powerful roadmap for tackling our state's most urgent environmental challenges in a structured and accountable way. It provides a practical and targeted vision for reducing Short-Lived Climate Pollutants. By addressing these pollutants across key sectors, including transport, agriculture, and industry, we can achieve immediate tangible benefits for public health, air quality, and the overall resilience of our State.

This report is a call to action for every Government Department, institution, and citizen. It is a plan for collaboration which recognizes that environmental protection is a shared responsibility. The Government of Haryana is fully committed to the effective implementation of this plan, ensuring that all departments work in close synergy. It is only when we break down traditional silos and work together with a shared sense of purpose that we can achieve the ambitious goals laid out in this report. I am confident that by embracing this vision, Haryana will not only protect its natural heritage but will also become a leading example of sustainable development for other States of the country. Let us unite to build a greener, healthier, and more prosperous legacy for generations to come.

Rao Narbir Singh

Shri Sudhir Rajpal, IAS
Additional Chief Secretary
Environment, Forest &
Wildlife Department Government of Haryana

Message

As Haryana continues its remarkable journey of development, we're at a critical juncture where economic progress must be inseparably linked with environmental sustainability. The traditional development model has often come at the cost of our natural resources, but it's now clear that our future prosperity and resilience depend on a harmonious relationship with our environment. This means that in addition to focusing on long-term pollutants like CO_2, we must also prioritize the mitigation of **short-lived climate pollutants (SLCPs),** which have an immediate and powerful impact on our climate.

I am privileged to introduce this landmark report, **"A Dual Strategy Sprint towards Sustainability: Non-CO_2 Pathways for Haryana."** This document is a testament to our state's proactive commitment to tackling environmental challenges head-on. It moves beyond conventional approaches by focusing on the swift and tangible benefits of reducing Short-Lived Climate Pollutants, such as black carbon, tropospheric ozone, and methane. By targeting these specific pollutants, the report presents a strategic pathway to not only mitigate climate change but also to significantly improve air quality and public health across the State of Haryana.

The insights and recommendations within this report are a product of meticulous research and collaborative effort, and I extend my gratitude to the **Institute for Governance & Sustainable Development (IGSD)** and **The Energy and Resources Institute (TERI)** for their expert authorship. The active support and involvement of the **Haryana State Pollution Control Board (HSPCB)** was also instrumental in shaping its practical and implementable solutions.

Sudhir Rajpal

Shri Vineet Garg, IAS,
Chairman
Haryana State Pollution Control Board

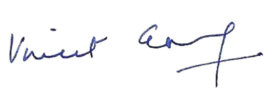
Foreword

Haryana stands at a critical crossroads where tackling air pollution and climate change is no longer an option—it is an imperative. As a State that plays a pivotal role in India's agricultural and industrial landscape, we must ensure that our progress is built on a foundation of environmental sustainability. The growing burden of air pollution not only endangers public health but also affects our economy, food security, and overall quality of life.

This report on **Short-Lived Climate Pollutants (SLCPs)** marks a significant step towards understanding and addressing pollutants such as black carbon, methane, and tropospheric ozone—key drivers of both air pollution and climate change. These pollutants have far-reaching consequences for air quality, climate stability, and agricultural productivity. By targeting their reduction, we can achieve immediate and tangible benefits for public health, environmental sustainability, and economic resilience.

The Government of Haryana is committed to implementing comprehensive strategies to ensure cleaner air and a healthier future for our citizens. The revised Haryana State Action Plan on Climate Change (SAPCC) provides a strong foundation for integrating air quality management with climate resilience. The insights and policy recommendations in this report will further strengthen our efforts to reduce emissions across key sectors, including agriculture, industry, transport, and urban development. I commend our on-ground team at **Haryana State Pollution Control Board (HSPCB),** in collaboration with IGSD and TERI, for their efforts in compiling this vital findings. I firmly believe that this report will serve as a guiding document for policymakers, researchers, and stakeholders, enabling decisive action towards a cleaner and more sustainable Haryana. Let us work together to make Haryana a leader in environmental stewardship, setting an example for the rest of the country in combating air pollution and climate change.

This foreword is not merely an introduction; it is a declaration of unwavering commitment from our department and the entire State. We pledge to work tirelessly with all stakeholders—Government agencies, private industries, and citizens alike—to ensure this dual strategy is implemented with both effectiveness and transparency. I am certain that this report will serve as a beacon, allowing Haryana to lead by example and pave the way for a greener, healthier, and more sustainable future.



Vineet Garg

Ms. Zerin Osho
Director, IGSD

Message

On behalf of the Institute for Governance & Sustainable Development (IGSD), I am pleased to present our report, '**A Dual Strategy Sprint towards Sustainability: Non-CO_2 Pathways for Haryana'**.

IGSD has proactively worked to ensure climate change mitigation in India by focusing on non-CO_2 super climate pollutants. Over the years, the aim has been to develop and enable strategic initiatives at the sub-national level, identify appropriate technology solutions, engineer inter-state collaboration, and facilitate the flow of private sector finance. Through forward-looking policy research and capacity-building, IGSD strives to augment climate resilience, slow near-term warming, and promote sustainable development in India.

Countries worldwide, especially those in the Global South, are increasingly becoming cognisant of the need to have an alternate blueprint to tackle climate change bearing in mind its ongoing impacts. At IGSD, we have always believed it's essential to have a dual-pronged strategy to mitigate climate change. One which addresses the marathon of decarbonisation for the longer term and, crucially, takes on the sprint to decrease potent emissions in the form of Short-Lived Climate Pollutants (SLCPs) for the shorter term. These SLCPs include methane (CH_4), black carbon (BC), hydrofluorocarbons (HFCs), and tropospheric ozone (O_3). Hence, it has become imperative to ensure focused, data-driven research that can support the government's efforts at ensuring a cleaner future for India.

This report for Haryana identifies significant challenges for air pollution and climate change impacts. But these also present powerful opportunities for growth and innovation. As per research findings, climate change is likely to lead to a 15-17% reduction in irrigated rice and wheat yields in the state by mid-century, exacerbating food security concerns. However, the policy strategies outlined in this report can help to drive the adoption of advanced agricultural techniques and water management strategies that can build long-term climate resilience. We must remember that Haryana is located within the Indo-Gangetic Plain, a global hotspot for PM emissions. This underscores the critical need for comprehensive air quality improvement initiatives. In 2023, the average annual PM_{10} and $PM_{2.5}$ levels in the state surpassed national limits by over 1.5 times. Proactively addressing these issues will, therefore, not only mitigate risks but also unlock substantial health and economic benefits for the people of Haryana.

This IGSD study is crucial because it establishes a baseline for SLCPs and other non-CO_2 pollutant emissions and models their near-term projections under different alternate scenarios for a range of sectors – from transport and industry to residential. This helps in showcasing the emission reduction potential of targeted and effective policy actions.

Looking ahead, IGSD is firmly committed to ensuring continuity and fostering collaboration, supporting states in their implementation of commitments, and consistently championing equity and ambition in all climate initiatives.

SLCPs are a major hurdle in the state's journey toward a cleaner future. I hope this report - developed with invaluable support from the Haryana State Pollution Control Board- can help eliminate all such hurdles and ensure a better future for Haryana.

Zerin Osho
Director, Institute for Governance & Sustainable Development

Preface

Air pollution and climate change stand out as two of the most critical environmental issues, posing significant threats to public well-being, agricultural productivity, ecosystem integrity, and economic stability. As a major agricultural and industrial state, Haryana is particularly vulnerable due to its reliance on climate-sensitive sectors and its urban growth. To address these challenges, an integrated approach of aligning air quality management with climate action is paramount.

In order to respond to these issues, the Government of Haryana is determined to implement sustainable solutions that reduce emissions while enhancing economic and environmental resilience. This report offers a comprehensive analysis of **Short-Lived Climate Pollutants (SLCPs)** in Haryana, exploring their sources, trends, and potential mitigation pathways. SLCPs, which include black carbon, methane, and tropospheric ozone, not only contribute to climate warming but also degrade air quality. Reducing these pollutants presents a crucial opportunity to achieve immediate health and environmental benefits.

This report aligns with Haryana's comprehensive climate and air quality strategies, including the revised Haryana State Action Plan on Climate Change (SAPCC) and the National Clean Air Programme (NCAP). It identifies sources of short-lived climate pollutant (SLCP) emissions and outlines a roadmap to integrate their mitigation into state policies. The report also highlights the need for intersectoral collaboration to maximize benefits for food security, public health, and economic stability. Moreover, to support the development of Haryana's State Environment Plan (SEP) for 2025, this study is a technical analysis of sector-wise baseline emissions which projects the mitigation potential of key SLCPs, thereby highlighting data analysis to the development of the SEP.

Institute for Governance and Sustainable Development (IGSD), with support from **The Energy and Resources Institute (TERI),** has conducted this study and submitted the same to **Haryana State Pollution Control Board (HSPCB)** in order to support evidence-based policymaking and action. By providing robust data and strategic insights, this report aims to serve as a foundation for informed decision-making, guiding Haryana toward a more climate-resilient future.

It is our hope that this report will inform policy actions, strengthen institutional capacities, and encourage collaborative efforts across sectors to effectively reduce air pollution and its climate impacts in Haryana.

Contents

Tables

Figures

Glossary

Baseline Scenario (BAU): A Business-as-Usual (BAU) scenario reflects the sectoral growth projections for Haryana under current conditions. It takes into account certain interventions that have already been implemented to address short-lived climate pollutant (SLCP) emissions.

Alternate 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): Short-lived climate pollutants (SLCPs) are a group of greenhouse gases and air pollutants that have a near-term warming impact on climate and can affect air quality. SLCPs include black carbon, methane, ground-level ozone, and 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 time period.

System of Rice Intensification (SRI): A set of agricultural practices aimed at improving rice productivity while reducing methane emissions from paddy fields.

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.

Crop Diversification: The practice of growing a variety of crops instead of relying on a single crop, helping to improve soil health, reduce dependency on water-intensive crops like rice, and lower emissions from agricultural activities.

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.

Sulphates: Sulphate aerosols, with an atmospheric lifetime ranging from a few days to weeks[1], form in both gaseous and aqueous phases, primarily from sulphur dioxide (SO_2) emissions (from coal fired power plants and volcanic eruptions) and dimethyl sulphide (DMS) from biogenic sources. A major component of PM, sulphates contribute significantly to atmospheric cooling. These aerosols typically measure between 0.3 to 0.7 μm in diameter. They also serve as cloud condensation nuclei (CCN), playing a crucial role in cloud formation and influencing precipitation patterns.[2]

Nitrates: Nitrate aerosols form through the oxidation of nitrogen oxides (NO_x), which are mainly emitted by vehicles and power plants. Their atmospheric lifetime is only a few hours, making them shorter-lived than sulphates, which persist for days to weeks.[3]

List of Abbreviations

AQI: Air Quality Index
BAU: Business-As-Usual
BC: Black Carbon
CAAQMS: Continuous Ambient Air Quality Monitoring Stations
CAGR: Compound Annual Growth Rate
CO: Carbon Monoxide
CO_2: Carbon Dioxide
CH_4: Methane
CPCB: Central Pollution Control Board
GHG: Greenhouse Gas
GWP: Global Warming Potential
HAMP: Heat Action Management Plan
HFCs: Hydrofluorocarbons
HSPCB: Haryana State Pollution Control Board
ICAP: India Cooling Action Plan
IPCC: Intergovernmental Panel on Climate Change
NAAQS: National Ambient Air Quality Standards
NAMP: National Air Monitoring Programme
NCAP: National Clean Air Programme
NDCs: Nationally Determined Contributions
NH_3: Ammonia
NMVOCs: Non-methane Volatile Organic Compounds
NOx: Nitrogen Oxides
NSSO: National Sample Survey Office
O_3: Tropospheric Ozone
OH: Hydroxide
PM: Particulate Matter
SAPCC: State Action Plan on Climate Change
SDGs: Sustainable Development Goals
SLCP: Short-lived Climate Pollutants
SO_2: Sulphur Dioxide
SPM: Suspended Particulate Matter
UNEP: United Nations Environment Programme
VOCs: Volatile Organic Compounds

1

Executive Summary

This report presents a comprehensive and first-of-its-kind emission inventory of non-CO_2 pollutants for the state of Haryana, using 2019 as the baseline year. It highlights the critical need to sharpen focus on such non-CO_2 pollutants especially **Short-Lived Climate Pollutants (SLCPs)**—including methane (CH_4), black carbon (BC), hydrofluorocarbons (HFCs), and tropospheric ozone (O_3) in order to mitigate shorter term climate impacts, while maintaining the long-term momentum on CO_2. To work towards this holistic strategy, the report analyzes the projected trends in **SLCPs and other non-CO_2 pollutants** under a **Business-As-Usual (BAU)** scenario through 2047.

The report also evaluates a set of **policy-driven alternative scenarios (ALT)** across sectors, identifying pathways to achieve maximum emission reductions. Two key insights emerge from this study:

It offers a sector-wise breakdown of SLCP and other non-CO_2 pollutant emissions, highlighting the relative contributions of key sectors across the state.

It identifies priority sectors and policy interventions that are essential for integrating climate and air quality action, based on scenario-based analysis.

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

Temperatures are breaking records year after year, underscoring the urgent need to drastically reduce greenhouse gas emissions to avoid the worst impacts of climate change.[4] Haryana has a **clear opportunity to enhance agricultural resilience.** Strategic interventions can **mitigate projected 15-17% yield variations** in irrigated rice and wheat and **2% in milk yield, strengthening food security** for the future.[5] Agriculture will also be one of the primary sectors impacted by the disruption of energy production in the state due to increasing temperatures and potential water scarcity. At the same time, air pollution continues to undermine both public health and economic productivity. Haryana is demonstrating a **strong commitment to public health and economic growth.** Addressing the 2019 air quality challenges, which carried an economic impact of **USD 1,566 million, presents a significant opportunity for Haryana to lead the nation** in achieving healthier environments and greater prosperity.[6]

Focusing on short-lived climate pollutants allows Haryana to address air quality and manage unpredictability of weather in the short & medium term.

While CO_2 is the largest single contributor to current warming, SLCPs are responsible for roughly half (45%) of current global warming.[7] Research has confirmed that solely focusing on CO_2 mitigation is insufficient to address rising temperatures—a comprehensive dual-strategy is essential, with holistic CO_2 and non-CO_2 mitigation approaches.[8] Cutting methane emissions can lower temperature rise rates by 20% from 2010-2030, 25-40% from 2030-2050, and 20-

30% from 2010-2050 globally. Parallelly, cutting black carbon (soot from burning fossil fuels) can reduce warming by 10-20% by 2030.[9]

This approach provides significant co-benefits, including improved air quality, reduced health impacts, and enhanced food security. For Haryana, reducing emissions is essential to combat its increasing vulnerability to climate change and mitigate projected temperature rise, as highlighted in the State Action Plan on Climate Change (SAPCC)[10] and the Winter Action Plan.[11] Haryana's 2022 experience with heat waves, affecting **10–15% of late-sown wheat and up to 19% of chickpea production, offers valuable insights for boosting agricultural resilience.** This presents a **proactive opportunity to refine climate-smart farming** and secure future yields.[12] Rising temperatures also threaten the state's energy generation capacity by reducing the efficiency of thermal power stations, which Haryana relies on extensively.[13] Haryana has a **significant opportunity to lead sustainable environmental practices. By optimizing rice farming and enhancing waste management,** especially given the **2019 landfill emissions estimated at 38.66 kt/yr,** the state can **effectively reduce methane emissions** and boost resource efficiency. Being a part of the Indo-Gangetic Plain (IGP), which is a global hotspot of PM emissions. In 2023, the average annual PM_{10} and $PM_{2.5}$ levels in the state were reported to be surpassing the national permissible limit by over 1.5 times.[16]

This study establishes a baseline for SLCP and other non-CO_2 pollutant emissions and models their near-term projections under different alternate scenarios. This helps in showcasing the emission reduction potential of targeted and effective policy actions.

Two key assessments have been undertaken in this study. First, a baseline inventory of SLCP and other non-CO2 pollutant emissions was established for 2019 using data from various government sources, complemented by academic literature. Second, emissions scenarios were developed, including a Baseline Scenario and Alternate Scenarios aligned with the state's policy direction and overarching vision. These scenarios feature quantifiable targets for 2030, 2040, and 2047, in line with the state's and India's developmental goals. The study identifies the contribution of each sector towards SLCPs and air pollutants. It also highlights theprecursors to both, for Haryana, and projects the emission reduction potential of existing strategies during 2030 and 2047.

The analysis reveals that Haryana is already positioned to achieve significant emission reductions through existing policies and ongoing initiatives, even under the BAU scenario.

Efforts such as increased LPG adoption in households, gradual electrification of the transport sector, and the implementation of partial emission controls in the industrial sector are expected to reduce SLCP and other non-CO_2 pollutant emissions. The state's focus on transitioning households to LPG, promoting cleaner cookstoves, and enforcing crop residue management policies showcases its commitment to improving air quality. These measures set a strong foundation for further improvements in air quality and GHG mitigation.

1.1 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 Haryana'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.

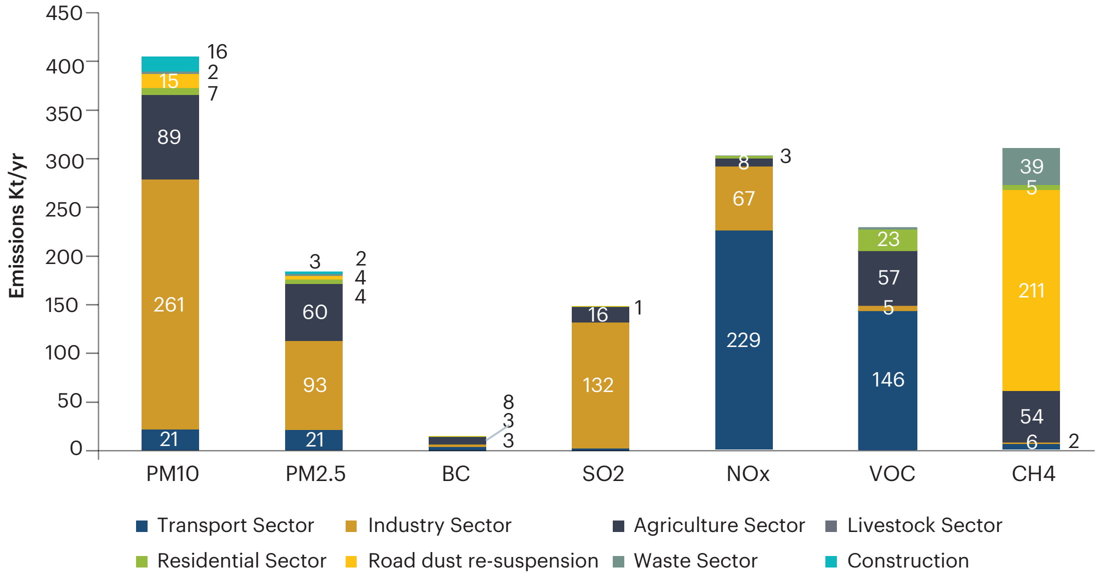


Figure 1: Emissions Distribution of SLCPs and other pollutants in Haryana for 2019 and Sectoral Contributions

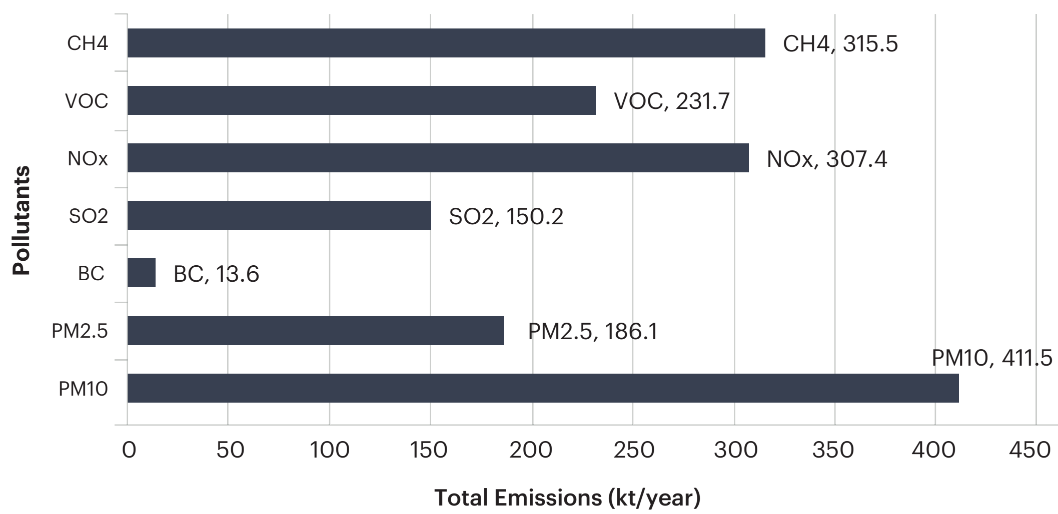


Figure 2: Total Emissions of PM_{10}, CH_4, NO_x, NMVOCs, $PM_{2.5}$, SO_2 and BC in Haryana for 2019

Table 1: Total Emissions of PM_{10}, CH_4, NO_x, NMVOCs, $PM_{2.5}$, SO_2 and BC in Haryana for 2019 (in kt/yr) and Major Sectoral Contributions

Pollutant	Total Emissions (kt/year)	Major Emitting Sectors (Emissions in kt/yr)
PM10	411.50 kt/year	Industry (261), Agriculture (88.89), Transport (21.20)
CH4	315.532 kt/year	Livestock (210.8), Agriculture (53.86), Waste (38.66)
NOx	307.39 kt/year	Transport (229.3), Industry (66.99), Agriculture (8.49)
NMVOCs	231.68 kt/year	Transport (145.9), Agriculture (57.4), Residential (22.78)
PM2.5	186.14 kt/year	Industry (93), Agriculture (59.82), Transport (20.50)
SO_2	150.15 kt/year	Industry (132.34), Agriculture (15.89)
BC	13.56 kt/year	Agriculture (7.8)

As can be seen from the table, PM_{10} emissions are the highest in the state followed by methane and NO_x.

The study findings indicate that in the baseline year 2019, particulate matter (PM_{10}) emissions have been the highest SLCP emissions in Haryana, followed by methane and NO_x. A substantial proportion of PM_{10} emissions can be attributed to the industrial sector, stemming from coal combustion in industries, brick kilns, and thermal power plants. Agriculture is the second largest contributor to PM_{10} emissions, primarily due to crop residue burning practices. Enteric fermentation in livestock is the largest source of methane emissions in the state, followed by methane emissions from rice cultivation in the agriculture sector.

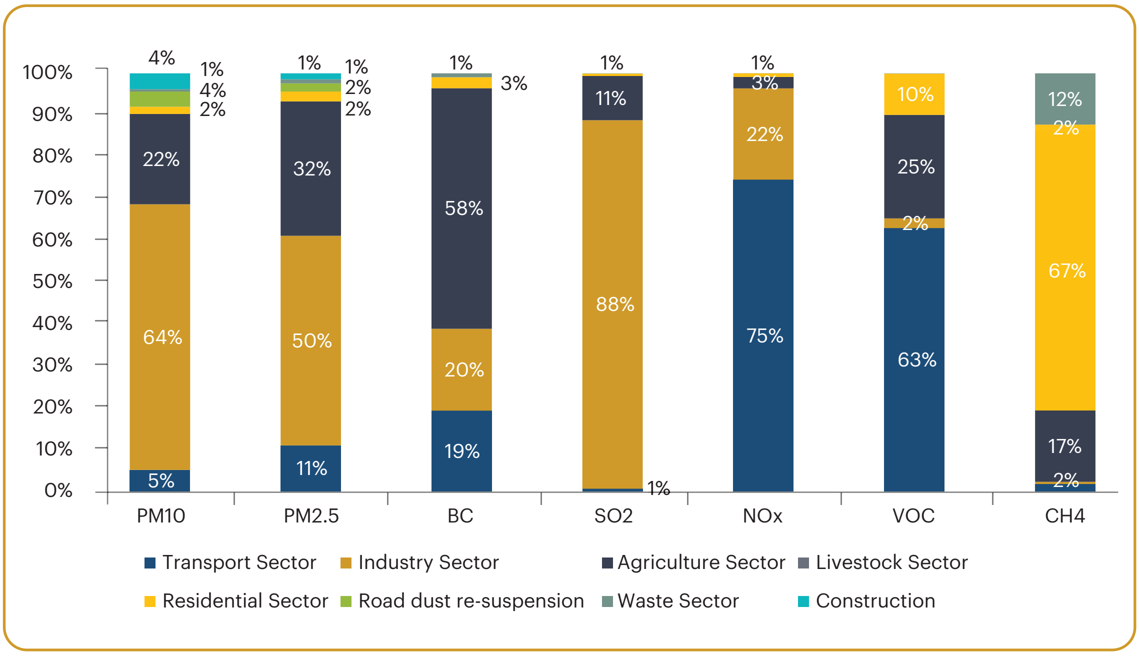


Figure 3: Proportional Contributions of Sectors to pollutant emissions in Haryana

Table 2: Priority sectors for SLCP and other non-CO_2 pollutants mitigation in Haryana based on ALT scenario findings

Priority Sectors for Haryana	Priority Policy Interventions
Transport	Phased implementation of (ALT-2) **vehicle scrappage policy**, in conjunction with **phased transition to EVs** (ALT-4).
Industry	Implementation of **community boiler systems within industrial clusters** (ALT-2) which can significantly reduce emissions along with (ALT-1) **transition to natural gas** while methane emissions are closely monitored.
Agriculture	For methane mitigation, System of Rice Intensification (SRI) should be introduced as the entry point for agricultural transformation, followed by natural farming and crop diversification (ALT-3). The state must align targeted policy interventions with the aim to completely **eliminate open burning of crop residues** by 2030 to reduce emissions of particulate matter, black carbon, NO_x and SO_2.
Livestock	For methane mitigation in the livestock sector, **fodder management practices** like phased transition to **open grazing** (ALT-2) must be targeted. Complete transition to open grazing would require large-scale land resource management and diversion of public resources.

1.1.a Transport

The transport sector is a major contributor to air pollution in Haryana, responsible for 75% (229.30 kt/year) of the state's nitrogen oxide (NOx) emissions and 63% (145.90 kt/year) of its non-methane volatile organic compound (NMVOC) emissions. It also accounts for approximately 20% (2.62 kt/year) of black carbon emissions and 11% (20.50 kt/year) of PM2.5 emissions.[17]

Tropospheric ozone (O_3), a harmful secondary pollutant, is formed through chemical reactions between NOx and NMVOCs in the presence of sunlight. In rural areas, where the NOx/NMVOC ratio is lower, reducing transport emissions leads to a decline in O_3 levels. However, in urban areas—where the NOx/NMVOC ratio is high—cutting NO_x emissions alone can paradoxically increase O_3 formation.[18] Given that the transport sector is the dominant source of NO_x in Haryana, it plays a critical role in shaping the state's tropospheric ozone levels and must be a central focus of emission reduction strategies.

BAU AND ALT SCENARIOS:

The business-as-usual scenario (BAU) accounts for already planned interventions in the state such as the adoption of BS-VI emission norms from 2020. **In BAU, by 2047, the following increase in emissions may be witnessed: (i) 37% in PM2.5 emissions, (ii) 47% in NOx emissions, and (iii) 43% in black carbon emissions compared to the 2019 baseline emissions.** Despite this trajectory, emission intensity (emissions per vehicle) from the transport sector is expected to reduce. A primary reason is that over time the number of vehicles is expected to increase on account of a rising population and urbanization.

The study constructs four alternate policy scenarios to project reduction in emissions compared to the 2019 baseline. The policies are expected to be implemented in phases by 2047 (see Table 3).

RESULTS and INFERENCE

Table 3: Targets Assumed Under Alternate Scenarios for the Transport Sector until 2047

Scenarios	2030	2040	2047
ALT 1: Electrification of bus fleet	100% in Gurugram and Faridabad	50%	100%
ALT 2: Vehicles scrappage policy	30%	60%	80%
ALT 3: Hydrogen blending in CNG	0%	18% (buses)	18% (cars, autos, LCVs, and buses)
ALT 4: Electrifying the vehicular fleet (covering newly registered vehicles such as buses, two-wheelers, three-wheelers, and cars)	50%	70%	100%

Table 4: Change in Transport Emissions Under Alternate Scenarios, Compared to 2047 Emissions Under BAU

Scenarios	$PM_{2.5}$	PM_{10}	SO_2	NOx	NMVOCs	BC	CH4
ALT 1: Electrification of bus fleet	-10.1%	-12.6%	-14.8%	-11.0%	-13.8%	-11.9%	-24.5%
ALT 2: Vehicles scrappage policy	-29.3%	-37.2%	-17%	-24.3%	-19.9%	-23.3%	-50.4%
ALT 3: Hydrogen blending in CNG	-3.5%	-5.0%	-4.9%	-6.4%	-3.2%	-10.3%	-11.4%
ALT 4: EV Policy for all vehicles	-33%	-41%	-21%	-28%	-24%	-27%	-54%

Emission reductions were assessed under each of the alternate scenarios (see Table 4). Analysis reveals that **phased implementation of vehicle scrappage policy (ALT-2) emerges as the most feasible strategy,** in terms of emission reductions and practical implementations. While a complete transition to EVs offers the maximum emission reductions, it may not be feasible, and a phased approach should be considered.

1.1.b Waste

The waste sector in Haryana accounts for 12% (38.66 kt/year) of the state's methane emissions and 1% each of PM_{10} (2.29 kt/year), $PM_{2.5}$ (1.88 kt/year) and BC (0.13 kt/year) emissions. Emissions under all scenarios including the BAU rise until 2030, and decrease thereafter, owing to expected landfill closures in 2034.

Six key pollutants are emitted from the waste sector: CH_4 from landfills; and PM_{10}, $PM_{2.5}$, SO_2, and BC, from open waste burning. Open waste burning includes residential waste burning and spontaneous combustion at landfill sites. CH_4 emissions are expected to decline after the planned landfill closures in 2034. As waste disposal at landfills decreases after 2034, spontaneous burning will also decline, leading to an overall reduction in emissions of PM_{10}, $PM_{2.5}$, SO_2, and BC.

BAU AND ALT SCENARIOS:

BAU represents a scenario where the state has a 99% waste collection efficiency[20], but processes only 8% of it based on the analysis done by the SWEET tool. Various alternate scenarios are built where increased levels of waste are diverted towards waste-to-energy, composting, anaerobic digestion, material recovery facilities (MRFs), refuse derived fuels (RDFs), and recycling. These scenarios begin in 2025.

RESULTS AND INFERENCE:

Table 5: Targets Assumed Under Alternate Scenarios for the Waste Sector until 2047

Scenario	Treatment of Diverted Waste						Open Burning	
	Waste-to-energy	MRFs	Composting	Anaerobic Digestion	Recycling	RDFs	At Residences	At Landfills
ALT 1: 32% diversion	28.05%	72%	0%	0%	0%	0%	3%	7%
ALT 2: 40% diversion	0%	0%	12.88%	1.37%	61.68%	24.05%	3%	5%
ALT 3: 50% diversion	0%	0%	12.88%	1.37%	61.68%	24.05%	2%	4%
ALT 4: 60% diversion	0%	0%	12.88%	1.37%	61.68%	24.05%	2%	4%

Table 6: Change in Waste Emissions Under Alternate Scenarios, compared to 2047 Emissions Under BAU

Scenario	CH_4	$PM_{2.5}$	PM_{10}	SO_2	BC
ALT 1: 32% diversion	-26%	+13053%	+10980%	+15262%	+235%
ALT 2: 40% diversion	-32%	+14027%	+11801%	+16393%	+247%
ALT 3: 50% diversion	-58%	+17524%	+14741%	+20480%	+296%
ALT 3: 60% diversion	-66%	+17738%	+14915%	+20748%	+282%

***It is essential to note here that, although the relative amount of emissions of PM_{10}, $PM_{2.5}$, SO_2, and BC are higher in 2047 as compared to their BAU, the absolute difference in these pollutant emissions is marginal.**

This increase in pollutant emissions is attributable to a **high reliance on waste combustion (RDFs)** and **insufficient infrastructure**. The former suggests that, when diverting waste for processing, it's essential to **prioritize methods such as composting, anaerobic digestion (AD), and recycling that minimize greenhouse gas emissions.** Each of these processes offer lower emissions compared to waste combustion. Moreover, adoption of these methods can accrue additional co-benefits; e.g., operationalizing large-scale AD plants and ensuring their performance quality is upto global standards. This will not only contribute to effective organic waste management but also reduce methane emissions and produce energy and bio-fertilizers that can benefit agriculture and residential sectors.

Methane emissions in 2047 are expected to be lower than the BAU projections for 2047 ranging from 26% to 66%, depending on the proportion of waste diverted. **If 50% of the waste going to landfills is diverted to processing facilities (ALT-3), methane emissions in 2047 are expected to be 58% lower than the BAU** (Table 6). PM_{10}, $PM_{2.5}$, and SO_X emissions rise across alternative scenarios compared to the BAU, owing to insufficient waste collection, transportation and waste handling equipment. **Efficient waste processing requires adequate infrastructure such as vehicles and equipment for collection and transportation.** Insufficient or outdated vehicles and equipment can lead to increased fuel consumption and emissions from the transportation sector. Delays in processing can also lead to longer decomposition times for organic waste, resulting in higher emissions.

1.1.c Industry

Industries are the largest contributors to SO_2 emissions at 88% (132.34 kt/year), PM10 at 66% (261 kt/year) and PM2.5 at 51% (93 kt/year), followed by NOx at 22% (66.99 kt/year).

BAU AND ALT SCENARIOS:

A substantial portion of industrial emissions arises due to coal combustion in industries, brick kilns, and thermal power plants. If BAU is continued, emissions are projected to increase at a 7% compounded annual growth rate, meaning **emissions of PM_{10}, $PM_{2.5}$, SO_2, NO_x, NMVOCs, and CH_4 are expected to increase approximately six-fold compared to the base year, 2019.**

For this sector, alternate scenarios are constructed to assess the implementation of three distinct fuel-based interventions, namely: (i) natural gas adoption, (ii) community boiler utilization, and (iii) green hydrogen expansion. Additionally, certain overarching measures are assumed to be implemented across scenarios to address the emission intensity of particular sectors, i.e., power, brick kilns, and DG sector. Table 7 provides an overview of scenarios modelled.

RESULTS AND INFERENCE:

Table 7: Targets Assumed Under Alternate Scenarios for the Industry Sector

Scenarios	2030	2040	2047
ALT 1: Transition from coal to natural gas for combustion in industrial boilers	25%	50%	100%
ALT 2: Fuel consumption reduction due to community boilers	30%	30%	30%
ALT 3: Expansion of Green Hydrogen	-	5%	8%
Overarching Measures Taken in All Scenarios			
Transition from coal-fired thermal power plants to renewable energy sources and biomass-based generation in power sector			
In brick kiln sector, transition from zig-zag to tunnel kiln technology			
Introduction of Retrofitting of Emission Control Devices (RECD) in DG sector			

Emission reductions were studied under each scenario; (Table 8) presents the yielded results. Natural gas, while generally cleaner than coal in terms of most pollutants, has a higher CH_4 emission potential due to its composition. Hence, under ALT-1, **transition to natural gas leads to a decline in most emissions from 2040 onwards and leads to a rise in methane emissions in all years.** This increase in methane emissions should be carefully monitored to fully assess the climate impact of the transition.

ALT-2 and ALT-3 project emission reduction for all pollutants, with ALT-2 offering higher reductions. ALT-2 involves implementing community boilers, which supply centralized steam to multiple industrial units within an industrial cluster. These systems are expected to reduce operational costs and enhance fuel efficiency. Consumption of fuel is assumed to decrease by 30% in industrial clusters that use community boilers. In addition, consolidation of emissions allows for more effective pollution monitoring and control. ALT-3 pertains to a transition to green hydrogen and offers a reduction in emissions of all pollutants. However, the benefits of higher reductions are observed for ALT-2.

Table 8: Change in Industry Emissions Under Alternate Scenarios, compared to 2047 Emissions Under BAU

Scenarios	$PM_{2.5}$	PM_{10}	SO_2	NO_x	NMVOCs	BC	CH_4
ALT 1: Transition to Natural Gas	-97%	-98%	-46%	-38%	-35%	-89%	+80%
ALT 2: Implementation of community boilers	-14%	-13%	-37%	-31%	-35%	-19%	-28%
ALT 3: Expansion of Green Hydrogen	-10%	-9%	-36%	-30%	-35%	-15%	-28%

Overarching measures have significant emission reduction impacts as well. Notably, adoption of renewable energy sources and biomass-based generation is projected to **reduce emissions attributable to the power sector by 40%** compared to the BAU scenario for the same year. Furthermore, transitioning from zigzag to tunnel kiln technology in brick kilns is anticipated to **decrease emissions of pollutants by 15-30%,** with the exception of NOx emissions, which are projected to rise. For the DG sector, **RECD (Retrofit Emission Control Device) retrofitting is expected to reduce both particulate matter ($PM_{2.5}$ and PM_{10}) and BC emissions by approximately 70% compared to the BAU scenario for the same year.**

1.1.d Livestock

Haryana's livestock sector accounts for 67% (210.80 kt/year) of the state's total methane emission, with the state contributing to 6% of India's total milk production.

BAU AND ALT SCENARIOS:

To meet rising demand, the country's milk production is projected to oversee a 6% annual increase, leading to a further increase in methane emissions. For the purpose of this study, alternative strategies to mitigate methane emissions are modelled based on existent state policies. These include replacing crossbreed cattle with indigenous breeds and promoting open grazing practices, which has the highest reduction potential as highlighted below.

RESULTS AND INFERENCE:

Table 9: Description of ALT Scenarios for the Livestock Sector and emission reduction of CH4

	CH_4 Reductions Compared to BAU in each year		
	2030-31	2040-2041	2050-51
ALT-1: Gausamvardhan Systematic decadal reduction of cross breed cattle population by 20% and converting 5% buffalo population to Murrah buffalo while increasing the indigenous cattle population to achieve the targeted milk demand in the state.	2.5%	2.5%	2.5%
ALT-2: Limited Gau Charan Bhumi All indigenous cattle above 1 year of age would be grazed in pastureland; in line with government initiatives to protect grazing lands and assist gaushalas.	36%	36%	36%
ALT-3: Purna Gau Charan Bhumi Assuming there would be enough land for open grazing of all dairy cattle, they will graze in open pasture while 10% of adult non-dairy cattle will also be allowed to graze in open pasture compared to Scenario 1.	44%	44%	44%

The Purna Gau Charan Bhumi (ALT-3) policy offers significant emission reductions within the livestock sector. ALT-3 approach assumes that all indigenous cattle would graze in pasturelands, facilitating faster digestion and reducing fermentation time. This has the potential to reduce methane emissions by 44% by 2047. However, implementation of ALT-3 relies on the assumptions of enough area of pastureland being available and accessible to all dairy cattle and 10% adult non-dairy cattle; which in turn requires large-scale land resource management and diversion of public resources. A more pragmatic expectation is **ALT-2, which falls in line with the state governments' initiatives to earmark Gau Charan lands and empower gaushalas through panchayats – this would lead to emission reductions of upto 37% over BAU scenario for the same year.**

1.1.e Agriculture

The primary focus of this section is assessing methane emissions from the agriculture sector in Haryana, which influences both regional air quality and climate change through temperature rise. **Haryana produces 3.38% of India's rice. The agriculture sector (mainly through rice cultivation) contributes 17% (53.86 kt/yr) of the state's methane emissions.**

BAU AND ALT SCENARIOS:

This high emission level stems from the traditional practice of continuously flooding rice fields, which creates anaerobic conditions that generate methane. Beyond methane, the study has developed a BAU scenario based on the current policies of Haryana, under which the state aims to eliminate open burning of agricultural residues by 2030. If this target is achieved, there would be no direct emissions of pollutants like PM_{10}, $PM_{2.5}$, BC, NO_X, and SO_2 from residue burning in the BAU scenario. **Thus, the proposed interventions in agriculture could lead to emissions reductions to the tune of 48%-60% by 2047, as compared to the BAU emissions for that year.**

This study calculates methane reduction strategies under three scenarios: gradual implementation of System of Rice Intensification (SRI), natural farming adoption in SRI areas, and additional crop diversification beyond SRI and natural farming. Methane emission reductions are assessed across three alternative scenarios, each compared against the Business-as-Usual (BAU) projections for the corresponding year (see Table 10).

RESULTS AND INFERENCE:

Table 10: Description of ALT Scenarios for the Agriculture Sector and emission reduction of CH_4

Scenario	Description	Reduction in CH_4 emissions compared to BAU for each year		
		2030	2040	2047
ALT 1	Implementation of System of Rice Intensification (SRI) 5% annual growth in adoption	19%	40%	53%
ALT 2	Implementation of Natural Farming on SRI converted land 5% annual growth in adoption	24%	47%	60%
ALT 3	Combined implementation of ALT 1, ALT 2, and crop diversification – where area under rice is diverted to non-rice crops, particularly leguminous crops. 5% annual diversion to non-rice crops	26%	50%	66%

SRI focuses on improving rice production efficiency. Thus, aligning agricultural practices with SRI principles makes it possible to achieve a balance between higher productivity and lower emissions. **Additional complementary interventions, i.e., natural farming and crop diversification, implemented in a phased manner with SRI can lead to drastic methane emission reductions over time (ALT-3).**

1.1.f Residential

The residential sector is a significant emitter of SLCPs and other non-CO_2 pollutants largely due to the continued use of solid fuels such as firewood, coal, dung cakes, and agricultural residues for cooking and heating.

Traditional cooking practices—especially the use of inefficient biomass stoves—emit substantial amounts of black carbon (BC) and carbon monoxide (CO), along with a variety of volatile organic compounds (VOCs) that contribute to the formation of tropospheric ozone.

BAU AND ALT SCENARIOS:

All SLCP emissions, except for NO_x, are expected to be lower than 2019 levels from 2030 onwards, in all scenarios, including the BAU - owing to assumed 4.6% annual growth in LPG coverage as expected by the MoPNG. However, under the BAU, NO_x emissions are expected to increase by 7%, 11% and 18% in 2030, 2040 and 2047 respectively compared to baseline 2019 levels due to the increase of LPG consumption. Scenarios are modelled to determine the impact of adoption of alternative lower-emission cooking methods in non-LPG households over their transition years to LPG.

Table 11: Description of ALT Scenarios under Residential Cooking Sector

Scenario	Annual LPG Adoption Rate	Alternate methods used by non-LPG households during transition (to LPG) period		
		Improved Cookstove	Biogas	Solar Cooking Systems
ALT 1	4.6%	100%	0%	0%
ALT 2	4.6%	30%	30%	40%
ALT 3 – by 2030	4.6%	20%	20%	40%
ALT 3 – by 2040	4.6%	10%	20%	70%
ALT 3 – beyond 2040	0%	0%	0%	100%

RESULTS AND INFERENCE:

All scenarios approximately converge in their resultant emissions by 2047, showcasing a decline in pollutants resulting from LPG penetration. This highlights that, even at the current trajectory, the state of Haryana is faring well in terms of regulating the residential sector and, **provided LPG adoption continues as per reports, the BAU scenario is also a viable outcome. A transformative shift towards solar cooking beyond 2040 (ALT-3) shows the maximum reduction potential, but it will require immense policy support, investment, and 100% consumer behaviour change to be adopted.** The emission load of different pollutants is expected to reduce between 49% and 86% by 2030 in the alternative scenarios compared to BAU 2030 emissions (Table 12). Similarly, in the alternative scenarios, by 2040, the emission load of different pollutants is expected to reduce between 17% and 93% compared to BAU 2040 emissions (Table 12).

A diversified shift to alternate cooking methods, *i.e.*, improved cookstoves (30%), biogas (30%), and solar cooking systems (40%), as modelled in ALT-2 represents a more viable and achievable outcome. The emission load of different pollutants is expected to reduce between 24% and 79% by 2030 in the alternative scenarios compared to BAU 2030 emissions (Table 12). Similarly, during 2040, the emission load of different pollutants is expected to reduce between 8% and 79% in the alternative scenarios by 2040 compared to BAU 2040 emissions indicating significant air quality improvements (Table 13).

Table 12: Change in Residential Cooking Emissions Under Alternate Scenarios, compared to 2030 Emissions Under BAU

Scenario	$PM_{2.5}$	PM_{10}	CO	BC	CH_4	SO_2	NO_x	NMVOCs
ALT 1	-26.20%	-26.91%	-27.33%	-28.10%	-26.75%	-18.58%	-10.12%	-13.43%
ALT 2	-72.34%	-74.42%	-76.07%	-78.43%	-68.54%	-40.13%	-24.09%	-37.40%
ALT 3	-79.31%	-81.54%	-83.14%	-85.62%	-77.43%	-48.79%	-28.07%	-40.87%

Table 13: Change in Residential Cooking Emissions Under Alternate Scenarios, compared to 2040 Emissions Under BAU

Scenario	$PM_{2.5}$	PM_{10}	CO	BC	CH_4	SO_2	NOx	NMVOCs
ALT 1	-21.77%	-23.87%	-25.25%	-28.10%	-23.38%	-9.19%	-3.46%	-5.22%
ALT 2	-60.10%	-66.00%	-70.28%	-78.43%	-59.89%	-19.85%	-8.23%	-14.54%
ALT 3	-71.46%	-78.42%	-83.26%	-92.81%	-73.64%	-26.49%	-10.47%	-17.22%

2

Context

The world is entering an era of record-breaking heat, with each year surpassing the previous as the warmest year on record. In Haryana, the average annual maximum temperature is expected to rise between 1.2°C and 1.4°C by mid-century and between 2.1°C and 4.5°C by the end of century.[29] Anticipating this rise in temperatures globally, the Intergovernmental Panel on Climate Change (IPCC) has stressed the need for drastic greenhouse gas reductions by 2030 to avert the worst consequences of climate change. This urgency aligns with the Paris Agreement's objective of keeping global warming below 2°C while striving for a 1.5°C limit. However, decarbonisation alone is insufficient to achieve these targets—a comprehensive dual-strategy is essential, with holistic CO_2 and non-CO_2 mitigation approaches.[31] Mitigating SLCPs and other non-CO_2 pollutants can minimize air pollution-related illnesses, improve crop yields and food security, and support the transition to sustainable energy sources.[32]

2.1 Beyond Decarbonization: What are SLCPs

SLCPs are chemically and physically reactive compounds with atmospheric lifetimes typically shorter than two decades. They include aerosols which are also called particulate matter (PM), and chemically reactive gases such as methane and ozone. While decarbonizing the energy system is a crucial long-term goal, a more holistic understanding of GHGs is essential for effective climate mitigation.

The IPCC Sixth Assessment Report also highlights the importance of mitigating SLCPs to achieve short-term climate goals and address the mitigation gap. Furthermore, recent research indicates that focusing solely on decarbonization may inadvertently exacerbate near-term warming due to the masking effect of sulphate aerosols.

Some critical SLCPs which are major contributors to warming and air quality generally include:

Methane (CH_4): Methane is a highly potent greenhouse gas. Over 20 years, one kilogram of methane has more than 80 times the warming impact of the same amount of carbon dioxide (CO2).35 Approximately 45% of today's net global warming is driven by methane emissions from human activities.[36] Sources of methane include both natural processes, such as wetlands, and human activities, including agriculture (e.g., rice paddies, livestock digestion), landfills, and fossil fuel extraction out of which human activities account for about 60% of global methane emissions.[37] Methane also acts as a precursor to ozone (O_3). It reacts with hydroxyl radicals (OH) in the atmosphere, forming methyl radicals (CH_3), which subsequently oxidize to produce ozone in the presence of nitrogen oxides (NOx).[38]

Tropospheric Ozone (O_3) and Its Precursors: Tropospheric ozone is the third most important greenhouse gas after CO2 and CH4.39 It absorbs infrared radiation (heat) from the Earth's surface, reducing the amount of radiation that escapes to space. It is not emitted directly but forms through reactions between precursor gases—such as CO, NOx, and NMVOCs (including methane)—which result from both natural and human activities. Ozone interacts with both shortwave and longwave radiation, contributing to climate warming.

Black Carbon (BC): Black carbon is a powerful climate-forcing aerosol with a short atmospheric lifetime of just a few days to weeks.[41] It is a key driver of global warming and is the light-absorbing component of particulate matter (PM). Primarily emitted from the incomplete combustion of fossil fuels and biomass-based fuels, its climate impact depends on its location in the atmosphere. At ground level, black carbon directly warms the air by absorbing solar radiation and emitting heat. It also impacts cloud microphysics, altering precipitation patterns posing as a hazardous air pollutant with severe health consequences.

Hydrofluorocarbons (HFCs): HFCs are synthetic greenhouse gases primarily used as refrigerants, solvents, and in foam production. Some HFCs have global warming potentials (GWP) hundreds to thousands of times greater than CO_2 over a 20-year period. HFC emissions mainly result from leakage during the use and disposal of products containing these gases.

Addressing SLCPs offers a critical opportunity to complement decarbonization efforts and achieve rapid reductions in warming. This approach provides significant co-benefits, including improved air quality, reduced health impacts, and enhanced food security. Air pollution was responsible for 1.67 million deaths in India in 2019 alone.[42]

Haryana is demonstrating a **strong commitment to public health and economic growth.** Addressing the 2019 air quality challenges, which carried an economic impact of **USD 1,566 million,** presents a **significant opportunity for Haryana to lead the nation** in achieving healthier environments and greater prosperity.[43] Targeting pollutants like methane and tropospheric ozone—both SLCPs and major air contaminants—can significantly reduce these health and economic burdens while enhancing air quality.

Table 14: SLCPs and their Global Warming Potential (GWP)

SLCP	Global Warming Potential (GWP)
Methane	More than 80 times that of CO_2 over a 20-year horizon
Black Carbon	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 through its formation

Note: *Global Warming Potential (GWP) is 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. Essentially, the higher the GWP of a gas, the more that given gas warms the planet when compared to CO_2 over that period. This time for GWP is typically 100 years.*[44]

2.2 Why Haryana Needs to Focus on SLCPs

Building on its legacy as a Green Revolution leader, Haryana is evolving to sustainably manage the environmental and resource demands brought about by its agricultural prosperity. As India's foodgrain bowl, with a cropping intensity of 181%[45], agriculture remains a cornerstone of the state's economy. Despite an ongoing structural transformation of the state's economy[46], agriculture contributed 16.2% to the state's GSVA in FY 2023-24 . However, excessive usage of natural resources and intensified heat stress pose a serious threat to agricultural productivity.

Haryana's 2022 experience with heat waves, affecting **10–15% of late-sown wheat and up to 19% of chickpea production,** offers **valuable insights for boosting agricultural resilience.** This presents a **proactive opportunity to refine climate-smart farming** and secure future yields[48]. Climate change impact assessments for Haryana indicate that by mid-century, Haryana is likely to witness a 15-17% loss in yield of irrigated rice and wheat, exacerbating food security concerns.[49] While CO_2 significantly contributes to global warming and heat stress, methane traps 80 times more heat than carbon dioxide, making it a major contributor to rising temperatures and heat stress. Haryana has a **significant opportunity to lead sustainable environmental practices.** By **optimizing rice farming and enhancing waste management,** especially given the **2019 landfill emissions estimated at 38.66 kt/yr,** the state can **effectively reduce methane emissions** and boost resource efficiency. The state struggles with inadequate waste management practices, including the lack of waste segregation at the source and the disposal of untreated waste. This is reflected in the Swachh Sarvekshan rankings announced in January last year, where none of the 20 surveyed cities in Haryana secured a spot in the top 100 clean cities list—highlighting the significant progress required for waste management.[51]

Rising temperatures also threaten the state's power usage. Haryana is recognized as an energy-efficient state, scoring 22 out of 30 in the Bureau of Energy Efficiency's ranking.[52] However, rising temperatures reduce the efficiency of thermal power stations, which rely on temperature differentials between the heat source and the cooling system. With the state's heavy dependence on thermal power, increasing temperatures and potential water scarcity could disrupt energy production. This, in turn, forces greater reliance on unscheduled power procurement, straining DISCOM finances. Its impact further extends to agriculture—Haryana's second-largest electricity consumer—compounding challenges for farmers, who are already struggling with climate-induced uncertainties.[53] This sentiment has also been reiterated by the Task Force for Farmer's Welfare Policy, which believes that energy is likely to become a limiting factor for agriculture in the near future.[54]

The IGP is a global hotspot of PM emissions, of which Haryana is a core part. The largest sources of air pollution in the IGP region are household emissions from cookstoves, open burning of agricultural residue, industrial sources (such as brick kilns), transportation emitting significant NO_x emissions contributing towards ozone formation, and solid waste burning. In 2023, the average annual PM_{10} and $PM_{2.5}$ levels in the state were reported to be 128.2 and 63.6 μg/m respectively, both of which surpass the national permissible limit by over 1.5 times.[55] Even though the number of cities reporting poor air quality in winters has reduced from 12 to 5 in the last five years.[56]

Therefore, **to ensure sustainable economic growth of its crucial sectors, and protect them from environmental risks,** the state should move towards a dual strategy approach addressing both CO_2 and non-CO_2 emissions. Reducing SLCPs can have immediate and significant climate benefits with additional co-benefits for food security, livelihood, and human health.

Haryana's Progress towards SLCP mitigation: Reduction in Stubble Burning and incentivizing EV adoption

Haryana saw a significant decline in stubble burning, with a 38% reduction in 2023 compared to the previous year and a 57% decrease over the past two years.[57] Farm fire incidents also saw a decline of 39.7% compared to 2022 and 54.7% fewer than in 2021.[58] This was seen as a result of the government's enforced regulations, where 1,256 challans were issued, imposing fines totalling over ₹32.55 lakh, with 72 FIRs registered related to farm fires.

The state's EV policy is also an important incentive for the people to switch from diesel vehicles to cleaner fuels. The state also has one of the highest vehicle ownership rates in the country, with around 15.3% in terms of four-wheelers and 63.3% in terms of two-wheelers.[59] The total number of registered vehicles in Haryana is around 8.6 million (2019) with a CAGR of 6.87" % (from 2009-19).[60] The Haryana Electric Vehicle (EV) Policy 2022 sets ambitious targets, including converting 100% of the state-owned bus fleet to electric by 2029, and plans to phase out fossil fuel-based commercial fleets in the state by 2030.[61]

3

Report Methodology

Estimating SLCP and other non-CO2 pollutant emissions at the sub-national level is crucial for informed policymaking and effective resource allocation. This localized approach empowers regions to address their unique challenges and maximize the benefits of SLCP mitigation and mitigation of other non-CO2 pollutants.

Against the above backdrop, it becomes evident that the most effective strategy overall is to combine the marathon of decarbonizing the energy system with the sprint to rapidly reduce non-CO_2 and SLCP emissions. This report provides a crucial analysis of SLCPs and other non-CO_2 pollutants in Haryana, a state grappling with significant air quality and climate challenges.

By meticulously examining SLCP and other non-CO_2 pollutant emissions across various sectors, this study illuminates key mitigation opportunities that can pave the way for cleaner air, improved public health, and a more sustainable future. The findings and recommendations presented herein are poised to inform policy decisions, guide strategic investments, and empower stakeholders to take decisive action. Moreover, this report serves as a valuable model for other states in India and beyond, underscoring the pivotal role of sub-national action in addressing SLCPs and other non-CO2 pollutants and achieving a more sustainable future for all.

To effectively address SLCPs and other non-CO_2 pollutant emissions in Haryana, a comprehensive approach is necessary. This involves assessing the current emission levels, evaluating existing policies, and exploring additional strategies. First, a baseline inventory of SLCP and other non-CO_2 pollutant emissions has been established for the year 2019 using available activity data from various government sources, supplemented by academic literature. Second, emissions scenarios were developed: the Baseline Scenario, and Alternate Scenarios which have been aligned with the state's current policy direction and overall vision. These scenarios are marked by quantifiable targets for 2030, 2040, and 2047, aligning with India's developmental aspirations leading up to the 100th year of independence.

3.1 Estimating Baseline Emissions

The baseline emissions for various pollutants — PM_{10}, $PM_{2.5}$, CO, SO_2, NO_x, BC, NMVOCs, and CH_4—were estimated by developing an emissions inventory for the year 2019. Since current policy targets align broadly with the SAPCC 2.0 timeline (2020-2030), 2019 was chosen as the base year for this assessment. The analysis encompasses key sectors such as transportation (tailpipe emissions), industry (including brick kilns, diesel generator sets, and power plants), residential (household cooking and heating), 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). Emissions estimates were based on activity types, emission factors, pollution abatement technologies used, and control efficiency.

The basic equation followed by the study is,

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

where, Ep is the annual emission of a pollutant (p) (kt); R is the region/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[62]. 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.

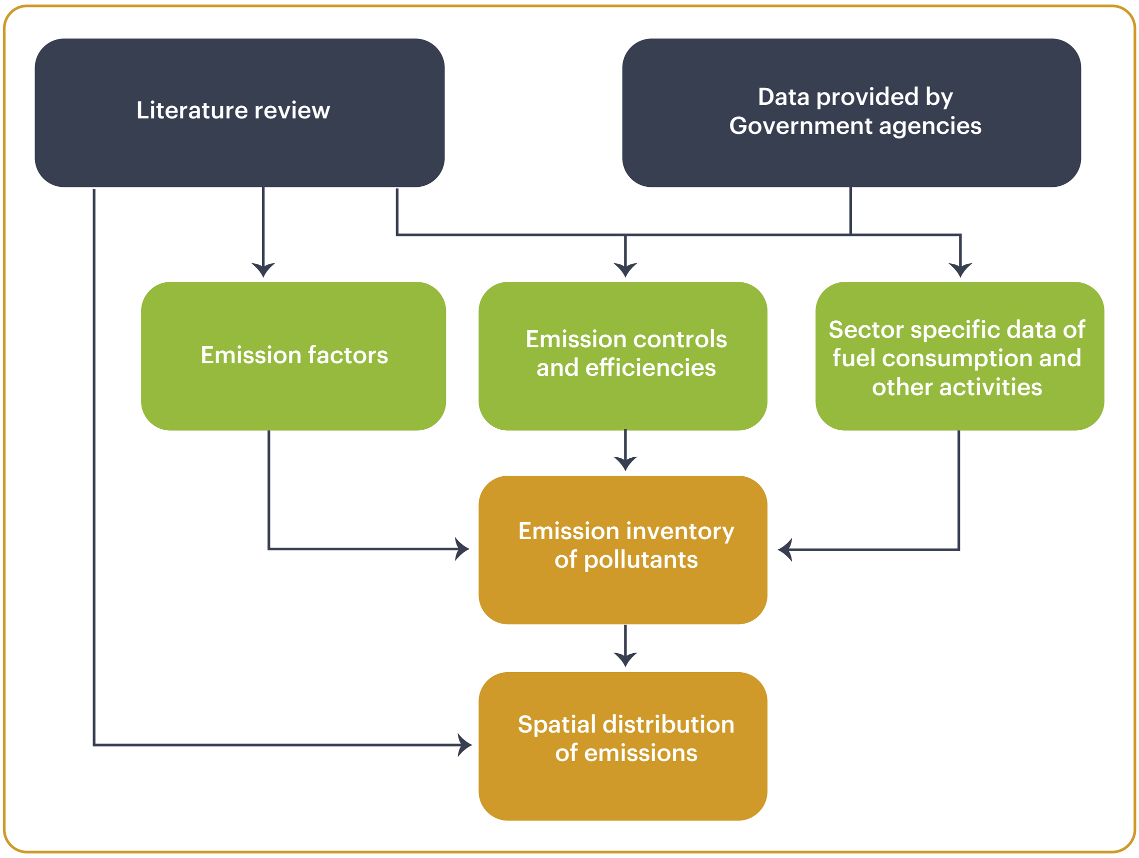


Figure 4: Emission Estimation Framework followed by the Study

3.2 Building Scenarios for the Study

The study analysed the emission growth trajectories of different SLCPs and other non-CO_2 pollutants in Haryana, and two emissions scenarios were developed — Baseline and Alternate. Each represents distinct combinations of policy ambitions and strategies, calculating emission trajectories for milestone years (2030, 2040, and 2047). These scenarios align with the State's Action Plan on Climate Change (SAPCC) and specific sectoral policies enumerated in table 16 in the section below. The scenarios are as follows:

Baseline Scenario (BAU): This scenario reflects the sectoral growth projections for Haryana under current conditions. It takes into account certain interventions that have already been implemented to address SLCP and other non-CO_2 pollutant emissions.

Alternate Scenarios (ALT): These scenarios assume the successful implementation of additional interventions aimed at reducing SLCP and other non-CO_2 pollutant 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.

3.2.1 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 in Table 15) and no additional policy measures are implemented by the state government to specifically address emissions of SLCPs and other non-CO_2 pollutants in these sectors. Essentially, the BAU scenario serves as the reference point against which we compare the effectiveness of mitigation interventions in the alternate scenarios. By contrasting the BAU emissions with those in the Alternate scenarios, we can assess the efficacy of various mitigation strategies.

Table 15: Reference Points for Sector-Wise Growth Projections

Sector	Growth Rate (y-o-y)	Rationale	Reference for Growth rate
Transport	5.16%	Based on the average growth rate of the transport sector from 2012- 13 to 2019-20, as reported in the Haryana Economic Survey Report, 2023. **Controls assumed** ▪ Mopeds: 100% complying with Bharat Stage 3 controls ▪ Light-duty vehicles (cars and vans), Gasoline: 70% of vehicles complying with Bharat Stage VI controls. Diesel: 56% of vehicles complying with Stage VI and 15% of vehicles with Stage IV controls	Transport Sector Growth, Haryana Economic Survey, 2023
Waste	8.4%	Based on the waste collected data as per the CPCB Annual Reports on Implementation of Solid Waste Management Rules, 2016 (2014-21) and the Haryana Pollution Control Board 2023-24	Central Pollution Control Board Annual Reports on Implementation of Solid Waste Management Rules, 2016 (2014-21) Haryana Pollution Control Board 2023-24 (Form –V)
Industry	6.87%	The Average Annual Growth Rate of the Industrial Sector was calculated using data from 2012-13 to 2019-20, as reported in the Haryana Economic Survey Report, 2023. **Controls assumed** Major industries equipped with PM Controls as per the CPCB norms/guidelines.	Industrial Sector Growth, Haryana Economic Survey, 2023
Power	6.55%	The Composite Growth Factor was calculated using a weighted ratio of 85% for GDP and 15% for population. **Controls assumed** Larger power plants equipped with PM controls as per the CPCB norms/guidelines.	Composite Growth Factor of Population and GDP
Livestock	6%	According to the Livestock Census, the total livestock population declined between 2012 and 2019. However, considering future milk demand, it is assumed in this study that the livestock population in the state will increase to meet the rising milk demand while keeping the share of milk production constant at national scale for Haryana.	20th Livestock Census and Haryana Economic Survey, 2023

Sector	Growth Rate (y-o-y)	Rationale	Reference for Growth rate
Agriculture	0.88%	The growth of rice production is assumed based on maintaining Haryana's current 3.38% share of national production, necessitating an expansion of the rice cropping area to meet the projected national demand of 227 Mt/annum by 2050-51.	Agriculture Sector Growth, Haryana Economic Survey, 2023
Residential	4.6%	Emissions were projected based on the growth pattern of LPG consumption in residential households for the state of Haryana. The growth rate of LPG consumption was estimated at 4.6% annually for both urban and rural areas. This estimate is based on LPG consumption data from the Indian Petroleum & Natural Gas Statistics report for the years 2019-22.	Indian Petroleum & Natural Gas Statistics, Government of India

3.2.2 Alternate Scenarios

The Alternate Scenarios represent a combination of existing and planned sectoral interventions by the state and the expected emission reduction outcomes from their implementation. Further, the scenarios also analyse a few policies which are either in the pilot stage or in discussions in other parts of the country, and implementation of these hypothetical scenarios will result in achieving higher standards of SLCP and other non-CO_2 pollutants reduction. These scenarios evaluate the aggregate quantitative impact on activity levels in each sector for the years 2030, 2040, and 2047. In these scenarios, various sectoral policy documents were referred to evaluate the impact.

The selection of specific policy interventions for quantification was based on two criteria: the direct impact of the policy on SLCP and other non-CO_2 pollutant emission sources in the state and the ease of quantifying the policy through set targets to measure its direct mitigation benefits. Since many policies are directional in nature and do not specify exact activity level targets; thus, quantitative estimates for sectoral activities have been assumed, as detailed inTable 17. Wherever the relevant state policies specify quantitative targets, these have been included and extrapolated to address gaps.

The sectoral target assumptions are based on observed trends from 2020 to 2024, under the premise that these trends represent the effective implementation of sectoral policies for the 2020–2030 period—such as the expansion of LPG use, the introduction of BS-VI standards, a complete ban on open burning of agricultural residue, and increased milk production in line with national targets. Further assumptions are informed by the strategic directions outlined in Haryana's sector-specific policies and regulations, supplemented by national policy targets wherever applicable.

3.2.2.a Policy Description and Assumptions:

The Table 16 below provides a description of the different policies and strategies of the state of Haryana which have formed the basis of the alternative scenarios defined in this report.

Table 16: Sector-wise Description of Policies Forming the Basis of the Alternative Scenarios in Each Sector

Sector	Scenario	Policy Basis/Strategy	Description
Transport	ALT-1: Electrification of bus fleet	Haryana EV Policy, 2022	Assesses SLCP and GHG reduction through electrification of the public bus fleet
	ALT-2: Vehicle scrappage policy	Vehicle Scrappage Policy, Haryana 2022	Evaluates emission reduction potential from phasing out 15-mld petrol and 10-year-old diesel vehicles.
	ALT-3: Hydrogen blending in CNG	National Green Hydrogen Policy, 2022 / MoPNG guidelines	Introduces Hydrogen-Enriched CNG (H-CNG) blending in transport fuel.
	ALT-4: Electrifying the vehicular fleet	National FAME-II Scheme, 2019	Evaluates a comprehensive fleet-wide EV transition.
Waste	ALT-1: Of the collected waste, 32% is diverted to waste-to-energy and material recovery facilities	Cluster-Wise Integrated Centralized Waste Processing Strategy and Decentralized Approach, HSPCB, 2024; Department of Environment, 2023	Maximizing Recycling through Decentralized Waste Management Approaches
	ALT-2: Of the collected waste, 40% is diverted to composting, anaerobic digestion, waste combustion and recycling	Cluster-Wise Integrated Centralized Waste Processing Strategy, HSPCB, 2024	Short-Term Rollout of enhancing resource recovery and maximising recycling efforts
	ALT-3: Of the collected waste, 50% is diverted to composting, anaerobic digestion, waste combustion and recycling		Medium-term scaling of resource recovery and recycling efforts
	ALT-4: Of the collected waste, 60% is diverted to composting, anaerobic digestion, waste combustion and recycling		Long-Term Development of Integrated Cluster-Based Centralized Waste Treatment Facilities

Sector	Scenario	Policy Basis/Strategy	Description
Industry (Including power plants, brick kilns, and DG sets)	ALT-1: Transition from coal to natural gas for combustion in industrial boilers	NCAP Industrial Emission Guidelines (MoEFCC)	Advocates gaseous fuels and stringent PM, SO_2, and NO_2 standards for industries using solid fuels.
	ALT-2: Fuel consumption reduction due to community boilers	CPCB Guidelines on Community Boilers, 2024	Promotes shared energy-efficient boilers for MSME clusters to reduce emissions.
	ALT-3: Expansion of Green Hydrogen	Haryana Green Hydrogen Policy, 2024 (Draft)	Explore the use of green hydrogen in industrial applications as an alternative fuel.
	Overarching measures covered in all industry scenarios	For Brick Kilns sector: Report by CPCB in O.A. No. 1016 of 2019 (Utkarsh Panwar vs. Central Pollution Control Board & Ors.), NGT	Zig-Zag brick firing technology to Coal-fired Tunnel brick kiln
		For DG Sets: NCAP Industrial Emission Guidelines (MoEFCC), CPCB Guidelines	Retrofitting of Emission Control Devices/Equipment on generators in use.
		For Power sector: Haryana Solar Policy 2023 Haryana Bio-energy Policy 2018 Renewable Purchase Obligation and Renewable Energy Certificate Haryana SAPCC 2023	Energy generation from renewable energy and biomass
Livestock	ALT-1: Gausamvardhan Systematic decadal reduction of cross breed cattle population by 20% and converting 5% buffalo population to Murrah buffalo while increasing the indigenous cattle population to achieve the targeted milk demand in the state.	The Haryana Gauvansh Sanrakshan and Gausamvardhan Act, 2015	Promotion of Sustainable Livestock Practices through Indigenous Breeds
	ALT-2: Limited Gau Charan Bhumi All indigenous cattle above 1 year of age would be grazed in pastureland; in line with government initiatives to protect grazing lands and assist gaushalas.	Gau Charan Bhumi policy, under The Haryana Gauvansh Sanrakshan and Gausamvardhan Act, 2015	Utilizing Panchayati Land for Pasture-Based Grazing to Promote Indigenous Cattle and Reduce Methane Emissions

Sector	Scenario	Policy Basis/Strategy	Description
	ALT-3: Purna Gau Charan Bhumi Assuming there would be enough land for open grazing of all dairy cattle, they will graze in open pasture while 10% of adult non-dairy cattle will also be allowed to graze in open pasture compared to Scenario 1.	Combined Strategy	Expansion of Open Pasture Grazing for Dairy Cattle Leading to Significant Methane Emission Reductions
Agriculture	ALT-1: Implementation of System of Rice Intensification (SRI)	System of Rice Intensification (SRI) programme, 2015-16	Implementation of System of Rice Intensification (SRI)
	ALT-2: Implementation of Natural Farming on SRI converted land	System of Rice Intensification (SRI) Programme, 2020	Implementation of Natural Farming on SRI converted land
	ALT-3: Combined implementation of ALT 1, ALT 2, and crop diversification	State Agriculture Policy, SAPCC 2021-2030	Combined implementation of ALT 1, ALT 2, and crop diversification.
Residential	ALT-1: Adoption of Improved Less-smoke Emitting Cookstoves	National Biomass Cookstove Programme (NBCP), MNRE	Promote improved biomass cookstoves to reduce indoor air pollution and SLCP emissions.
	ALT-2: Shift to Improved Cookstoves, Biogas, Solar-based Cooking Systems	New National Biogas and organic Manure Management Programme (NNBOMP)	Encourages adoption of improved cookstoves, biogas plants and solar cooking systems in rural households.
	ALT-3: Phased Transition to Solar Cooking System	"Surya Nutan" Solar Cooking Initiative (Indian Oil and Ministry of Petroleum & Natural gas)	Maximising the share of clean indoor solar cooking in rural households by distributing "Surya Nutan" devices, along with biogas and improved cookstoves

***The policies and guidelines considered in this study, as summarized in the table above, form the basis for assessing emission reduction potential across sectors. However, most of these policies are directional in nature and do not specify explicit year-wise or long-term quantified targets. To facilitate the assessment, a set of assumptions has been made regarding the phased implementation of these strategies. These assumptions are intended to reflect a realistic level of adoption over time, based on the feasibility of implementation and expert judgment.**

Table 17 below presents the assumed implementation levels under each alternative scenario. The indicative percentages reflect the likelihood of achieving the specified targets within the given timelines and serve to quantify the potential impacts of these strategies. This approach allows the development of plausible pathways for the state to evaluate and prioritize policy options.

Table 17: Sector-wise Activities and (Quantified) Targets for SLCP and Other Non-CO_2 Pollutant Emission Reductions under the Alternative Scenarios

Sector	Strategies	Description of Assumptions
Transport	ALT-1	**Bus Fleet Electrification** ▪ 100% conversion of state transport buses and bus fleets in Faridabad and Gurugram to EVs in 2030. ▪ 50% conversion of all bus fleets in all districts to EVs in 2040. ▪ 100% conversion of all bus fleets in all districts to EVs in 2047.
	ALT-2	**Vehicle Scrappage Policy** ▪ 30% scrappage of all 15-year-old petrol and 10-year-old diesel vehicles in 2030. ▪ 60% scrappage of all 15-year-old petrol and 10-year-old diesel vehicles in 2040. ▪ 80% scrappage of all 15-year-old petrol and 10-year-old diesel vehicles in 2047.
	ALT-3	**Hydrogen Blending in CNG** ▪ 0% blending of hydrogen in CNG (H-CNG) in 2030. ▪ 18% H-CNG blending in buses in 2040. ▪ 18% H-CNG blending in cars, autos, light commercial vehicles (LCVs), and buses in 2047.
	ALT-4	**Comprehensive EV Policy for All Vehicles** ▪ 50% conversion of newly registered buses, two- and three-wheelers, and cars to EVs in 2030. ▪ 70% conversion of newly registered buses, two- and three-wheelers, and cars to EVs in 2040. ▪ 100% conversion of newly registered buses, two- and three-wheelers, and cars to EVs in 2047.
Waste	ALT-1	▪ 32% of waste going to landfill/dumping area is diverted of which 28.05% is diverted to waste-to-energy plant and 71.9% to MRFs
	ALT-2	▪ 40% of waste going to landfill/dumping area is diverted of which 12.88% is diverted for composting, 1.37% for anaerobic digestion, 24.05% for waste combustion and 61.68% for recycling.
	ALT-3	▪ 50% of waste going to landfill/dumping area is diverted of which 12.88% is diverted for composting, 1.37% for anaerobic digestion, 24.05% for waste combustion and 61.68% for recycling.
	ALT-4	▪ 60% of waste going to landfill/dumping area is diverted of which 12.88% is diverted for composting, 1.37% for anaerobic digestion, 24.05% for waste combustion and 61.68% for recycling.
Industry (including power plants, brick kilns, and DG sets)	ALT-1	▪ The transition of coal to Natural Gas is assumed to reach 25%, 50% and 100% in industries by 2030, 2040 and 2047, respectively. ▪ The Retrofit Emission Control Device (RECD) in DG sets is expected to reduce emissions (PM and BC) by 70% for the years 2030, 2040 and 2047 ▪ Conversion from Zig-Zag brick firing technology to Coal-fired Tunnel brick kiln: By 2030 - 90% Zig-Zag, 10% Tunnel Kiln; by 2040 - 80% Zig-Zag, 20% Tunnel Kiln; by 2047 - 70% Zig-Zag, 30% Tunnel Kiln. ▪ Energy generation from renewable energy and biomass. 20%, 30% and 40% of power generation from Biomass and Renewable energy by 2030, 2040 and 2047 respectively.

Sector	Strategies	Description of Assumptions
	ALT-2	▪ Implementation of community boilers and fuel consumption is expected to decrease by 30% for the years 2030, 2040 and 2047. ▪ The Retrofit Emission Control Device (RECD) in DG sets is expected to reduce emissions (PM and BC) by 70% for the years 2030, 2040 and 2047 ▪ Conversion from Zig-Zag brick firing technology to Coal-fired Tunnel brick kiln: By 2030 - 90% Zig-Zag, 10% Tunnel Kiln; by 2040 - 80% Zig-Zag, 20% Tunnel Kiln; by 2047 - 70% Zig-Zag, 30% Tunnel Kiln. ▪ Energy generation from renewable energy and biomass. 20%, 30% and 40% of power generation from Biomass and Renewable energy by 2030, 2040 and 2047 respectively.
	ALT-3	▪ The introduction of Green Hydrogen is assumed to reach 5% and 8% in industries by 2040 and 2047, respectively. ▪ The Retrofit Emission Control Device (RECD) in DG sets is expected to reduce emissions (PM and BC) by 70% for the years 2030, 2040 and 2047 ▪ Conversion from Zig-Zag brick firing technology to Coal-fired Tunnel brick kiln: By 2030 - 90% Zig-Zag, 10% Tunnel Kiln; by 2040 - 80% Zig-Zag, 20% Tunnel Kiln; by 2047 - 70% Zig-Zag, 30% Tunnel Kiln. ▪ Energy generation from renewable energy and biomass. 20%, 30% and 40% of power generation from Biomass and Renewable energy by 2030, 2040 and 2047 respectively.
Livestock	ALT-1	▪ Gausamvardhan - Gradually reducing the crossbreed cattle population and replacing it with Buffalo and indigenous cattle population as per the Scheme for the Conservation and Development of Indigenous Cattle
	ALT-2	▪ Limited Gau Charan Bhumi - The Haryana government has implemented this policy, to support the open grazing of cattle, particularly through initiatives that provide and protect grazing lands, to assist cow shelters.
	ALT-3	▪ Purna Gau Charan Bhumi - Under this scenario, it was assumed that there will be enough land for open grazing of all dairy cattle of cross breed, indigenous and buffalo.
Agriculture	ALT-1	▪ Implementation of System of Rice Intensification (SRI) - Gradual increase in the adoption of SRI, with a targeted annual growth rate of 5% based on the rice cultivation area during 2019-20.
	ALT-2	▪ Implementation of Natural Farming in rice cropping - It has been projected that 5% of the SRI-adopted area will transition to Natural Farming practices annually.
	ALT-3	▪ Crop diversification- In addition to ALT1 and ALT2, it is assumed that 5% of the rice cultivation area (based on the 2019-20 baseline) will be converted annually to non-rice crops, particularly leguminous crops.
Residential	ALT-1	▪ Annual LPG consumption growth of 4.6% at the state level ▪ Biomass-using households (remaining after LPG penetration) will shift to improved cookstoves with a thermal efficiency of 28% during 2030,2040 and 2047
	ALT-2	▪ Annual LPG consumption growth of 4.6% at the state level ▪ 30%, 30% and 40% of non-LPG-using households in rural Haryana will shift to improved cookstoves, biogas and solar-based cooking systems respectively during 2030 and 2040.

Sector	Strategies	Description of Assumptions
	ALT-3	▪ Annual LPG consumption growth of 4.6% at the state level during 2030, 2040. Beyond 2040 no further LPG penetration is assumed in rural Haryana and accordingly, newly estimated households will depend on solar-based cooking ▪ 20%, 20% and 40% of non-LPG-using households in rural Haryana will shift to improved cookstove, biogas and solar-based cooking respectively during 2030 ▪ During 2040, 70% of non-LPG-using households in rural Haryana will shift to solar-based cooking whereas, the remaining 20% and 10% will use biogas and improved cookstove respectively ▪ 100% of non-LPG households during 2047 will shift to solar-based cooking.

3.2.3 Data Limitations and Resolution

01 Due to the absence of region-specific emission factors (EFs), emission factors from similar regions have been used as proxies.

02 In the absence of state-specific targets and data on fuel transition trends, national-level goals have been used. While these may need adjustment to reflect local conditions, they offer useful directional guidance for policymakers.

03 Certain small sectors, such as roadside eateries, are not included in the emission inventory due to a lack of compiled state-level data and reliance on primary surveys. However, their contribution to overall state emissions is expected to be negligible.

04 Data on household fuel consumption for cooking and heating in the residential sector is collected every ten years. Recent changes in usage patterns have been estimated using the 76th NSSO report by the Ministry of Statistics and Programme Implementation.

05 Due to limited district-level data on vehicle de-registration, it is assumed that the central government's directive is being implemented uniformly across the state.

06 The extent of policy implementation across different regions or industries is not fully known. Therefore, uniform assumptions—such as control efficiency—have been applied across similar industries based on government directives.

07 Given the lack of information on location-specific sectoral strategies for future years, it has been assumed that interventions will be implemented uniformly across the state.

4

Results of the Study

4.1 Baseline Emissions

The results of estimations and emission contributions from different sectors for Haryana in 2019 are shown in Figure 5.

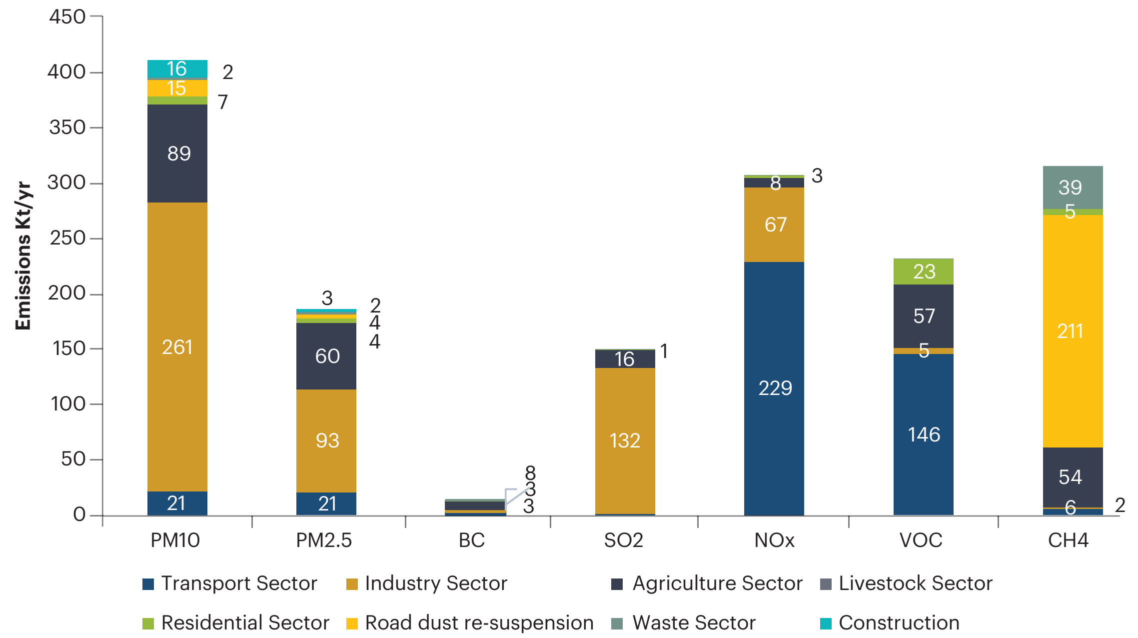


Figure 5: Sectoral Emissions of PM_{10}, CH_4, NO_X, NMVOCs, $PM_{2.5}$, SO_2 and BC in Haryana for 2019

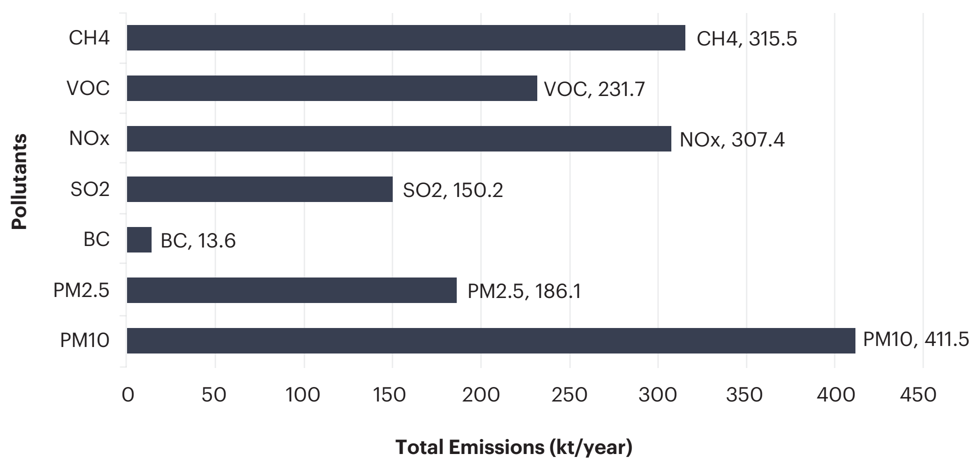


Figure 6: Total Emissions of PM_{10}, CH_4, NO_X, NMVOCs, $PM_{2.5}$, SO_2 and BC in Haryana for 2019

This section outlines a pollutant-wise analysis of pre-dominant SLCP and other non-CO2 pollutant emissions in Haryana along with sectoral insights to aid the development of potential mitigation scenarios for the state. The absolute emissions presented in the graph provide a clear picture of the total amount of pollutants being emitted in the state of Haryana. This will be crucial for understanding the scale of the problem and for setting realistic targets for reduction in each sector. These findings indicate that efforts to reduce methane emissions should prioritize livestock management and agricultural interventions and consider remediation of landfills. Notably, the absolute emissions of black carbon in the state are significantly lower compared to the other SLCPs and non-CO_2 pollutant. One potential reason for this discrepancy could be the underestimation of BC emissions from unorganized sectors, such as restaurants and MSMEs, due to a lack of comprehensive fuel consumption data during analysis.

Table 18: Pollutant-wise analysis of pre-dominant SLCP and other non-CO_2 pollutant emissions in Haryana in 2019

Pollutant	Total Emissions (kt/yr)	Major Contributing Sectors	% Share by Major Sectors	Key Observations
PM_{10}	411.50	Industry, Agriculture, Transport, Road dust	Industry: 64% (261 kt/yr), Agriculture: 22% (89 kt/yr) Road dust: 4% (15 kt/yr)	Industrial sources (coal, kilns, thermal power plants) dominate; crop burning and road dust also contribute significantly.
$PM_{2.5}$	186.14	Industry, Agriculture, Transport	Industry: 50% (93 kt/yr), Agriculture: 32% (60 kt/yr), Transport: 11% (21 kt/yr)	Transport sector's share in PM2.5 is higher compared to PM10 due to emissions from diesel vehicle exhausts.
Black Carbon (BC)	13.56	Agriculture, Transport, Industry	Agriculture: 58% (8 kt/yr), Transport: 20% (3 kt/yr), Industry: 19% (3 kt/yr)	Mostly from open burning of crop residue, coal use and incomplete combustion of fossil fuels, particularly in diesel engines.
SO_2	150.15	Industry, Agriculture	Industry: 88% (132 kt/yr), Agriculture: 11% (16 kt/yr)	Dominated by coal-based industrial emissions and partially stemming from crop residue burning.
NO_x	307.39	Transport, Industry	Transport: 75% (229 kt/yr), Industry: 22% (67 kt/yr)	Highest emissions from transport sector indicating that emphasis needed on improvement of vehicle emission standards and promotion of cleaner modes of transportation. High NOx emissions from transport also indicates high sensitivity to ozone formation.
VOCs	231.68	Transport, Agriculture, Residential	Transport: 63% (146 kt/yr), Agriculture: 25% (57 kt/yr), Residential: 10% (23 kt/yr)	Transport has highest contribution to VOCs through fossil fuel combustion. Residential sector also contributes partially towards VOC emissions through residential cooking.
CH_4	315.53	Livestock, Agriculture, Waste	Livestock: 67% (211 kt/yr), Agriculture: 17% (54 kt/yr), Waste: 12% (39 kt/yr)	Enteric fermentation in livestock is dominant source of methane emissions, followed by rice cultivation and landfills

4.1.1 Priority Sectors for Emission Reduction

Figure 7 provides a comprehensive overview of the percentage contributions of different sectors to the emissions of key pollutants. Understanding these contributions and the range of pollutants emitted by a sector's activities is crucial for selecting a priority sector for targeted interventions for emission reduction of different SLCPs and other non-CO_2 pollutants.

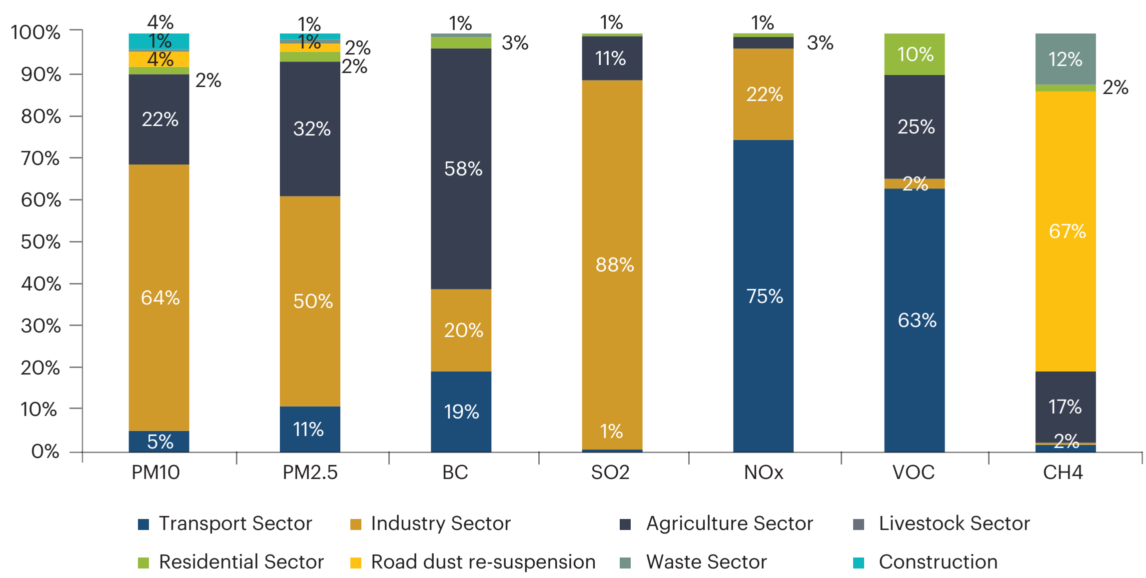


Figure 7: Proportional Contributions of Sectors to Emissions of PM_{10}, $PM_{2.5}$, BC, SO_2, NO_X, NMVOCs and CH_4 in Haryana for 2019

The analysis of baseline emissions for Haryana indicates that, at a broader level, emission mitigation from the industry, transport, and agricultural sectors should be prioritized due to their contributions to the emission of a larger number of pollutants, and the consequent potential to achieve greater gains in terms of overall reductions in SLCPs and other non-CO_2 pollutants per intervention. Further in the case of the transport sector, mitigating NO_x and NMVOC emissions would also reduce the presence of secondary pollutants like ozone and nitrates. Mitigating SLCP and other non-CO_2 pollutant emissions from the industry sector, specifically in the case of Particulate Matter and SO_2 must also be prioritized. However, emissions from the residential sector in the case of NMVOCs as well as waste and livestock sector in the case of methane, must not be overlooked. A comprehensive, multi-sectoral approach can aid the achievement of holistic improvements in air quality and emission reductions across Haryana see in Table 19

Table 19: Proportional contribution of Different Sectors to SLCP and other non-CO_2 pollutant emissions in Haryana in 2019

Sector	Key Pollutants and Emission Contribution of the Sector	Description
Transport	75% of total NOx emissions 63% of total NMVOC emissions	The NOx emissions from the transport sector have the highest sensitivity towards ozone formation in the country.
Waste	12% of total CH_4 emissions 11% of total SO_2 emissions	Major contributor of CH_4 emissions in Haryana largely due to prevalent waste management and landfill practices of the state.
Industry	88% of total SO_2 emissions 64% of total PM_{10} emissions 50% of total $PM_{2.5}$ emissions 22% of total NO_x emissions	The NOx and SO_2 emitted from these sources travel by air and might transform into fine particulate matter within one week, further contributing to high levels of PM2.5 concentrations.
Livestock	67% of total CH_4 emissions	Highest contribution to methane emissions amongst all sectors
Agriculture	32% of total $PM_{2.5}$ emissions 25% of total NMVOC emissions 22% of total PM_{10} emissions 17% of total CH_4 emissions	Significant contribution to particulate matter emissions and methane emissions.
Residential	10% of total NMVOC emissions	Minimal contribution to other pollutants compared to other sectors.
Construction and Road Dust Re-suspension	Marginal contribution to particulate matter emissions	

4.2 Sectoral assessments

4.2.1 Transport

The transport sector plays a critical role in propelling India's economic growth and fulfilling its developmental ambitions. However, it also poses a substantial challenge due to its role as a major polluter at local, state, and regional levels. Primarily relying on fossil fuels, the transport sector significantly contributes to air pollution and climate change along with related health impacts. To mitigate air pollution from transportation, India has implemented a range of policies that focus on stringent fuel emission standards (Bharat Stage) and fuel efficiency standards (CAFE Norms). Additionally, there is a recent push by the Government of India to support the adoption of e-mobility (FAME scheme) through targeted subsidies and incentives for both public and private transport segments. Integrated transport

planning has also gained emphasis, encompassing strengthening public transport systems, improving last-mile connectivity, reducing transport demand, and promoting non-motorized transport. India has introduced a Vehicle Scrappage Policy (2022) to incentivize the systematic removal of old polluting vehicles.

The transportation sector in Haryana plays a crucial role in supporting the state's urbanization and industrialization, but it also significantly contributes to the region's air quality issues. With Haryana's extensive and expanding road network and over 1.32 crore vehicles registered as of 2023, vehicular emissions have become a prominent source of air pollution in the state[64]. These emissions are estimated to contribute significantly to BC and NO_x levels, impacting both air quality and public health. In response to these environmental concerns, the Government of Haryana has proactively undertaken measures to reduce transport-related emissions by promoting cleaner alternatives, implementing stricter emission norms, and enhancing public transportation infrastructure. Through initiatives encouraging electric vehicle adoption, cleaner fuel use, and public involvement in sustainable transport practices, Haryana aims to lower the carbon footprint of its transport sector and foster healthier air quality for its residents.

BAU Scenario of the Transport Sector

The study used vehicle registration growth rates from the VAHAN database and the Ministry of Road Transport and Highways (MoRTH) 2019 Statistical Yearbook to project transport emissions under a BAU scenario. Vehicle numbers are assumed to grow at a rate of 5.16% annually, reflecting current patterns without additional interventions[65]. Additionally, the adoption of BS-VI emission norms from 2020 has been factored in, with BAU emission projections calculated for 2030, 2040 and 2047. Emission loads are estimated for the years 2019, 2030, 2040, and 2047, illustrated in Figure 8 below.

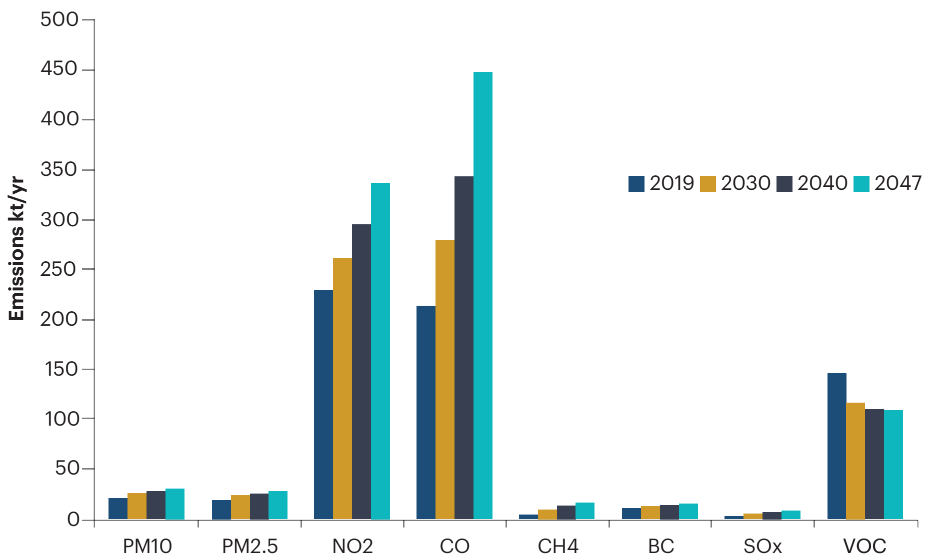


Figure 8: Emissions of PM_{10}, $PM_{2.5}$, NO_X, CO, CH_4, BC, SO_2 and NMVOCs during 2020, 2030, 2040 and 2047 from the transport Sector under the BAU scenario

Under the BAU scenario, emissions from Haryana's transport sector are projected to rise substantially over time.

Table 20: Projected Percentage Increase in Emissions from Haryana's Transport Sector by 2047 (BAU Scenario)

1. PM_{10} emissions increase by 46%, reaching 31 kt in 2047, while $PM_{2.5}$ emissions grow by 37%, reaching 28 kt by the same year.[66]
2. NO_x emissions show a significant rise of 47%, from 229.3 kt in 2019 to 337 kt in 2047.[67]
3. Both CH_4 and BC emissions also increase, with CH_4 rising by 196% and BC by 43%.[68]

The growth in emissions is moderately lesser than the growth of the sector due to already planned interventions which reduce the emission intensity of the sector in the region.[69]

Alternate Scenarios of the Transport Sector

The study has evaluated four alternate scenarios (Table 26) which include electrification of the bus fleet (ALT-1), vehicle scrappage policy (ALT-2), hydrogen blending in CNG (ALT-3), and a comprehensive EV policy for all vehicle types (ALT-4). A detailed description of all the assumed control strategies in the sector, which have been tested for their emission reduction potential, is provided in Table 21.

Table 21: Targets Assumed Under Alternate Scenarios for the Transport Sector

Scenarios	2030	2040	2047
ALT 1: Electrification of bus fleet	100% in Gurugram and Faridabad	50%	100%
ALT 2: Vehicle scrappage policy	30%	60%	80%
ALT 3: Hydrogen blending in CNG	0%	18% (buses)	18% (cars, autos, LCVs, and buses)
ALT 4: Electrifying the vehicular fleet (covering newly registered vehicles such as buses, two-wheelers, three-wheelers, and cars)	50%	70%	100%

Alternative scenario 1 (ALT1): Electrification of Bus Fleet

(Based on Haryana EV Policy, 2022)

In the **ALT-1 scenario,** we assess the impact of electrifying the bus fleet across Haryana to align with the state's environmental and urban mobility goals. The Haryana government, under its Electric Vehicle Policy 2022, has set out comprehensive plans to reduce transport-related emissions through a phased transition to electric buses, specifically targeting full electrification of state transport and city buses in Faridabad and Gurugram by 2030, followed by progressive electrification across all districts by 2040 and 2047. This policy is designed to establish Haryana as a leader in EV adoption, leveraging subsidies for manufacturers and buyers, charging infrastructure expansion, and dedicated research and development in EV technology. These initiatives support both national objectives under the FAME II scheme (Faster Adoption and Manufacturing of Hybrid and Electric Vehicles in India- Phase II) and Haryana's commitment to air quality improvement, energy independence, and sustainable urban growth.

In this scenario, electrification of the bus fleet is planned in stages, aiming for 100% conversion of state and city buses in Faridabad and Gurugram by 2030, 50% electrification of all bus fleets across districts by 2040, and complete fleet conversion by 2047. These target assumptions are supported by policies that facilitate vehicle cost reduction, infrastructure advancements, and increased accessibility of EVs. The impact of this intervention is expected to be significant, with projected reductions in emissions by 2047 compared to the BAU scenario: a 12.6% decrease in PM_{10}, 10.1% in $PM_{2.5}$, 14.8% in SO_2, 11.0% in NO_x, 13.8% in NMVOCs, 24.5% in CH_4, and 11.9% in BC.

Alternative scenario 2 (ALT2): Phased Implementation of Vehicles Scrappage Policy

(Based on Vehicle Scrappage Policy, Haryana 2022)

In the ALT-2 scenario, we analyse the impact of a vehicle scrappage policy in Haryana, aimed at reducing emissions from older, less efficient vehicles. The Haryana government has implemented a comprehensive vehicle scrappage policy targeting the scrapping of petrol vehicles over 15 years old and diesel vehicles over 10 years old. This initiative aligns with the state's goals for improved air quality and sustainable urban mobility. By removing older vehicles from the roads, the policy not only aims to reduce emissions but also encourages the adoption of cleaner, more efficient vehicles in the market.

The scrappage strategy is set to achieve varying levels of vehicle replacement, with targets of 30% scrappage by 2030, 60% by 2040, and 80% by 2047. The impact of this intervention is expected to be significant, with projected reductions in emissions by 2047 compared to the BAU scenario: a 37.2% decrease in PM_{10}, 29.3% in $PM_{2.5}$, 24.3% in NO_x, 50.4% in CH_4, 23.3% in BC, and 19.9% in NMVOCs.

Alternative scenario 3 (ALT3): Hydrogen-Enriched CNG Blending

(Based on National Green Hydrogen Policy, 2022 and MoPNG guidelines)

The ALT-3 scenario analysed Hydrogen-Enriched CNG (H-CNG) blending in the transport sector. In this scenario, the study explores the gradual integration of H-CNG into the transportation sector. Specifically, we consider a hydrogen blend of 0% in 2030, increasing to 18% in buses by 2040, and extending to 18% in cars, autos, LCVs, and buses by 2047. This approach is based on the growing emphasis on hydrogen as a cleaner energy source and the supportive policy framework for its adoption.

Hydrogen, being light, highly combustible, and environmentally benign, plays a pivotal role in India's clean energy transition, particularly through Green Hydrogen (GH) initiatives under the National Green Hydrogen Mission. This mission aspires to position India as a global hub for GH production, utilization, and export, fostering innovations in the transportation sector among others.

The Ministry of Petroleum & Natural Gas (MoPNG) has spearheaded efforts such as the pilot project at Delhi's Rajghat Bus Depot with an 18% hydrogen blend and future green hydrogen-based refuelling stations.[70] In Haryana, the government is committed to advancing hydrogen technology through its own policies, including the Green Hydrogen Policy 2024.[71] This policy framework encourages pilot projects, industry partnerships, and infrastructure development to facilitate H-CNG adoption. The state's efforts include providing subsidies and incentives to create a conducive environment for the integration of hydrogen into the transport sector. By implementing this H-CNG blending scenario, emissions reductions are projected by 2047 compared to the BAU scenario as depicted in the following Table 22.

Alternative scenario 4 (ALT4): Electrification of Vehicular Fleet Segments

(Based on National FAME-II Scheme, 2019)

The ALT-4 scenario examines the impact of electrifying the vehicular fleet in Haryana, similar to the initiatives explored in ALT-1. In the ALT-4 scenario, the electrification of various segments of the vehicular fleet—covering newly registered vehicles such as buses, two-wheelers, three-wheelers, and cars—is planned in phases, targeting 50% conversion by 2030, 70% by 2040, and full conversion by 2047. These target percentages are based on Haryana's commitment to EV adoption, the development of supportive infrastructure, and the incentives and tax exemptions provided to encourage uptake. The impact of these efforts is expected to be significant, with projected reductions in emissions by 2047 compared to the Business-As-Usual (BAU) scenario: a 41% decrease in PM_{10}, a 33% decrease in $PM_{2.5}$, a 28% decrease in NO_x, a 54% decrease in CH_4, a 27% decrease in BC, a 21% decrease in SO_2, and a 24% decrease in NMVOCs.

Table 22: Change in Transport Emissions Under Alternate Scenarios, Compared to 2047 Emissions Under BAU

Scenarios	$PM_{2.5}$	PM_{10}	SO_2	NO_x	NMVOCs	BC	CH4
ALT 1: Electrification of bus fleet	-10.1%	-12.6%	-14.8%	-11.0%	-13.8%	-11.9%	-24.5%
ALT 2: Vehicles scrappage policy	-29.3%	-37.2%	-17%	-24.3%	-19.9%	-23.3%	-50.4%
ALT 3: Hydrogen blending in CNG	-3.5%	-5.0%	-4.9%	-6.4%	-3.2%	-10.3%	-11.4%
ALT 4: EV Policy for all vehicles	-33%	-41%	-21%	-28%	-24%	-27%	-54%

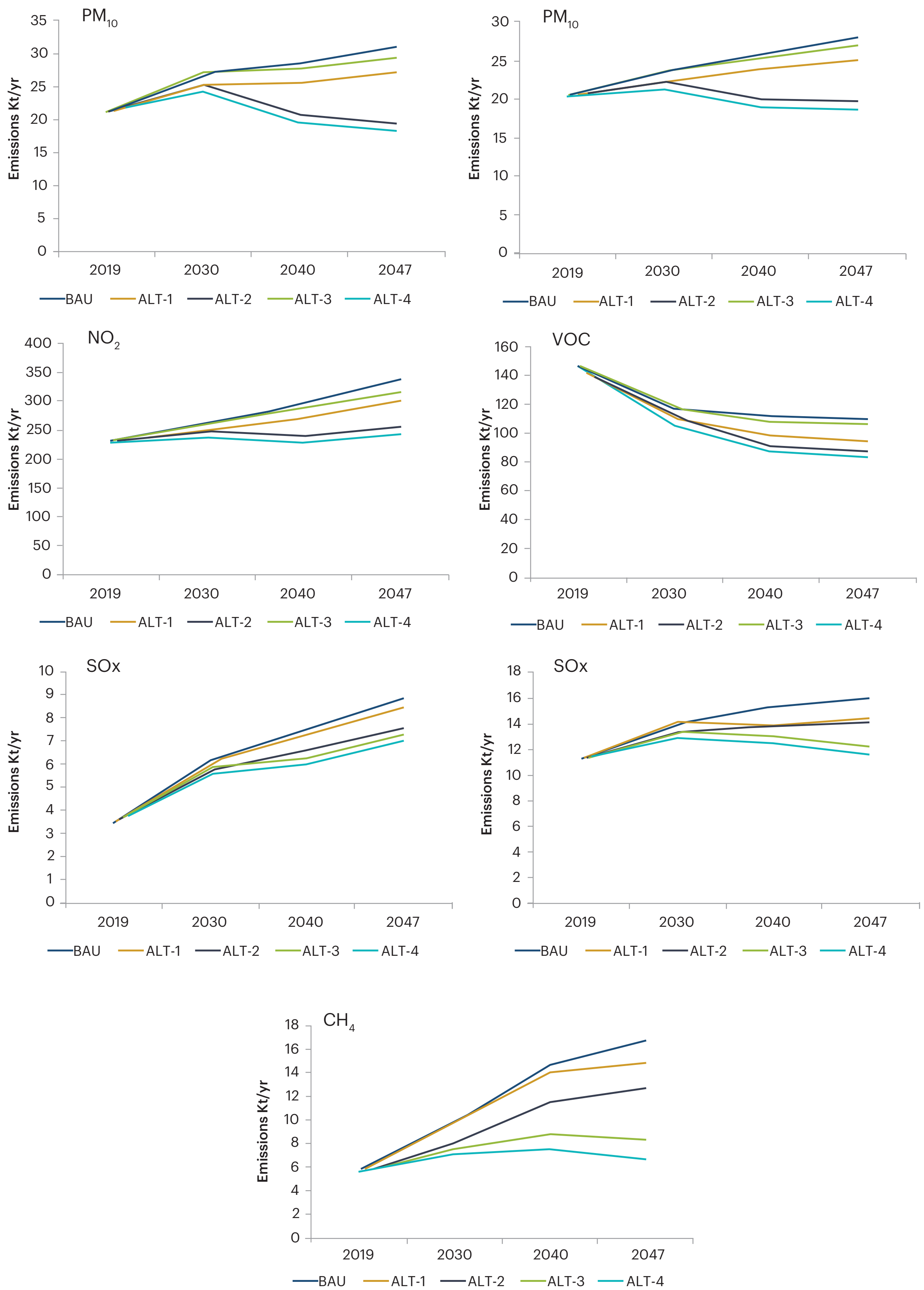


Figure 9: Emissions of PM_{10}, $PM_{2.5}$, NO_X, NMVOCs, SO_2, BC and CH_4 during 2030, 2040 and 2047 from the Transport sector under BAU, ALT-1, ALT-2, ALT-3 and ALT-4 scenario

4.2.2 Waste Sector

With over 27 million residents, Haryana generates a substantial volume of municipal solid waste (MSW) daily, creating significant strain on its waste collection, treatment, and disposal systems. Despite various efforts to enhance waste management, the state continues to experience challenges such as low waste processing rates, heavy reliance on landfills, and the prevalence of open burning—factors that contribute to environmental degradation and pose public health risks.

Currently, Haryana achieves 99% collection efficiency in urban areas, capturing nearly all waste generated. However, only 8% of this waste is processed (as per SWEET analysis), with the state primarily relying on composting and anaerobic digestion for organic waste. A large share of unprocessed waste ends up in dumpsites, which not only consume valuable land but also release substantial amounts of methane and other pollutants. Open burning remains a critical issue, emitting particulate matter ($PM_{2.5}$ and PM_{10}), BC, and other harmful substances that worsen local air quality.

To mitigate these challenges, Haryana is gradually shifting towards more sustainable waste management policies. Increased focus is being placed on source segregation, promoting recycling, and enhancing processing infrastructure, including material recovery facilities (MRFs) and waste-to-energy plants. These efforts are aligned with India's Swachh Bharat Mission (Clean India Mission), which aims to reduce landfill dependence and boost material recycling and reuse.

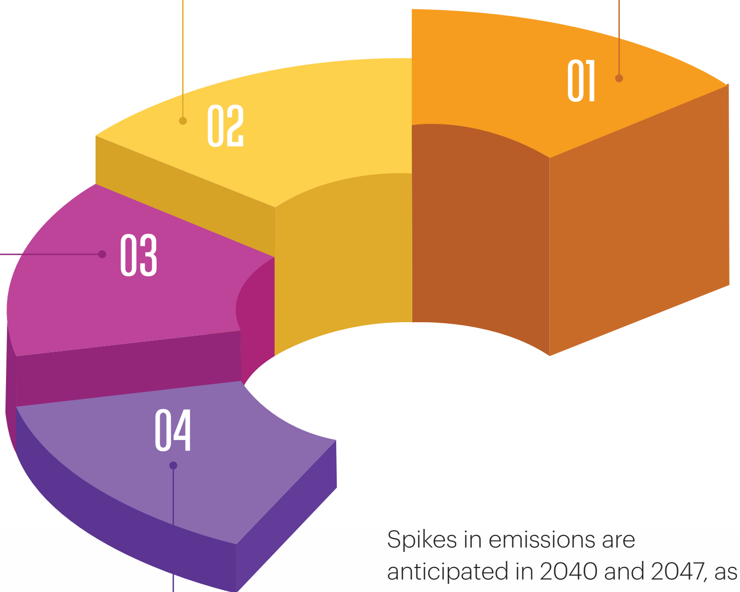
BAU Scenario of the Waste Sector

A BAU scenario for waste sector emissions has been developed which projected the emissions till 2047 in the Solid Waste Emission Estimation Tool (SWEET). The BAU scenario represents a scenario where, of the total waste generated, 1,906,961 tons per annum (TPA) (with a 99% collection efficiency) is being collected, but only about 8% is processed. In this BAU, the state focuses solely on composting and anaerobic digestion for organic waste treatment. Of the approximately 8% of waste being processed, the majority (7.1%) is composted, while the remaining 0.76% is directed towards anaerobic digestion. The emissions have been projected till 2047 based on the assumption that current trends and patterns will continue without significant changes. In the case of open burning, although it is banned in India, municipal solid waste (MSW) is still burned due to gaps in the waste management system. Based on findings from TERI's previous studies, this study includes open waste burning rate in the baseline scenario as 5% of uncollected waste being burnt by residents and 10% being burnt at landfill. Only municipal solid waste is considered in this analysis, excluding agricultural, construction, and demolition waste and other types of waste. Based on the growth rates (8.4%) 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 10.

Figure 10 outlines the BAU emissions projections for Haryana's waste sector, focusing on six key pollutants: CH_4, PM_{10}, $PM_{2.5}$, SO_2, and BC. The emissions in the baseline primarily result from the open burning of waste by residents and the spontaneous burning and decomposition of waste at landfill sites.

For PM_{10}, $PM_{2.5}$, SO_2, and BC, the primary source of emissions is open waste burning. The emission values from open burning reflect the total contributions from both residential waste burning and spontaneous combustion at landfill sites.

Figure 10 depicts that CH_4 emissions rise in 2020 and 2030 and decline in 2040 and 2047. In baseline, the primary source of CH_4 emission is from landfills. Assuming the landfill closes in 2034, methane emissions from the landfill decrease significantly, causing an overall reduction in emissions in the baseline scenario.



As the landfill is assumed to close in 2034, emissions are expected to decrease along with the amount of waste disposed off in the landfill, and spontaneous burning will significantly decline, leading to an overall reduction in emissions in the baseline scenario.

Spikes in emissions are anticipated in 2040 and 2047, as waste collection, transportation, and handling equipment will still be in use to facilitate the diversion of collected waste to processing facilities.

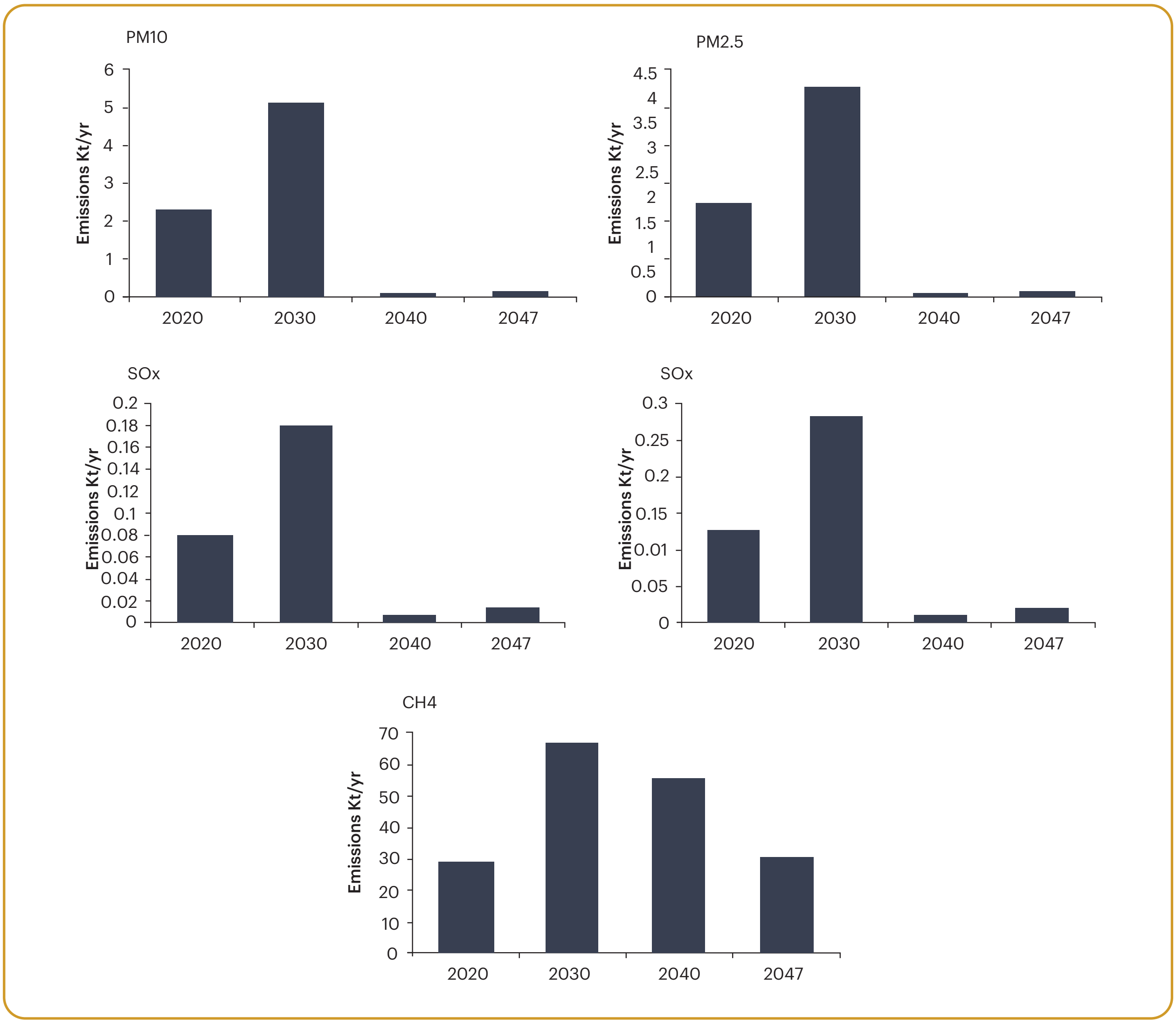


Figure 10: Emissions of PM_{10}, $PM_{2.5}$, BC, SO_2 and CH_4 during 2019, 2030, 2040 and 2047 from the Waste Sector under BAU scenarios

Alternate Scenarios of the Waste Sector

The ALT-1, ALT-2, ALT-3, and ALT-4 scenarios are built upon the baseline using increasing levels of waste diversion to the four processing facilities i.e., composting, anaerobic digestion, waste combustion, and recycling. The four alternate scenarios begin in the year 2025.

Table 23: Targets Assumed under Alternate Scenarios for the Waste Sector until 2047

Scenario	Treatment of Diverted Waste						Open Burning	
	Waste-to-energy	MRFs	Composting	AD	Recycling	RDFs	At Residences	At Landfills
ALT 1: 32% diversion	28.05%	72%	0%	0%	0%	0%	3%	7%
ALT 2: 40% diversion	0%	0%	12.88%	1.37%	61.68%	24.05%	3%	5%
ALT 3: 50% diversion	0%	0%	12.88%	1.37%	61.68%	24.05%	2%	4%
ALT 4: 60% diversion	0%	0%	12.88%	1.37%	61.68%	24.05%	2%	4%

As outlined in the table above, the ALT-1 scenario outlines a 32% diversion of collected waste (total collected waste is 7819.7 TPD of which 2495 TPD (32%) is diverted) to processing facilities which includes waste to energy plant of 700 TPD (28.05%) and MRFs of a cumulative capacity of 1795 TPD (72%). These interventions will result in more diversion of waste from landfills and a reduction of the burning of waste, which will in return control air pollution emissions attributable to this scenario. For instance, PM2.5 emissions from open waste burning are estimated to decrease by 30% by 2030, 40% by 2040 and 40% by 2047. A similar diversion has been developed for other alternative scenarios as depicted in the table above.

Alternative scenario 1 (ALT1): Of the collected waste, 32% is diverted to waste-to-energy and material recovery facilities

(Based on Cluster-Wise Integrated Centralized Waste Processing Strategy and Decentralized Approach)

The scenario involves plants proposed by the State government, including the diversion of collected waste to a 700 TPD waste-to-energy facility and decentralized Material Recovery Facilities (MRFs) with a combined capacity of 1,795 TPD. This initiative results in 32% of the total collected waste (7,819.7 TPD) being diverted to processing facilities, amounting to 2,495 TPD. Of the diverted waste, 28.05% (700 TPD) is processed at the waste-to-energy plant, while 72% (1,795 TPD) is handled by MRFs. Additionally, open burning contributes to waste management, with 3% of uncollected waste burned by residents and 7% burned at landfill sites.

Alternative scenario 2 (ALT2): Of the collected waste, 40% is diverted to composting, anaerobic digestion, waste combustion and recycling

(Based on Cluster-Wise Integrated Centralized Waste Processing Strategy, HSPCB, 2024)

In this scenario, of the total of 7819.7 TPD waste collected, 40% (3128TPD) of the waste is diverted to processing facilities. This diversion scenario is based on the Haryana government's proposed interventions to direct waste into different processing methods—composting, anaerobic digestion, waste combustion, and recycling—while also taking into account the current waste diversion practices. In this scenario, of 3128 TPD sent for diversion, 402.88TPD (12.88%) is set for composting, 42.85TPD (1.37%) is set for anaerobic digestion, 752.26TPD (24.05%) is set for waste combustion (as refuse-derived fuel (RDFs)), and 1929.29TPD (61.68%) is set for recycling. Further, for open burning, the rate of open waste burning takes into account 3% of uncollected waste being burned by residents and 5% being burned at the landfill.

Alternative scenario 3 (ALT3): Of the collected waste, 50% is diverted to composting, anaerobic digestion, waste combustion and recycling

(Based on Cluster-Wise Integrated Centralized Waste Processing Strategy, HSPCB, 2024)

Within this scenario, out of the total of 7819.7 TPD waste collected, 50% (3909.89 TPD) of the waste is diverted to diversion facilities. This diversion scenario is based on the Haryana government's proposed interventions to direct waste into different processing methods—composting, anaerobic digestion, waste combustion, and recycling—while also considering the current waste diversion practices. Of 3909.89 TPD sent for diversion, 503.59 TPD (12.88%) is set for composting, 53.56TPD (1.37%) is set for anaerobic digestion, 940.33TPD (24.05%) is set for waste combustion (as RDFs), and 2411.625 TPD (61.68%) is set for recycling. Further, for open burning, the rate of open waste burning takes into account 2% of uncollected waste being burned by residents and 4% being burned at the landfill.

Alternative scenario 4 (ALT4): Of the collected waste, 60% is diverted to composting, anaerobic digestion, waste combustion and recycling

(Based on Cluster-Wise Integrated Centralized Waste Processing Strategy, HSPCB, 2024)

Within this scenario, out of the total of 7819.7 TPD waste collected, 60% (4691.87 TPD) of the waste is diverted to diversion facilities. This diversion scenario is based on the Haryana government's proposed interventions to direct waste into different processing methods—composting, anaerobic digestion, waste combustion, and recycling—while also taking into account the current waste diversion practices. Of 4691.87 TPD sent for diversion, 604.31 TPD (12.88%) is set for composting, 64.27 TPD (1.37%) is set for anaerobic digestion, 1128.39TPD (24.05%) is set for waste combustion (as RDFs), and 2893.94 TPD (61.68%) is set for recycling. As a significant portion of the waste is being diverted to the formal treatment pathways, open burning of waste at source level is eliminated and 2% of the waste being burned at the landfill site is considered.

Table 24: Change in Waste Emissions Under Alternate Scenarios, compared to 2047 Emissions Under BAU

Scenario	CH4	PM2.5	PM10	SO2	BC
ALT 1: 32% diversion	-26%	+13053%	+10980%	+15262%	+235%
ALT 2: 40% diversion	-32%	+14027%	+11801%	+16393%	+247%
ALT 3: 50% diversion	-58%	+17524%	+14741%	+20480%	+296%
ALT 3: 60% diversion	-66%	+17738%	+14915%	+20748%	+282%

In case of net emissions from PM_{10}, $PM_{2.5}$, and SO_2, across all the alternative scenarios, the aforementioned emissions are observed to increase than baseline scenario as there is high reliance on waste combustion, which is more carbon-intensive, resulting in an increase of these emissions compared to the BAU scenario. Additionally, PM_{10}, $PM_{2.5}$, and SO_2 emissions are more across alternative scenarios than the BAU, owing to insufficient waste collection, transportation and waste handling equipment. As waste generation increases and the diversion of waste to processing facilities also increases, with insufficient vehicles and equipment for waste management, it could result in higher emissions due to inefficiencies in transportation and processing.

This suggests that when diverting waste for processing, it's essential to prioritize methods such as composting, anaerobic digestion (AD), and recycling that minimize greenhouse gas emissions. Each of these processes offer lower emissions compared to waste combustion, which is more carbon-intensive. Additionally, efficient waste processing also requires adequate infrastructure, particularly vehicles and equipment for collection and transportation. Insufficient or outdated vehicles and equipment can lead to inefficient operations, such as repeated trips, longer routes, or slower processing times. These inefficiencies increase fuel consumption and emissions from the transportation sector. Additionally, delays in processing can lead to longer decomposition times for organic waste, resulting in higher emissions.

Furthermore, in the case of CH_4 and BC, similar to the BAU, as the landfill closes in 2034, waste deposition to the landfill and spontaneous burning at the landfill decreases significantly, causing an overall reduction in emissions in the scenarios. However, a spike in emissions is observed in the years 2040 and 2047 across all scenarios, as waste combustion continues and collection, transportation, and waste handling equipment are being used. From Figure 11 below the same can be interpreted for all the aforementioned pollutants across the various alternative scenarios. With subsequent years, net CH_4, the largest contributor of emissions, is significantly reducing. However, other emissions like PM_{10}, $PM_{2.5}$, and SO_2 are increasing due to heavy reliance on waste combustion and the use of limited collection, transportation, and waste-handling infrastructure.

According to the SWEET analysis, emissions in Haryana's waste management system stem primarily from sources such as open burning, waste combustion, inadequate collection, transportation, and waste handling equipment. This analysis highlights the critical need for an optimized, low-emission waste management strategy that targets these emission sources effectively. Enforcing a ban on open waste burning necessitates a comprehensive strategy that incorporates consistent waste collection, source segregation, and the establishment of efficient processing facilities. Some important factors to be considered while designing interventions for the waste sector in the state are highlighted below.

Table 25: Key Strategies and Interventions for Reducing SLCP and other non-CO_2 pollutant Emissions in Waste Management

Strategy	Description	Benefits
Prioritizing Composting and Anaerobic Digestion	Emphasize methods like composting and anaerobic digestion to manage organic waste.	Significantly reduces greenhouse gas emissions by effectively managing organic waste and limiting reliance on carbon-intensive processes like combustion.
Promoting Composting	Actively promote composting as a key waste diversion strategy, especially in regions with a strong agricultural base like Haryana.	Reduces the burden on landfills, produces nutrient-rich compost for enhancing soil fertility, supports sustainable farming practices, and creates a circular waste management system where organic waste is transformed into a valuable resource for farmers.
Improving Waste Collection and Transportation	Enhance operational efficiency in waste management by improving waste collection, transportation, and handling equipment.	Reduces emissions through more efficient operations.
Incorporating Electric Vehicles (EVs)	Integrate electric vehicles into waste management fleets.	Reduces the carbon footprint of waste transportation.

Broadly, these interventions can help reduce waste littering, decrease the amount of uncollected waste susceptible to open burning, and divert a larger portion of waste away from landfills with significant benefits for the mitigation of SLCP and other non-CO_2 pollutant emissions in the state.

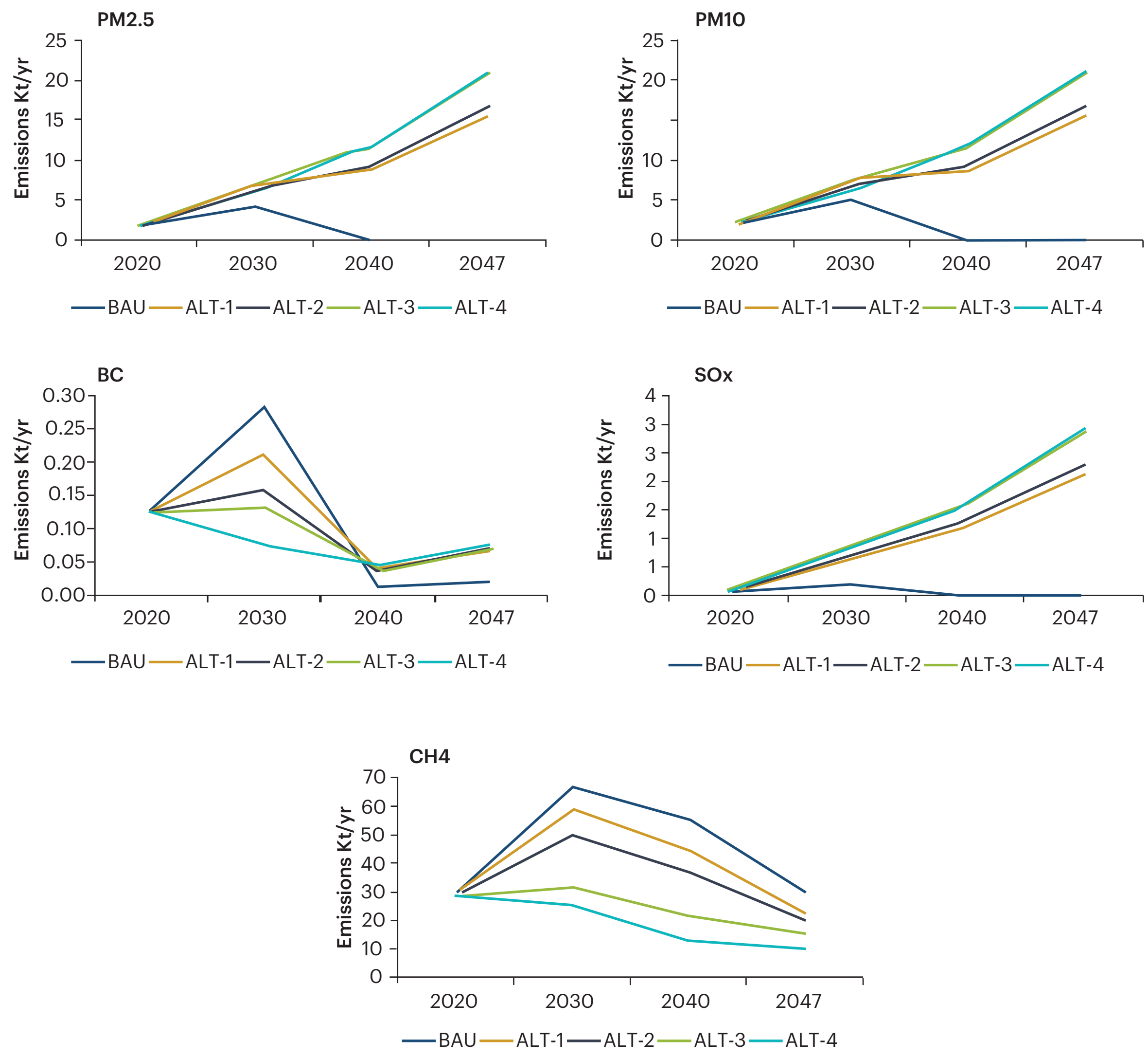


Figure 11: CH_4, PM_{10}, $PM_{2.5}$, SO_2, and BC emissions during 2020, 2030, 2040 and 2047 from the waste sector under BAU, ALT-1, ALT-2, ALT-3, and ALT-4 scenarios

4.2.3 Industry

Haryana, a rapidly industrializing state in northern India, has become a key hub for manufacturing, textiles, automotive production, and chemicals. This industrial expansion, driven by both large-scale and micro, small, and medium enterprises (MSMEs), has powered significant economic growth and job creation.

Rapid industrial growth, however, has brought notable environmental challenges, particularly concerning air quality. Industrial activity, fuelled significantly by coal-fired power, has driven up emissions of particulate matter (PM_{10} and $PM_{2.5}$), SO_2, and NO_x, alongside other SLCPs like CH_4 and BC, and greenhouse gases (GHGs) such as carbon dioxide (CO_2) and nitrous oxide (N_2O). The pollutant mix from industrial and energy sectors not only worsens air quality but also amplifies climate change risks and public health concerns, highlighting an urgent need for science-based assessments and targeted mitigation strategies.

Haryana's industrial and power sectors are thus closely intertwined, with coal-based power generation both enabling industrial development and adding to pollution burdens. The coal-fired thermal power plants (TPPs) that have powered Haryana's industrial rise play a dual role in economic growth and environmental impact. Over the past two decades, these TPPs have met more than 50% of Haryana's electricity demand, relying on a mix of domestic and imported coal. The high ash content (30–40%) in Indian coal significantly contributes to particulate matter (PM_{10} and $PM_{2.5}$) emissions. Despite its lower sulphur content (<0.6%), the extensive coal consumption in the sector leads to substantial SO_2 emissions. Emissions from TPPs depend on the quality of fuel, specific fuel consumption, and the efficiency of air pollution control devices. In 2019–20, Haryana's installed TPP capacity was 5,540 MW, with coal as the dominant source of energy. In addition, the state has biomass power projects with a total capacity of 27.4 MW, and cogeneration plants using bagasse and biomass contributing another 165.6 MW.[72]

This report provides a comprehensive analysis of Haryana's industry and power sector emissions profile for 2019, examining the scale, sources, and impacts of various pollutants. Through an integrated perspective, the study aims to support evidence-based policymaking and promote cleaner, more sustainable industrial and energy practices, steering Haryana toward a resilient future.

BAU Scenario of the Industrial sector (Industries, Power, DG sets, and Brick Kilns)

The BAU scenario for emissions from the industrial sectors has been projected for the years 2030, 2040, and 2047, using growth rates derived from literature reviews. These include an industrial sector growth rate of 6.87% based on the Haryana Economic Survey, 2023[73], a Composite Growth Factor of 6.55% reflecting both population and GDP growth for the power sector, and a production growth rate of 0.41% calculated from the past four years[74]. This BAU scenario assumes that current trends and patterns will continue through 2047 without significant policy or technological interventions.Using these growth rates, the BAU scenario was constructed, and emission loads for the years 2019, 2030, 2040, and 2047 have been estimated. These estimates are illustrated in Figure 12 below.

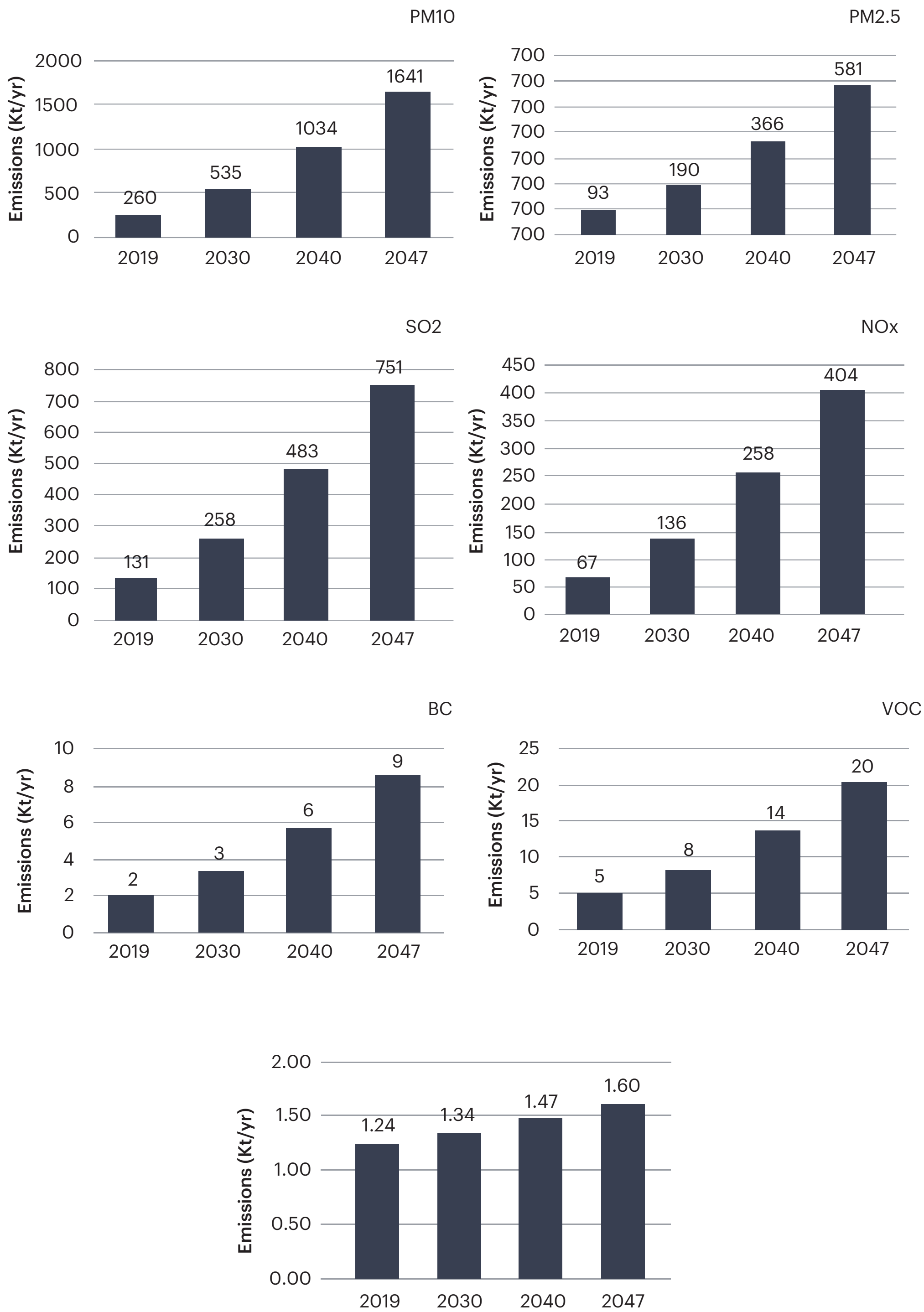


Figure 12: Emissions of PM_{10}, $PM_{2.5}$, BC, SO_2, NO_X, NMVOCs and CH_4 during 2019, 2030, 2040 and 2047 from the Industry Sector under BAU scenarios

Under the BAU scenario, emissions for the year 2047 are projected to grow at a Compound Annual Growth Rate (CAGR) of 7%. As a result, emissions of PM_{10}, $PM_{2.5}$, SO_2, NOx, NMVOCs, and CH_4 are expected to increase approximately sixfold compared to the base year, 2019.

Alternate Scenarios of the Industry Sector

In the ALT Scenarios, emissions from the industry, power, brick, and diesel generator (DG) sectors are collectively analysed to assess the impact of various mitigation measures.

Table 26: Targets Assumed Under Alternate Scenarios for the Industry Sector

Scenarios	2030	2040	2047
ALT 1: Transition from coal to natural gas for combustion in industrial boilers	25%	50%	100%
ALT 2: Fuel consumption reduction due to community boilers	30%	30%	30%
ALT 3: Expansion of Green Hydrogen	-	5%	8%
Overarching Measures Taken in All Scenarios			
Transition from coal-fired thermal power plants to renewable energy sources and biomass-based generation in power sector			
In brick kiln sector, transition from zig-zag to tunnel kiln technology			
Introduction of Retrofitting of Emission Control Devices (RECD) in DG sector			

Alternative scenario 1 (ALT1): Transition to Natural Gas for Industrial Boilers

(Based on NCAP Industrial Emission Guidelines)

In ALT1, the transition from coal to natural gas as a fuel for combustion in industrial boilers is evaluated. This shift offers several significant benefits. Natural gas combustion leads to lower emissions of particulate matter (PM_{10} and $PM_{2.5}$) (PM), SO_2, NO_x, and CO, thereby improving air quality. However, it is important to note that natural gas, while generally cleaner than coal in terms of most of the pollutants but has a higher CH_4 emission potential due to its composition. Methane (CH_4) is a potent short-lived climate pollutant, that leaks during extraction, transport, and combustion which results in offsetting some of the climate benefits typically associated with natural gas use.

The transition will also enhance combustion efficiency due to the higher energy content of natural gas, leading to better heat generation and reduced maintenance requirements compared to coal. Furthermore, natural gas boilers require less water for cooling, which is particularly advantageous in water-scarce regions. This shift supports industries in meeting stringent environmental regulations while reducing the need for costly pollution control measures. Natural gas boilers offer greater operational flexibility, with faster start-up times and more efficient emission control, enabling industries to quickly adjust to changing demands. Additionally, natural gas combustion produces minimal solid waste, reducing the environmental impact associated with ash disposal. By 2047, the transition from coal to natural gas is projected to result in a substantial reduction in emissions, including a 98% decrease in PM_{10}, 97% in $PM_{2.5}$, 46% in SO_2, 38% in NOx, 39% in NMVOCs, and 89% in BC, compared to the BAU scenario for the same year. However, CH_4 emissions are expected to increase significantly, with a projected rise of 223%. This increase in methane emissions should be carefully monitored to fully assess the climate impact of the transition.

Alternative scenario 2 (ALT2): Implementation of Community Boilers leading to Reduced Fuel Consumption

(Based on CPCB Guidelines on Community Boilers, 2024)

In ALT 2, which involves the implementation of community boilers, these centralized systems supply steam or heat to multiple industrial units within a community, offering significant advantages over individual boilers by centralizing the boiler operations. These systems are expected to reduce operational and maintenance costs, enhance fuel efficiency, and minimize downtime. Additionally, they improve environmental outcomes by consolidating emissions, which allows for more effective pollution monitoring and control and reduces overall coal consumption. When individual boilers are replaced with community boilers in an industrial cluster, fuel consumption is projected to decrease by 30%. By 2047, this reduction in fuel use is anticipated to result in a decrease in emissions of PM_{10} by 13%, $PM_{2.5}$ by 14%, SO_2 by 37%, NO_x by 31%, NMVOCs by 40%, BC by 19%, and CH_4 by 15% compared to the BAU scenario for the same year.

Alternative scenario 3 (ALT3): Expansion of Green Hydrogen

(Based on Haryana Green Hydrogen Policy, 2024 (draft))

In ALT3, the transition to green hydrogen as a fuel is evaluated. Green hydrogen is produced via electrolysis, which uses renewable energy sources—such as wind, solar, or hydropower to split water into hydrogen and oxygen, making it a clean alternative to conventional hydrogen production. This scenario proposes that green hydrogen will replace existing industrial fuels by, 5% by 2040, and 8% by 2047. The adoption of green hydrogen is expected to significantly reduce emissions by 2047, achieving a 9% reduction in PM_{10}, 10% in $PM_{2.5}$, 36% in SO_2, 30% in NO_2, 40% in VOCs, 15% in BC and 8% in CH_4 compared to the BAU scenario for the same year.

Further, in each ALT scenario power, DG and brick sectors have been clubbed to present a comprehensive picture of the industrial sector. Within the power sector, the transition from coal-fired thermal power plants to renewable energy sources and biomass-based generation is being considered. By 2047, this transition is projected to reduce emissions attributable to the power sector of PM10, PM2.5, SO_2, NO_x, NMVOCs, BC, and CH_4 by 40% compared to the BAU scenario for the same year.

In the brick sector, the predominant technology across Haryana currently involves zig-zag brick kilns. Under the ALT Scenario, transitioning from zig-zag to tunnel kiln technology is proposed. This technology shift is anticipated to decrease emissions of PM10 by 28%, PM2.5 by 29%, SO_2 by 25%, NMVOCs by 27%, BC by 29%, and CH_4 by 15% relative to the 2047 BAU scenario. However, due to the higher NO_x emissions associated with tunnel kiln technology, NO_x emissions are projected to rise from 0.001 kt/year to 1.59 kt/year.

For the DG sector, Retrofitting of Emission Control Devices (RECD) is introduced as an intervention. With a particulate matter (PM) capture efficiency of 70%, RECD retrofitting is expected to reduce both PM and BC emissions by approximately 70%, as BC is a component of PM.

Table 27: Change in Industry Emissions Under Alternate Scenarios, compared to 2047 Emissions Under BAU

Scenarios	$PM_{2.5}$	PM_{10}	SO_2	NO_x	NMVOCs	BC	CH_4
ALT 1: Transition to Natural Gas	-97%	-98%	-46%	-38%	-35%	-89%	+80%
ALT 2: Implementation of community boilers	-14%	-13%	-37%	-31%	-35%	-19%	-28%
ALT 3: Expansion of Green Hydrogen	-10%	-9%	-36%	-30%	-35%	-15%	-28%

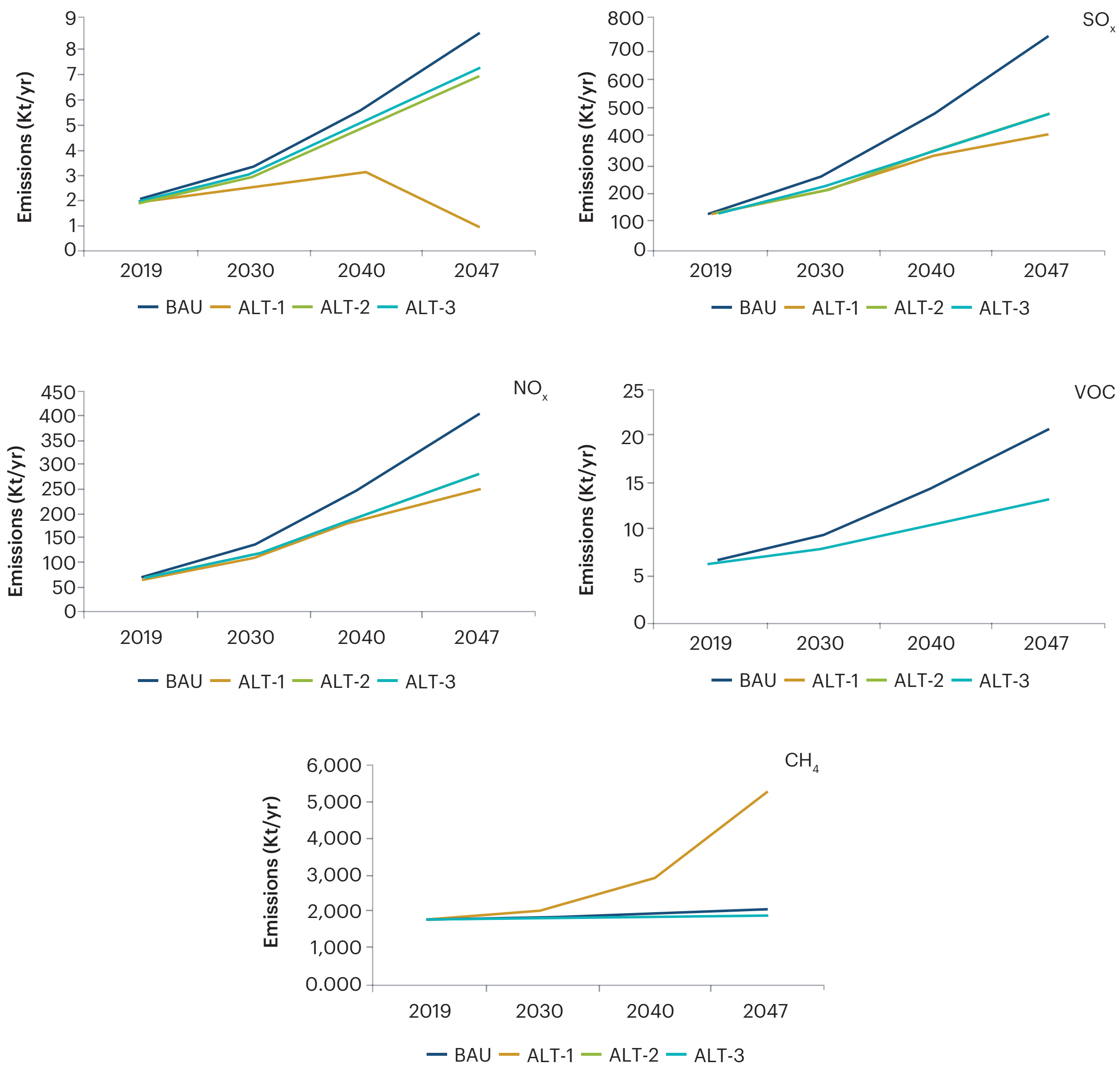


Figure 13: Emissions of PM_{10}, $PM_{2.5}$, BC, SO_2, NO_X, NMVOCs and CH_4 during 2019, 2030, 2040 and 2047 from the Industry Sector under ALT scenarios

4.2.4 Livestock

Livestock rearing in Haryana contributes to methane emissions through enteric fermentation and manure management. While dairy and livestock products remain central to the livelihoods of many in the state, the associated emissions highlight the need for targeted interventions like improving feed practices and manure management systems.

In this context, the study has developed a BAU scenario for Haryana's livestock sector to project future growth trends and assess their environmental impacts. The study also evaluates mitigation strategies, focusing on interventions in livestock management to curb methane and other sector-specific SLCP and other non-CO_2 pollutant emissions. These strategies offer significant potential for emission reduction in Haryana while ensuring that the growing demands for food and dairy products are met sustainably. The following sections outline separate scenarios developed for livestock activities as a comprehensive pathway towards a low-emission livestock system in the state.

BAU Scenario of Livestock Sector

Milk demand in India is projected to grow significantly, driven by population growth, rising incomes, and shifting dietary preferences. By 2030, the milk demand will reach around 300 million metric tons as estimated by the National Dairy Development Board (NDDB) of India.[75] This suggests annual growth of ~6% milk production. This demand surge is attributed not only to population growth but also to increasing urbanization and a higher focus on protein-rich diets, which include dairy products. Meeting this demand will require continued improvements in productivity, number of cattle and animal health, apart from rural milk infrastructure development.

Haryana produces about 6% (11.7 MMT (Million Metric Ton)) of the total annual milk production (198.4 MMT) in the country during 2019-20. Accordingly, the projected milk production in Haryana was estimated as 20.9 MMT in 2030-31, 37.5 MMT in 2040-41 and 67.1 MMT in 2050-51 following a 6% annual increase in milk production to meet the rising demand of the country.[76]

The milk production was converted to the total bovine population following the distribution of the total bovine population in the state during 2019-20. This suggested a significant increase in methane emissions, as mentioned ahead, from the livestock sector during 2050-51 compared to that in 2019-20. The 2019 Livestock census suggested that the buffalo population in Haryana is significantly higher than that of Indigenous cattle and cross-breed cattle. Under the BAU scenario, CH_4 emissions from livestock were estimated as 0.32 Tg/Annum (Terra gram/Annum), 0.58 Tg/Annum and 1.04 Tg/Annum during 2030-31, 2040-41 and 2050-51, respectively.

Alternative scenarios for Livestock sector

The state government supports different programs for the development of the dairy and livestock sector in Haryana. For example, the Haryana government has initiated the Murrah Buffalo Development Scheme to enhance the Murrah buffalo breed, known for its high milk yield, to boost milk productivity across the state. A systematic breed improvement program is also underway in Haryana, focusing on selective breeding to increase milk production and productivity of bovines thereby enhancing farmers' income.[77] Haryana Livestock Development Board has further boosted breeding activities by providing quality bulls, improving infrastructure at Gaushalas, and offering financial support for breeding initiatives.[78]

In addition to cattle breeding programs, the state also supports the dairy industry by improving the availability, quality and diversity of livestock feed. The Haryana government has implemented policies called Gau Charan Bhumi, to support the open grazing of cattle, particularly through initiatives that provide and protect grazing lands, to assist cow shelters (gaushalas). Recognizing that limited grazing land and modernization have reduced available pasture, the government allows village Panchayati land to be leased for cattle grazing when Gau Charan Bhoomi is unavailable. This land provision supports cattle by providing space for grazing and cultivating fodder. Policies like this aim to ensure a stable and nutritious supply of fodder for dairy animals to enhance milk production. Different types of fodder such as anti-methanogenic feed supplements have significant methane emission reduction potential from enteric fermentation of ruminants. Based on these plausible interventions, different scenarios to reduce future methane emissions from the livestock sector have been outlined below in Table 28.

Table 28: Description of ALT Scenarios in the Livestock Sector with CH_4 emission reduction

Scenarios	CH4 Reductions Compared to BAU in each year		
	2030-31	2040-41	2050-51
ALT-1: Gausamvardhan Systematic decadal reduction of cross breed cattle population by 20% and converting 5% buffalo population to Murrah buffalo while increasing the indigenous cattle population to achieve the targeted milk demand in the state.	2.5%	2.5%	2.5%
ALT-2: Limited Gau Charan Bhumi All indigenous cattle above 1 year of age would be grazed in pastureland; in line with government initiatives to protect grazing lands and assist gaushalas.	36%	36%	36%
ALT-3: Purna Gau Charan Bhumi Assuming there would be enough land for open grazing of all dairy cattle, they will graze in open pasture while 10% of adult non-dairy cattle will also be allowed to graze in open pasture compared to Scenario 1.	44%	44%	44%

Alternative scenario 1 (ALT1): Gausamvardhan

(Based on Haryana Gauvansh Sanrakshan and Gausamvardhan Act, 2015)

Under this scenario, within the ambit of Haryana's ongoing Scheme for the Conservation and Development of Indigenous Cattle, which is highlighted in the previous sub-section, we assumed a systematic decadal reduction of cross breed cattle population by 20%, and conversion of 5% buffalo population to Murrah buffalo while increasing the indigenous cattle population to compensate for the decrease in cross-bred cattle population to achieve the targeted milk demand in the state. This led to about a 2.5% reduction in methane emissions from the Enteric fermentation of livestock compared to the BAU scenario mentioned above as illustrated in Figure 14 below.

Alternative scenario 2 (ALT2): Limited Gau Charan Bhumi

(Based on Gau Charan Bhumi policy, under The Haryana Gauvansh Sanrakshan and Gausamvardhan Act, 2015)

Under this scenario, considering the implementation of Haryana's existing Gau Charan Bhumi policy as outlined above, it was assumed that all indigenous cattle above 1 year of age would be grazed in pastureland. As reported by Shibata and Terada (2010) and Wattiaux et al. (2019), high-nutrient forage in the pasture encourages faster digestion and reduces fermentation time, thus decreasing methane output by 20 to 30%. Under scenario 2 methane emissions were estimated to reduce by 36% compared to the BAU scenario as illustrated in Figure 9.

Alternative scenario 3 (ALT3): Purna Gau Charan Bhumi

(based on a combined strategy of ALT 1 and ALT 2)

- Under this scenario, it was assumed that there would be enough land for open grazing of all dairy cattle of cross breed, indigenous and buffalo. All adult dairy cattle will graze in open pasture while 10% of adult non-dairy cattle will also be allowed to graze in open pasture compared to Scenario 1. This reduces methane emission by 44% compared to the BAU scenario as illustrated in Figure 14.

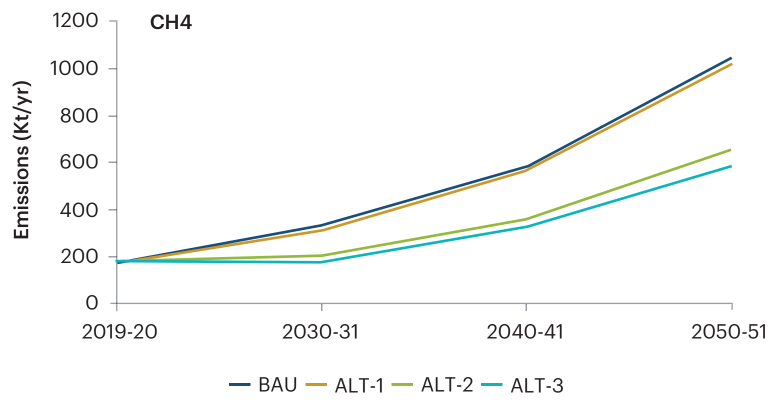


Figure 14: Annual changes in CH_4 emissions from BAU and alternative scenarios of Livestock sector in Haryana

4.2.5 Agriculture

The agricultural sector in Haryana is a key contributor to India's food production, with significant outputs from rice cultivation. However, this is also a major source of methane emissions, which contribute to regional air quality degradation and climate change.

Additionally, the open burning of agricultural residues is a critical environmental issue in Haryana. Farmers often resort to this practice to quickly clear fields for the next crop cycle, leading to substantial emissions of particulate matter (PM) and greenhouse gases. This exacerbates air pollution and contributes to climate change. Implementing alternative residue management practices, such as in-situ incorporation, mulching, or conversion to bioenergy, could significantly reduce these emissions and help lower the environmental impact of agriculture in the state.

In this context, the study has developed a BAU scenario for Haryana's agriculture sector to project future growth trends and assess their environmental impacts. The study also evaluates mitigation strategies, focusing on interventions in rice cultivation to curb methane and other sector-specific SLCP and other non-CO_2 pollutant emissions. These strategies offer significant potential for emission reduction in Haryana while ensuring that the growing demands for food and dairy products are met sustainably. The following sections outline separate scenarios developed for crop cultivation as a comprehensive pathway towards a low-emission agricultural system in the state.

BAU Scenario for crop cultivation activities

The study has developed a BAU scenario based on the current policies of Haryana. Under these policies, the state aims to completely eliminate open burning of agricultural residues by 2030. If this target is achieved, there would be no direct emissions of pollutants like PM_{10}, $PM_{2.5}$, BC, NO_X, and SO_2 from residue burning in the BAU scenario. This implies that the remaining emissions of SLCPs and other non-CO_2 pollutants from the agriculture sector would only come from other farming activities. The study, therefore, uses the existing government policies as a foundation to project future CH4 emissions under the BAU scenario.

In the BAU scenario, domestic demand for rice in India is projected to be 197 Mt/annum during 2047-48.[80] In addition, there is an expected increase in the export of rice to substantiate the projected economic growth of the country by 2047-48. Considering the export of rice, it was projected that the country would require about 227Mt/annum of rice during 2050-51.[81] At present, Haryana produces about 3.38% of the total annual rice demand of the country. Keeping the present share of different states to the annual rice production of the country, it was estimated that the rice production in Haryana will reach about 7.7Mt/annum during 2050-51. Under the present crop yield scenario, the rice cropping area in the state needs to be increased to 2.3 Mha by 2047-48 compared to 1.5 Mha in 2019-20.[82]

The rice cropping area in Haryana has significantly increased during the period 2014-15 to 2019-20 period[83]. If the rice cropping area in the state going to increase at the same space, the methane emissions from the agriculture sector are going to increase. It was estimated that the projected rice production in Haryana will increase methane emissions from rice cropland by around 47% under present management practices. However, to mitigate methane emissions from rice production in Haryana following scenarios were formulated and their impact on methane emission mitigation from rice cropping was estimated.

Alternate scenarios for crop cultivation activities

To address the environmental challenges posed by methane emissions from rice cultivation, three alternative scenarios were developed, each focusing on sustainable agricultural practices tailored to Haryana's cropping system. The scenarios aim to mitigate methane emissions from rice production in the state while maintaining or enhancing rice production levels, ensuring agricultural productivity and environmental sustainability see in Table 29.

Table 29: Description of ALT Scenarios for the Agriculture Sector and emission reduction of CH_4

Scenario	Description	Reduction in CH4 emissions compared to BAU for each year		
		2030	2040	2047
ALT 1	Implementation of **System of Rice Intensification** (SRI) 5% annual growth in adoption	19%	40%	53%
ALT 2	Implementation of **Natural Farming on SRI converted land** 5% annual growth in adoption	24%	47%	60%
ALT 3	**Combined implementation** of ALT 1, ALT 2, and crop diversification – where area under rice is diverted to non-rice crops, particularly leguminous crops. 5% annual diversion to non-rice crops	26%	50%	66%

Alternate scenario 1 (ALT1) – Implementation of System of Rice Intensification (SRI)

(Based on System of Rice Intensification (SRI) programme, 2015-16)

The SRI is an innovative agricultural practice designed to enhance rice production efficiency while minimizing environmental impacts. Instead of continuous flooding, SRI employs intermittent irrigation, keeping the soil moist but not waterlogged. This practice limits anaerobic conditions in the soil, which are responsible for methane generation during conventional rice cultivation. Further, SRI promotes planting fewer seedlings per unit area with wider spacing. This approach enhances root growth and increases nutrient uptake, resulting in healthier plants and potentially higher yields. As per the assessment in Haryana, the adoption of SRI is projected to have a significant impact on reducing methane emissions from rice paddies. The scenario assumes a gradual increase in the adoption of SRI, with a targeted annual growth rate of 5% based on the rice cultivation area during 2019-20.

Alternate scenario 2 (ALT2) – Implementation of Natural Farming in rice cropping

(Based on System of Rice Intensification (SRI) Programme, 2020)

In this scenario, it is projected that 5% of the SRI-adopted area will transition to Natural Farming practices annually, further enhancing the benefits of the SRI. Natural Farming is a chemical-free, organic approach that strengthens the soil's natural nutrient cycle and boosts its carbon sequestration capacity. It avoids the use of synthetic fertilisers and pesticides, which helps reduce soil and water contamination. This shift towards organic inputs fosters healthier microbial activity in the soil, leading to a decrease in methane emissions. Key bio-enhancers like Jeevamrit, a fermented microbial culture, are used in Natural Farming to enrich soil fertility and promote crop growth. This enhances aerobic soil conditions, further mitigating methane emissions. The combined implementation of SRI and Natural Farming is expected to have a synergistic effect, significantly lowering methane emissions from rice paddies while maintaining or even increasing crop yields.

Alternate scenario 3 (ALT3) – Crop diversification

(Based on State Agriculture Policy and SAPCC 2021-2030)

Under the ALT 3 scenario, in addition to ALT1 and ALT 2, it is assumed that 5% of the rice cultivation area (based on the 2019-20 baseline) will be converted annually to non-rice crops, particularly leguminous crops. This transition is expected to be balanced by the increased rice productivity from the implementation of ALT 1 and ALT 2, ensuring overall rice output remains unaffected despite the shift in cropping patterns.

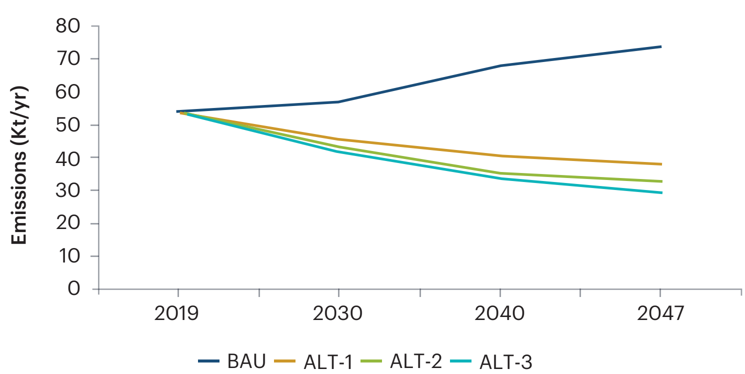


Figure 15: Annual changes in CH_4 emissions from rice cropland under different management scenarios in Haryana

It was estimated that ALT 1, ALT 2 and ALT 3 have the potential to reduce methane emission from rice cropping by about 19%, 24% and 26% respectively during 2030; 40%, 47% and 50% respectively during 2040 and 53%, 60% and 66% respectively during 2047 compared to the BAU scenario.

These alternative scenarios illustrate a comprehensive approach to reducing methane emissions from Haryana's rice cultivation sector through sustainable farming practices and crop diversification, paving the way for a resilient and low-emission agricultural system.

4.2.6 Residential

The residential sector is a significant emitter of SLCPs and other non-CO2 pollutants due to the widespread use of solid fuels such as firewood, coal, dung cakes, and agricultural residues for cooking and heating. Traditional cooking practices, characterized by inefficient biomass stoves, release substantial amounts of BC and CO along with a range of NMVOCs that contribute to ozone formation. These emissions not only contribute to climate warming but also have severe health implications, especially for women and children, who are disproportionately exposed to indoor air pollution.

In recent years, there has been a concerted push in India to transition households from solid biomass fuels to cleaner alternatives, mainly through the promotion of liquefied petroleum gas (LPG) through policy initiatives and schemes implemented at national and sub-national levels.[84] Increased LPG consumption in Haryana reflects these broader national trends; however, a significant portion of households in the state still rely on biomass for cooking, becoming sources of persistent SLCP and other non-CO_2 pollutant emissions.

This section provides an in-depth analysis of emission projections from residential cooking activities in Haryana under different scenarios, assessing the effectiveness of alternate cooking methods in reducing emissions while Haryana advances on its course to 100% LPG penetration in households.

BAU Scenario for the Residential Sector

Under the BAU scenario, emissions have been projected based on the growth pattern of LPG consumption in residential households for the state of Haryana. Indian Petroleum and Natural Gas Statistics report has been referred to estimate the growth trend of LPG consumption in residential households for the state of Haryana. Ministry of Petroleum and Natural Gas (MoPNG) reports LPG consumption at the state level and in the absence of LPG consumption information at rural and urban levels, LPG consumption during 2019-20, 2020-21 and 2021-22 (Indian Petroleum & Natural Gas Statistics, Government of India) was used to project the LPG growth for the entire state. Accordingly, household LPG usage was estimated to grow at 4.6% annually in urban and rural areas of Haryana.[85]

Table 30: Emission Reduction in Residential Cooking – BAU Scenario (Haryana)

Pollutant	% Change by 2030	% Change by 2040	% Change by 2047
$PM_{2.5}$	-24%	-66%	-90%
PM_{10}	-25%	-69%	-94%
SO_x, CO, BC, CH_4	-	Significant Reduction	Significant Reduction
NO_x	+13%	+23%	+40%

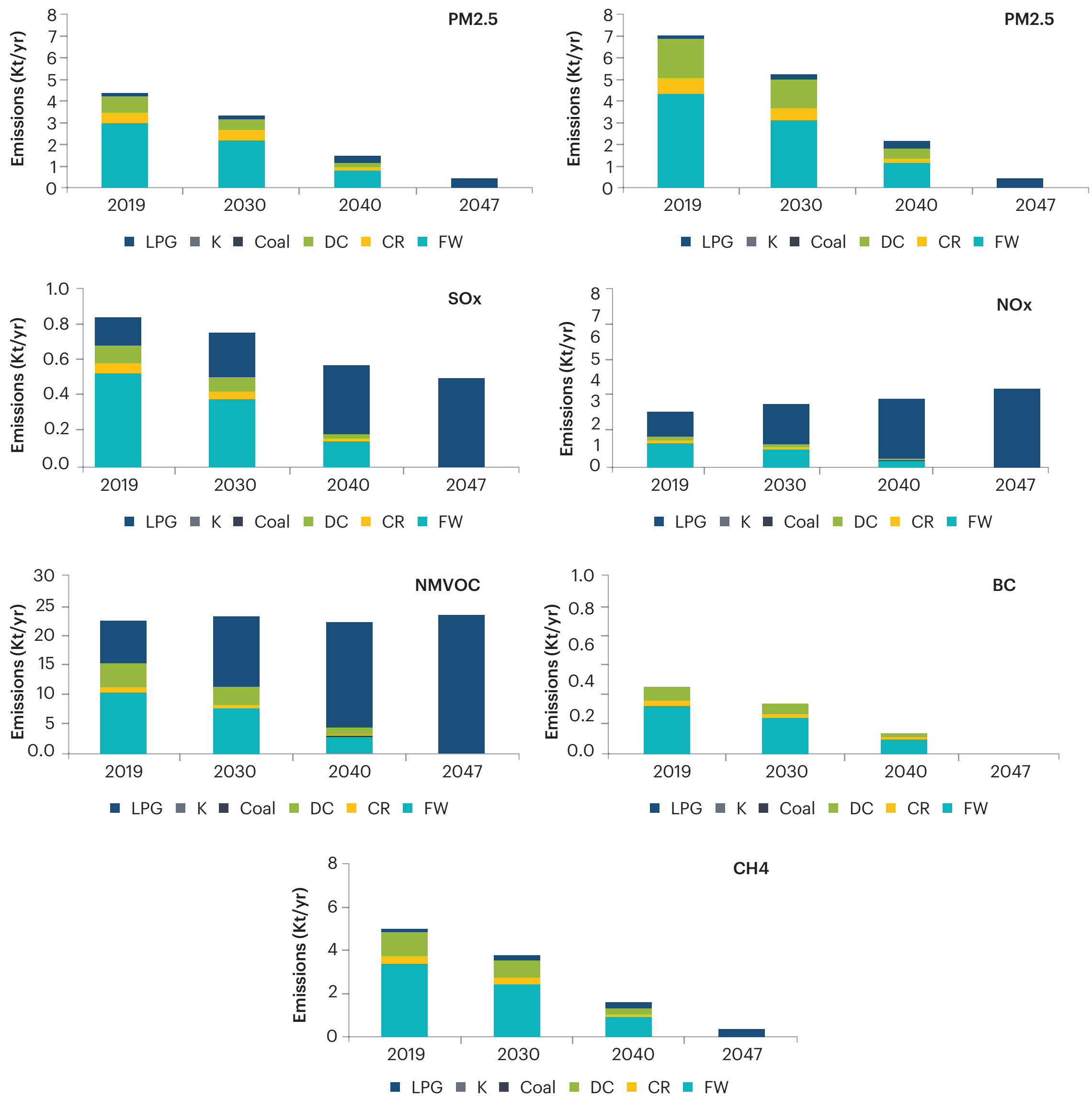


Figure 16: Emission (kt/yr) from residential cooking activity in the state of Haryana during 2019, 2030, 2040 and 2047

Alternate Scenarios for the Residential Sector

The study evaluated three alternate scenarios (Table 31). These scenarios are constructed based on the current levels of technology penetration in the state and the existing policies aimed at promoting cleaner technologies – such as increased usage of LPG and biogas, and reduced reliance on traditional cookstoves. Each scenario aligns with the existing plans of the state. Subsequently, the study analyzed the effects of promoting various technologies to understand their impacts on SLCP and other non-CO_2 pollutants. Below Figure 17 shows the impact of ALT scenarios on the sector's total emission load in Haryana, compared to the BAU scenario.

Table 31: Description of Scenarios under Residential Cooking Sector

Scenario	Annual LPG Adoption Rate	Alternate methods used by non-LPG households during transition (to LPG) period		
		Improved Cookstove	Biogas	Solar Cooking Systems
ALT 1	4.6%	100%	0%	0%
ALT 2	4.6%	30%	30%	40%
ALT 3 – by 2030	4.6%	20%	20%	40%
ALT 3 – by 2040	4.6%	10%	20%	70%
ALT 3 – beyond 2040	0%	0%	0%	100%

Alternative scenario 1 (ALT1): Adoption of Improved Less-smoke Emitting Cookstoves

(Based on the National Biomass Cookstove Programme)

Under the ALT1 scenario, the emission load from the residential sector is projected based on the assumption that LPG consumption will grow at 4.6% annually as considered under the BAU scenario. However, the remaining households i.e. biomass-dependent households (remaining after LPG penetration) will gradually shift from traditional cookstoves to improved less smoke-emitting solid fuel cookstoves. According to a test report approved by the Biomass Cookstove Test Centre under the Ministry of New and Renewable Energy (MNRE), an improved biomass cookstove with a thermal efficiency of 28% can achieve significant emission reduction[86]. Unless there is a sustainable supply of LPG for cooking activity in residential households particularly in rural and urban slums, implementation of improved solid fuel cookstoves emits less smoke compared to traditional cookstoves. Assuming co-implementation of LPG fuel (at 4.6% annually) and improved solid fuel cookstove, the emission load of particulate matter, CO, BC and CH4 is expected to reduce between 23% and 28% during 2030 and 2040 with respect to corresponding emissions under the BAU scenario. NOx and NMVOCs are expected to reduce between 3% and 13% during 2030 and 2040 compared to BAU emissions.

Alternative scenario 2 (ALT2): Shift to Improved Cookstoves, Biogas, Solar-based Cooking Systems

(Based on New National Biogas and organic Manure Management Programme and the "Surya Nutan" Solar Cooking Initiative)

Under the ALT 2 scenario, the residential sector's emission load is projected to assume that 30%, 30% and 40% of non-LPG households in rural Haryana will shift to improved cookstove, biogas and solar-based cooking systems respectively during 2030 and 2040. Considering the baseline situation and growing LPG consumption at 4.6% annually, rural Haryana is achieving 100% LPG coverage in 2047. However, about 40% of rural households during 2030 and 15% of rural households during 2040 would still depend on biomass fuel to meet their cooking needs. Therefore, 30%, 30% and 40% of non-LPG-using households in rural Haryana are assumed to shift to improved cookstove, biogas and solar-based cooking. Accordingly, the emission load of different pollutants is expected to reduce between 24% and 78% during 2030 compared to BAU-2030 emissions. Similarly, assuming a similar scenario during 2040, PM10 and PM2.5 emission is expected to decline by 66% and 60% respectively compared to BAU2040 emissions indicating significant air quality improvements.

Alternative scenario 3 (ALT3): Phased Transition to Solar Cooking Systems

(Based on New National Biogas and organic Manure Management Programme and the "Surya Nutan" Solar Cooking Initiative)

Under the ALT 3 scenario, the emission load from the residential sector is projected assuming that 20%, 20% and 40% of non-LPG-using households in rural Haryana will shift to improved cookstove, biogas and solar-based cooking respectively by 2030. Again, during 2040, 70% of non-LPG-using households in rural Haryana will shift to solar-based cooking whereas, the remaining 20% and 10% of non-LPG households will use biogas and improved cookstoves respectively. However, beyond 2040 no further LPG penetration is assumed in rural areas of Haryana and therefore, the newly estimated households along with existing non-LPG households in rural Haryana will shift to solar cookers as a source of primary energy for cooking. Considering this, entire non-LPG-using households during 2047 will shift to solar-based cooking. The emission load of different pollutants is expected to reduce between 49% and 86% during 2030 compared to BAU 2030 emissions. Similarly, during 2040, the emission load of different pollutants is expected to reduce between 17% and 93% compared to BAU2040 emissions indicating significant air quality improvements.

Table 32: Change in Residential Cooking Emissions Under Alternate Scenarios, compared to 2030 Emissions Under BAU

Scenario	$PM_{2.5}$	PM_{10}	CO	BC	CH_4	SO_2	NO_x	NMVOCs
ALT 1	-26.20%	-26.91%	-27.33%	-28.10%	-26.75%	-18.58%	-10.12%	-13.43%
ALT 2	-72.34%	-74.42%	-76.07%	-78.43%	-68.54%	-40.13%	-24.09%	-37.40%
ALT 3	-79.31%	-81.54%	-83.14%	-85.62%	-77.43%	-48.79%	-28.07%	-40.87%

Table 33: Change in Residential Cooking Emissions Under Alternate Scenarios, compared to 2040 Emissions Under BAU

Scenario	$PM_{2.5}$	PM_{10}	CO	BC	CH_4	SO_2	NO_x	NMVOCs
ALT 1	-21.77%	-23.87%	-25.25%	-28.10%	-23.38%	-9.19%	-3.46%	-5.22%
ALT 2	-60.10%	-66.00%	-70.28%	-78.43%	-59.89%	-19.85%	-8.23%	-14.54%
ALT 3	-71.46%	-78.42%	-83.26%	-92.81%	-73.64%	-26.49%	-10.47%	-17.22%

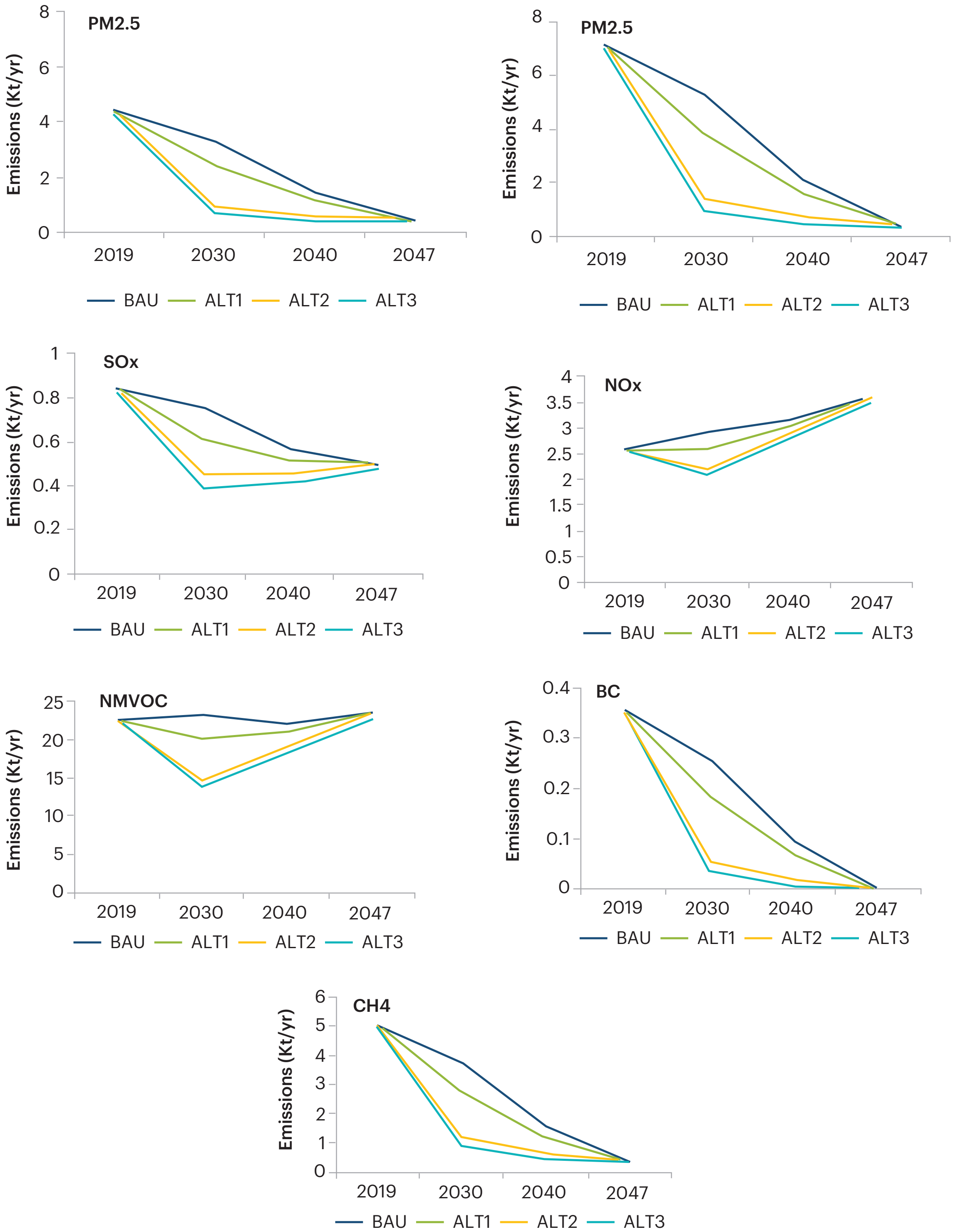


Figure 17: Emission (kt) of different pollutants from residential cooking activity in the state of Haryana during 2019, 2030, 2040 and 2047 under the BAU and ALT scenarios

5

Co-benefits and Scenarios

The sector-wise emission scenarios modelled in the previous section, along with their associated climate and air pollution challenges, do not exist in isolation. Emission trajectories from key sectors in Haryana will have spillover effects, leading to interconnected economic, social, and health-related impacts. Effective mitigation strategies must therefore account for these interdependencies, identifying both co-benefits and trade-offs to optimize policy outcomes. This section examines how different emission scenarios influence key sectors, highlighting the cross-cutting impact of various policy choices.

5.1 Impact of Heat Stress on Human Health and the Economy

Air pollution, now considered the greatest environmental threat to our health, kills seven million people globally each year and is linked to an increasing number of health impacts, including increased susceptibility to diseases.[87] According to a recent study, 1.67 million deaths were attributable to air pollution in India in 2019.[88] Haryana is demonstrating a **strong commitment to public health and economic growth**. Addressing the 2019 air quality challenges, which carried an economic impact of **USD 1,566 million,** presents a **significant opportunity for Haryana to lead the nation** in achieving healthier environments and greater prosperity.[89] Mitigating short-lived climate pollutants like methane and tropospheric ozone, which are also critical air pollutants, is key to protecting human health.[90] Increasing heat stress in the state is a particularly worrying factor for aggravation of these health impacts, particularly amongst vulnerable populations like the elderly, women and children. In addition to the rising emissions of PM_{10}, $PM_{2.5}$, SO_2, and NO_X, the threat of continued substantial presence of pre-cursors to tropospheric ozone formation in the BAU Scenario in Haryana indicates the likelihood of worsening health impacts in the state. Even in the Alternative Scenarios, the presence of PM_{10}, $PM_{2.5}$, SO_2, NOx, and methane emission would be a matter of concern from the human health perspective, however moderated compared to 2019 levels.

Haryana is projected to experience a significant rise in annual maximum temperature by mid-century.[91] The highest temperature before the monsoon season is predicted to rise between 1.8°C and 3.5°C. The maximum temperatures during the winter season are also expected to rise, between 1.5°C and 2.9°C. **The average annual maximum temperature is expected to rise between 1.2°C and 1.4°C. by mid-century and between 2.1°C and 4.5°C by the end of century.**[92] Increased temperatures will escalate the risk of heat-related illnesses, such as heat exhaustion and dehydration, particularly among vulnerable groups.[93] **Each 1°C rise in temperature correlates with a 2-5% increase in the risk of heat-related mortality, particularly amongst vulnerable populations.**[94] Additionally, the number of heatwave days is expected to increase.[95]

Extreme temperatures damage transportation infrastructure, including roads and railways, and reduce vehicle efficiency. The energy sector faces higher electricity demand, stressing power grids and decreasing thermal power plant efficiency.[96][97] Urban areas like Chandigarh[98], Faridabad[99], and Gurugram[100] are likely to experience intensified heat due to the Urban Heat Island effect[1], increasing cooling costs and accelerating infrastructure deterioration.[101] Research shows that urban heat island effect could result in a median increase of 19% in cooling energy consumption.[102] For every degree Celsius that temperatures rise in urban areas, electricity consumption increases by 0.45% to 4.6%.[103] Urban heat islands also impact water systems through a change in the chemical and biological processes of water through elevated temperatures. This can substantially increase water use and demand (3.8% increase), impact groundwater quality, increase risk of contamination and harm aquatic ecosystems.[104]

Strategies like controlling particulate matter emissions from industries, emissions of tropospheric ozone precursors from the transport and industry sectors, and methane mitigation from waste and livestock; which can reduce the adverse impacts of air pollutants and short-lived climate pollutants in the state, as also highlighted in the sector-specific alternative scenarios in this study, are therefore critical for claiming co-benefits like safeguarding public health, infrastructure resilience, and economic resilience in Haryana.

5.2 Impact on livelihood through Food Security

Air pollution and the resultant changes in atmospheric composition have a cascading impact on human lives and livelihoods through its implications for food security and the state's economy. Climate change and air pollution increasingly threaten food production and supply as changing weather patterns, natural disasters and heat events result in reduced crop yields, stunted growth and reduced nutritional value of major staple crops like rice, corn, soya and wheat. In terms of economic impact, **agriculture plays a very important role in driving the economy of Haryana but is also one of the most sensitive sectors to changes in climate.** Haryana has a clear opportunity to enhance agricultural resilience. Strategic interventions can mitigate projected 15-17% yield variations in irrigated rice and wheat and 2% in milk yield, strengthening food security for the future. While Haryana's MSP for rice has ensured food security, the state is now focused on balancing this support with initiatives to promote crop diversification towards more water-efficient agricultural practices.[105] The impact of air pollution and climate change on the economy and food production thus has a direct co-relation with hunger, poverty levels, employment, productivity and growth in the state.[106] Addressing short-lived climate pollutants and mitigating air pollution is crucial for alleviating these impacts on economic indicators in the region.

Interventions under the Alternative scenarios outlined in the previous chapter emerge as vital to mitigating emissions of NO_x, NMVOCs, and methane, as compared to 2019 levels, to reduce the formation of tropospheric ozone.[107] Overall, the envisioned interventions are key to combat the likelihood of increased tropospheric ozone concentration with adverse effects on agricultural productivity, and in turn, livelihood in the sector. Ground-level ozone is highly toxic to arable crops and can cause substantial yield losses or changes in crop quality. Tropospheric ozone alone causes annual global losses of approximately 110 million tonnes of these major staple crops.[108] These yield losses are further converted into production losses and economic losses in relation to crop commodity prices.[109] As highlighted in a recent study, ozone-related cumulative crop production loss for wheat alone in selected districts of the Indo-Gangetic Plain was 3.4 million tonnes between 2019–2021, amounting to 923 million USD, with a relative yield loss of 11.3% for wheat in 2021.[110] It is evident, therefore, that the pursuit of the Alternative Scenarios is necessary to ensure economic and food security related co-benefits.

Sectoral analysis from the study indicates that the transport sector holds the greatest potential for controlling tropospheric ozone concentrations, followed by the industry sector, due to their significant contributions to NO_x emissions.

Table 34: Sectors with highest potential for controlling Tropospheric Ozone formation in Haryana

Sector	Contribution to NO_x Emissions (2019)	Key Issues	Suggested Control Measures
Transport	75%	Major source of NOx and increasing influence on ozone due to NMVOCs sensitivity	Promote EVs, encourage non-motorized transport
Industry	22%	High NO_x contributor	Controlling fugitive emissions from solvent use

The alternative scenarios in the transport sector, which project significant reductions in both NO_x and VOC emissions, suggests a definitive control over rising tropospheric ozone concentrations in Haryana by limiting the availability of its precursors in the atmosphere. This underscores the importance of maximizing cross-sectoral emission reductions to ensure economic and food security co-benefits.

6

Challenges

Each sector's ALT scenarios encounter unique challenges during planning and implementation. This section provides an in-depth analysis of the sector-specific obstacles. We have outlined the various challenges that the state may encounter in successfully implementing the most viable alternative scenarios, as illustrated in the chart below.

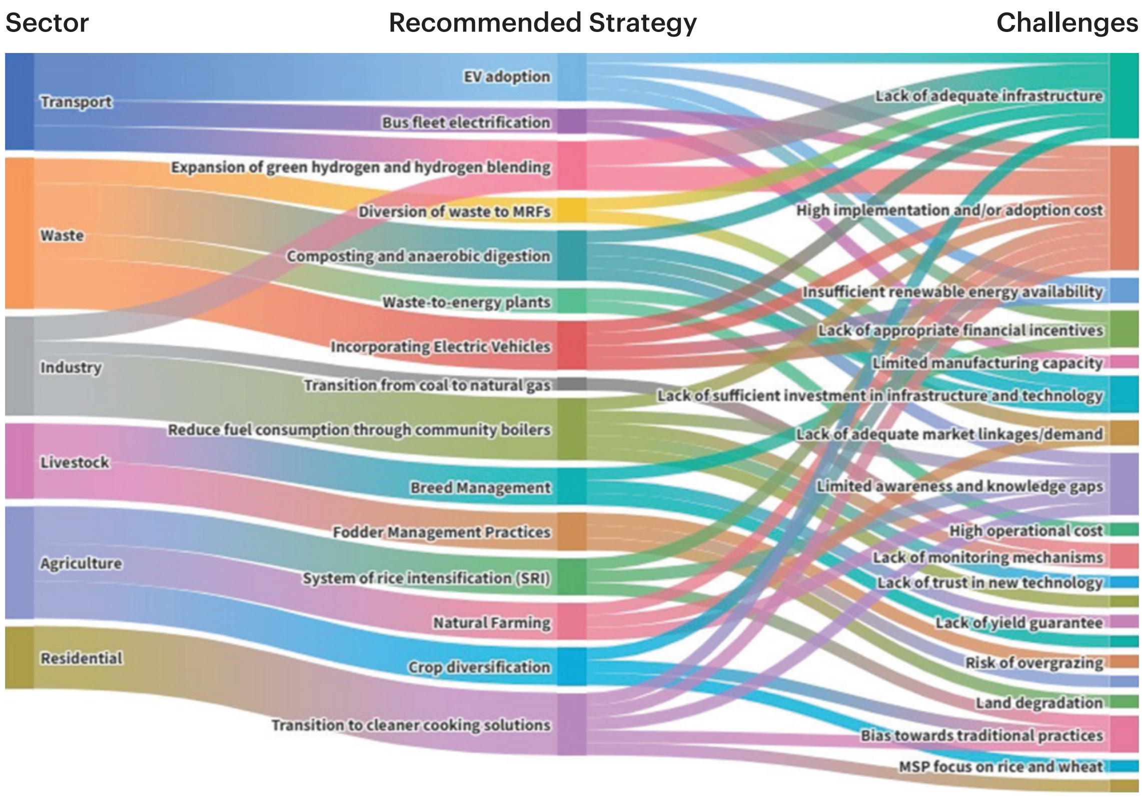


Figure 18: Sector wise strategies and challenges

This chart is designed to clearly identify the most effective strategies across various sectors, as well as the challenges that authorities may encounter during implementation. By highlighting these challenges, we can pinpoint the areas that require focused attention to achieve the desired outcomes

6.1 Sector-specific implementation challenges

Transport sector

The transport sector in Haryana faces significant challenges in transitioning to cleaner alternatives. As of 2022, the state had only 454 public EV charging stations, accounting for 2.9% of India's total, with just 1.3% being fast chargers, which exacerbates **range anxiety due to lack of a charging network and hence limits EV adoption.**[111] High costs of electric buses and limited local manufacturing capacity further impede progress. Additionally, insufficient renewable energy availability for charging EVs, resistance to the scrappage policy due to lack of incentives, and limited scrappage and recycling centers add to other barriers. High implementation costs and administrative challenges for hydrogen infrastructure, coupled with the absence of established supply chains and supportive policies for H-CNG blending, highlight the need for extensive policy support. The Haryana Electric Vehicle Policy, which includes hybrid vehicles, also identifies certain challenges like – high upfront costs of EVs and alternative fuel vehicles, availability of quality power supply, and the limited availability of cleaner fuels' supply chains across the state; especially during the interim period before EV penetration is maximized.[112]

Waste sector

The waste sector in Haryana struggles with increasing generation of waste due to population growth and urbanization, with segregation rates at only 72%, leading to **mixed waste reaching landfills[113] and causing emissions.** Inefficient diversion of waste to MRFs, high operational costs of waste-to-energy plants, and limited composting and anaerobic digestion facilities compound the problem. Additional challenges include the high carbon intensity of waste combustion, limited market demand for compost and biogas products, and insufficient waste collection and transportation infrastructure. Scaling up composting, anaerobic digestion, and recycling requires significant investments in infrastructure and technology, as well as robust systems for consistent waste collection and source segregation. Limited awareness and public participation in proper waste disposal and segregation practices also pose a challenge, as community engagement and behaviour change[114] are crucial for minimizing open burning and optimizing waste diversion. Addressing these barriers will require a holistic approach that prioritizes low-emission processing methods, upgrades waste handling infrastructure, and fosters public awareness to effectively reduce the environmental impact of waste management in the state.

Industry and Power sector

The industrial sector in Haryana presents **opportunities to improve oversight in regions with concentrated emissions, address unregulated mining practices, and strengthen monitoring systems.** MSMEs also face **knowledge gaps** regarding energy-efficient technologies, while high costs of retrofitting infrastructure, such as for waste heat recovery systems, deter cleaner technology adoption. Haryana is home to 1,595,732 MSMEs,[115] many of which are in sectors with significant energy-saving potential but lack the resources to upgrade. Challenges in accessing financial resources further increases the cost of technology upgradation. This is compounded by a lack of trust in new technological solutions within both the industry and financial sectors. Furthermore, new technologies often require reskilling of the workforce, which adds another layer of difficulty to upgrading industrial practices.[116]

Livestock sector

The livestock sector in Haryana faces declining populations having reduced by nearly 20% between 2012 and 2019.[117] The primary reason is resistance to transitioning from crossbreed to indigenous cattle breeds like Murrah buffaloes, which require higher maintenance but yield less milk. Limited availability of grazing lands caused by urbanization, degradation of Panchayati lands, prevalent use of stall-feeding systems, encroachment on designated grazing areas, and disputes complicates open grazing practices. Risks of overgrazing, land-use conflict, reduced agricultural productivity and land degradation persist due to insufficient land availability.[118] Additionally, challenges like infrastructure needs, disease management, and farmer adaptation to open grazing practices require strong policy support, financial incentives, and effective implementation strategies to achieve the targeted emission reductions.

Agriculture sector

While Haryana's MSP for rice has ensured food security, the state is now focused on **balancing this support with initiatives to promote crop diversification** towards more water-efficient agricultural practices. Rice cultivation accounted for about 24% of irrigated land under cultivation in the state in 2022-23.[119] **Farmers face high upfront investment requirements for System of Rice Intensification (SRI) tools and equipment, along with limited awareness and training programs.** Scaling up natural farming practices is constrained by high transition costs, lack of supportive market linkages for naturally farmed produce, and uncertainties in pricing for non-rice crops. Despite modernization, agriculture is still rooted in traditional practices and marred with low profit margins making farmers extremely sensitive to costs. Adoption of alternative technologies and practices is made difficult by a lack of awareness about alternative practices and their benefits, high upfront costs of adopting alternative practices combined with the absence of economic returns (or lack of awareness about them), inadequate government support, limited access to credit and markets that can enable and encourage the farmers to adopt sustainable practices, and so on.

Residential sector

The residential sector struggles with transitioning to cleaner cooking solutions due to unreliable LPG supply in rural areas and high upfront costs of improved cookstoves for cleaner fuels.[121] Transitioning to improved biomass cookstoves, biogas, and solar cooking systems also requires overcoming significant behavioral resistance, as many households are accustomed to traditional methods. High initial costs, limited awareness, and lack of maintenance infrastructure further hinder the adoption of biogas and solar technologies. Scaling up solar cooking systems faces issues like reduced efficiency during cloudy seasons and maintenance challenges. Large-scale behavioral change campaigns are needed alongside substantial investments in distribution channels for LPG and PNG to ensure widespread adoption across Haryana's rural communities.

Table 35: Summary of challenges for sector-specific strategies

Sector	Strategies	State Specific Challenges
Transport	ALT-1	▪ High costs of electric buses and limited local manufacturing capacity. ▪ Inadequate charging infrastructure across the state. ▪ Insufficient availability of renewable energy for charging EVs.
	ALT-2	▪ Resistance from vehicle owners towards scrappage policy due to lack of incentives. ▪ High implementation costs and administrative challenges. ▪ Limited availability of scrappage and recycling centers.
	ALT-3	▪ High initial investment required for hydrogen infrastructure. ▪ Lack of established supply chains for hydrogen. ▪ Absence of supportive policies and regulations for H-CNG blending.
	ALT-4	▪ Need for extensive policy support to achieve high conversion rates. ▪ High upfront costs of EVs for consumers. ▪ Inadequate charging infrastructure across the state.
Waste	ALT-1	▪ Lack of infrastructure for efficient diversion of waste to Material Recovery Facilities (MRFs). ▪ High operational costs of waste-to-energy plants. ▪ Issues with waste segregation at the source. ▪ Limited capacity for composting and anaerobic digestion facilities. ▪ High costs and low efficiency of waste combustion processes. ▪ Lack of market demand for compost and biogas products. ▪ Increased need for investment in recycling infrastructure. ▪ Challenges in scaling up waste processing to meet 50% or 60% diversion target due to high upfront costs and operational challenges.
	ALT-2	
	ALT-3	

Sector	Strategies	State Specific Challenges
	ALT-4	▪ Inconsistent waste collection practices across regions. ▪ Lack of public awareness and participation in waste segregation. ▪ Potential environmental risks from increased waste combustion activities.
Industry (including power plants, brick kilns, and DG sets)	ALT-1	▪ High capital investment needed for switching to natural gas. ▪ Inconsistent supply of natural gas in some regions. ▪ Challenges in integrating renewable energy with existing industrial setups.
	ALT-2	▪ High installation costs for community boilers. ▪ Logistical issues in biomass collection and transportation. ▪ Resistance from small industries due to cost concerns.
	ALT-3	▪ High costs and technical challenges of using green hydrogen in existing processes. ▪ Need for infrastructure development for green hydrogen production and supply. ▪ Lack of clear policy directives for hydrogen usage.
Livestock	ALT-1	▪ Slow adoption of indigenous cattle breeds due to lower milk yields compared to crossbreeds. ▪ Need for policy and financial support to farmers for breed transition. ▪ Limited capacity for maintaining indigenous cattle populations.
	ALT-2	▪ Insufficient land availability for open grazing due to urbanization. ▪ Encroachment and disputes over designated grazing lands. ▪ High maintenance costs for managing grazing lands.
	ALT-3	▪ Difficulty in providing adequate grazing lands for all cattle, especially in densely populated regions. ▪ Risk of overgrazing and land degradation. ▪ High cost and challenges in land acquisition for new grazing areas.
Agriculture	ALT-1	▪ Resistance from farmers due to high labor intensity of System of Rice Intensification (SRI). ▪ Limited awareness and training programs for farmers. ▪ High upfront investment required for SRI tools and equipment.
	ALT-2	▪ Challenges in scaling up natural farming practices across the state. ▪ Lack of supportive market linkages for naturally farmed produce. ▪ High cost of transitioning from conventional to natural farming methods.
	ALT-3	▪ Resistance from farmers due to the risk of lower yields with crop diversification. ▪ Market and pricing uncertainties for non-rice crops. ▪ Lack of infrastructure and incentives for crop diversification.
Residential	ALT-1	▪ High upfront costs of improved cookstoves. ▪ Lack of existing infrastructure and the high cost of building new distribution channels for LPG and PNG. ▪ Lack of awareness and training for using improved cookstoves. ▪ Inadequate infrastructure for biogas and solar cooking systems. ▪ Supply chain challenges for biogas, especially in rural areas. ▪ High cost of solar-based cooking systems and limited subsidies. ▪ Need for large-scale behavioural change among rural households. ▪ High upfront cost for solar cookers and maintenance issues.

7

Conclusion

Based on the study analyses, Haryana has substantial potential to reduce SLCP and other non-CO_2 pollutant emissions across multiple sectors. Such mitigation will contribute toward achieving India's climate goals and overall sustainability of the state economy, besides reducing the risk of increasing heat stress. However, strategies for any SLCP mitigation and mitigation of other non-CO_2 pollutants will need clear policy targets for fruition which, in turn, will hinge on granular understanding of the sector-specific emissions landscape. **Table 36** below provides a summary of the major sectors – industry, transport, agriculture and livestock – contributing towards SLCP and other non-CO_2 pollutant emissions in Haryana. It also presents an overview of which policies should be prioritised for SLCP mitigation and mitigation of other non-CO_2 pollutants in these sectors.

Table 36: Sector-wise Overview of Key Air Pollutants, Mitigation Strategies, and Expected Outcomes and the Description of Implementation Efforts.

Sector	Key Pollutants	Mitigation Strategies	Expected Outcomes	Description of Implementation Efforts
Industry	PM, SO_2, methane	– Transition to natural gas (ALT-1) (monitor methane emissions) – Implementation of community boiler systems within clusters (ALT-2)	Decline in PM and SO_2 emissions; improved energy efficiency; centralized monitoring	Support industrial clusters in transitioning to community boiler systems and monitor methane emissions from natural gas use.
Transport	NOx, VOCs, secondary pollutants (ozone, nitrate aerosols)	– Phased implementation of vehicle scrappage policy (ALT-2) – Transition to electric vehicles (EVs) (ALT-4)	Reduction in NOx and NMVOC emissions; decreased secondary pollutants like ozone and aerosols	Prioritize funding for vehicle scrappage programs and incentivize EV adoption despite infrastructure constraints.
Agriculture	PM, black carbon, NOx, methane	– Eliminate open burning of crop residues by 2030 – Introduce System of Rice Intensification (SRI), natural farming, and crop diversification (ALT-3)	Reduction in PM, black carbon, NOx; 48–60% reduction in methane emissions by 2047	Enforce strict bans on crop residue burning and subsidize SRI adoption and natural farming practices.
Livestock	Methane	– Improved fodder management practices – Partial transition to open grazing (ALT-2 and ALT-3)	Up to 37% reduction in methane emissions	Invest in fodder management programs and promote sustainable grazing practices.

Further, the table below parses the study data to show emissions reductions under different policy scenarios to illustrate potential impact of each in the future.

Table 37: Summary of emission reduction under different alternative scenarios compared to BAU in 2047

Sector	Strategies	$PM_{2.5}$	PM_{10}	SO_2	NO_x	NMVOCs	BC	CH_4
Transport	ALT-1	-10%	-12%	-14%	-11%	-14%	-12%	-24%
	ALT-2	-29%	-37%	-17%	-24%	-20%	-23%	-50%
	ALT-3	-3%	-5%	-4%	-6%	-3%	-10%	-11%
	ALT-4	-33%	-41%	-21%	-28%	-24%	-27%	-60%
Waste	ALT-1	13053%	10980%	15262%	0%	0%	235%	-26%
	ALT-2	14027%	11801%	16393%	0%	0%	247%	-32%
	ALT-3	17524%	14741%	20480%	0%	0%	296%	-48%
	ALT-4	17738%	14915%	20748%	0%	0%	282%	-66%
Industry (including power plants, brick kilns, and DG sets)	ALT-1	-97%	-97%	-46%	-38%	-35%	-89%	80%
	ALT-2	-14%	-13%	-37%	-30%	-35%	-22%	-28%
	ALT-3	-10%	-9%	-36%	-30%	-35%	-22%	-28%
Livestock	ALT-1	0%	0%	0%	0%	0%	0%	-2%
	ALT-2	0%	0%	0%	0%	0%	0%	-37%
	ALT-3	0%	0%	0%	0%	0%	0%	-44%
Agriculture	ALT-1	0%	0%	0%	0%	0%	0%	-48%
	ALT-2	0%	0%	0%	0%	0%	0%	-56%
	ALT-3	0%	0%	0%	0%	0%	0%	-60%
Residential	ALT-1	0%	0%	0%	0%	0%	0%	17%
	ALT-2	0%	0%	0%	0%	0%	0%	17%
	ALT-3	0%	0%	0%	-3%	-3%	0%	0%

It is evident that to align with its climate and air quality targets, Haryana needs to pursue an integrated approach that emphasizes renewable energy adoption, green industrial practices, widespread EV deployment, and modernization of agriculture. The state can achieve substantial emissions reductions by enhancing the policy framework and accelerating the implementation of targeted interventions in these sectors while promoting sustainable economic growth. Coordinated efforts involving regulatory reforms, financial incentives, technology adoption, and capacity building will be essential to drive this transformation and address state-specific challenges. In addition to these strategies, the state will need to undertake significant infrastructure development to ensure their successful implementation. This includes building extensive charging infrastructure for electric vehicles, enhancing supply chain systems for the distribution of cleaner fuels in the residential and power sectors, and developing robust facilities for waste collection and processing. These infrastructure upgrades are essential to effectively support the proposed interventions and achieve the desired emissions reduction and sustainable development outcomes. Engaging with private stakeholders, leveraging national mechanisms such as carbon credits, and fostering cross-sectoral collaboration can further amplify the impact of these strategies, ensuring a cleaner and healthier environment for the residents of Haryana.

Annexure 1: Sector-specific Methodologies for Estimating Emissions

Industry

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 particulate matter (PM_{10} & $PM_{2.5}$), SO_2, BC, CH_4, and NO_x into the ambient atmosphere mainly occur during the combustion process. The data concerning coal consumption is obtained from the annual survey of industries, 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:

$$Ep = Cf \times EF$$

Where Ep is the emission of pollutant p, Ef is the emission factor of the fuel consumed (Table 38), and Cf is the fuel consumed by the industry.

Table 38: Emission Factors (Kg/t) of Different Pollutants from Different Fuels used in Industries in Haryana

Emission Factor (Kg/t)	Coal*
PM_{10}	187.6
$PM_{2.5}$	65.66
SO_2	9.75
NO_x	4.5
CO	0.3

Source: SA Six cities, CPCB; *based on ash content and sulphur content for PM and SO_2

The estimated emissions from industries in Haryana are shown in Table 39 .

Table 39: Estimated Emissions from Industries in Haryana

Industry	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x	CO	CH_4
Food Products	9.00	3.15	0.04	0.47	0.22	0.01	0.00
Beverages	5.82	2.04	0.03	0.30	0.14	0.01	0.00
Tobacco Products	0.19	0.07	0.00	0.01	0.00	0.00	0.00
Textiles	45.21	15.82	0.20	2.35	1.08	0.07	0.01
Wearing Apparel	2.06	0.72	0.01	0.11	0.05	0.00	0.00
Leather and Related Product	0.38	0.13	0.00	0.02	0.01	0.00	0.00
Paper and Paper Products	19.14	6.70	0.08	0.99	0.46	0.03	0.00
Coke and Refined Petroleum Products	17.82	6.24	0.08	0.93	0.43	0.03	0.00
Chemicals and Chemical Products	76.35	26.72	0.33	3.97	1.83	0.12	0.01
Pharmaceuticals, Medicinal Chemical and Botanical Products	0.56	0.20	0.00	0.03	0.01	0.00	0.00
Rubber and Plastics Products	7.50	2.63	0.03	0.39	0.18	0.01	0.00
Other Non : Metallic Mineral Products	53.84	18.84	0.23	2.80	1.29	0.09	0.01

Industry	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x	CO	CH_4
Basic Metals	2.44	0.85	0.01	0.13	0.06	0.00	0.00
Fabricated Metal Products, Except Machinery and Equipment	0.19	0.07	0.00	0.01	0.00	0.00	0.00
Machinery and Equipment N.E.C.	2.81	0.98	0.01	0.15	0.07	0.00	0.00
Others	0.75	0.26	0.00	0.04	0.02	0.00	0.00
Total	244.07	85.42	1.06	12.68	5.85	0.39	0.04

Note: The estimated emissions are solely from the combustion of coal as other fuel data was unavailable in the public domain.

Brick Kilns

This study has employed an approach based on brick production and production technology to estimate emissions from brick kilns. The production-based approach utilizes the weight of each brick as the activity data. The cumulative weight of bricks produced annually across all kilns was used to estimate emissions from the brick kiln industry.

Emissions were calculated using the following equation:

$$Ep = B_T \; Ef$$

Where, **Ep** is the emission of pollutant *p*, $\mathbf{B_T}$ is the cumulative weight of bricks produced annually, and **Ef** is the production-based emission factor.

The main technology employed for brick production in Haryana has been assumed as the Zig-Zag brick firing technology. The total weight of bricks produced using this technology was estimated based on the total number of bricks produced annually in a region and the weight of the fired brick. After consultation with experts and drawing from TERI's experience in this sector, we assumed the weight of the fired brick to be 3 kg.

Emission factors for different pollutants associated with various production technologies were selected after reviewing published literature, including studies by GAINS, Greentech Energy Solutions (Table 40).

Table 40: Technology-wise Emission Factors for Different Pollutants from Brick Kilns

Technology	Emission factor (g/Kg of fired bricks)						
	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x*	CO	NMVOCs*
Zig-Zag	0.26	0.13	0.04	0.32	0.00004	1.47	0.1

The total emissions estimated from brick kilns in Haryana are summarised in Table 41

Table 41: Estimated Emissions from Brick Kilns in Haryana

District	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x	CO	NMVOCs
Ambala	0.30	0.15	0.05	0.37	0.00	1.69	0.11
Bhiwani	0.57	0.29	0.09	0.70	0.00	3.23	0.22
Faridabad	0.39	0.20	0.06	0.48	0.00	2.22	0.15
Fatehabad	0.22	0.11	0.03	0.27	0.00	1.25	0.09
Gurugram	0.02	0.01	0.00	0.03	0.00	0.14	0.01
Hisar	0.73	0.37	0.11	0.90	0.00	4.15	0.28
Jhajjar	1.28	0.64	0.20	1.58	0.00	7.24	0.49

District	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x	CO	NMVOCs
Jind	0.44	0.22	0.07	0.54	0.00	2.50	0.17
Kaithal	0.32	0.16	0.05	0.39	0.00	1.81	0.12
Karnal	0.34	0.17	0.05	0.42	0.00	1.94	0.13
Kurukshetra	0.24	0.12	0.04	0.29	0.00	1.33	0.09
Mahendragarh	0.24	0.12	0.04	0.29	0.00	1.35	0.09
Mewat	0.35	0.18	0.05	0.43	0.00	1.98	0.14
Palwal	0.55	0.27	0.08	0.67	0.00	3.10	0.21
Panchkula	0.07	0.04	0.01	0.09	0.00	0.42	0.03
Panipat	0.32	0.16	0.05	0.39	0.00	1.81	0.12
Rewari	0.38	0.19	0.06	0.46	0.00	2.12	0.14
Rohtak	0.39	0.19	0.06	0.48	0.00	2.18	0.15
Sirsa	0.46	0.23	0.07	0.57	0.00	2.62	0.18
Sonipat	0.81	0.41	0.12	1.00	0.00	4.58	0.31
Yamunanagar	0.23	0.11	0.04	0.28	0.00	1.29	0.09
Total	8.66	4.33	1.33	10.66	0.00	48.96	3.33

Power Plants

The equation used for estimation of emissions from coal-based power plant is,

$$[E_{PM}]_c = \sum_{(a=1)}^{n} [P_c]_a \times [A_c]a \times (1 - fb_r) \times \mathbf{M} \times (1 - RE_a)$$

$$[E_{Pg}]_c = \sum_{(a=1)}^{n} [P_c]_a \times EF_{pg} \times (1 - RE_a)$$

Where, EPM is the emission of particulates, E_{Pg} is the emission of gaseous pollutants, [Pc]a is annual coal consumption in plant a, [Ac]a is ash content of coal in TPP a, fbr is the ratio of bottom ash to fly ash, M is the particulate mass fraction (0.4 for $PM_{2.5}$ to PM_{10} and 0.75 for PM_{10} to total particulates following USEPA, 2015[123]), REa is the efficiency (%) of installed air pollution emission control equipment at TPP a and EFpg is the emission factor of the particular gaseous pollutant (p) from TPP. The emission factors used for calculation of emissions from coal and biomass-based power plants are provided in Table 42.

Table 42: Emission Factors Used for Emission Estimation of Coal- and Biomass-based Thermal Power Plants

Pollutant	Emission factor	Pollutant	Emissions Factors (kt/PJ)#
		PM_{10}	0.2136
SO2 (Kg/t)*	19.5* S	$PM_{2.5}$	0.1848
NOx (Kg/t)**	4.50	SO_2	0.0169
CO (Kg/t)**	0.30	NO_x	0.13
NMVOCs (Kg/t) ***	0.2713	BC	0.0072
		CO	0.1

The annual coal and biomass consumption (Pc) in each Thermal Power Plant (TPP) during 2019 was sourced from the CEA, 2020 database. The total annual coal (domestic and imported) consumed in TPPs in Haryana during 2019 amounted to 26.2 Mt. All coal-based TPPs in Haryana are equipped with Electrostatic Precipitators (ESPs) to control particulate matter emissions. The ash content (Ac) of domestic coal consumed at each TPP and the annual ESP efficiency data of each TPP were also collected from the CEA database. The sulphur content of domestic coal was considered as 0.5%. Studies suggest that the sulphur content of Indian coal ranges between 0.28% and 0.63%. Indonesia, Australia, and South Africa account for over 80 percent of India's coal imports . The average ash and sulphur content of imported coal were taken as 15% and 0.63%, respectively. A 20% ratio of bottom to fly ash was applied following AP-42. The estimated emissions from power plants are provided in Table 43.

Table 43: Emissions from Coal-based Power Plants during 2019 in Haryana

Power Plants	PM_{10}	$PM_{2.5}$	BC	NO_x	SO_2	CO	NMVOC
Indira Gandhi STPP	23.72	13.49	0.15	30.19	0.90	0.81	0.81
Mahatma Gandhi TPS	1.37	16.33	0.18	35.38	1.09	0.98	0.98
Panipat TPS	0.48	5.67	0.06	12.29	0.38	0.34	0.34
Rajiv Gandhi TPS	0.62	7.35	0.08	15.93	0.49	0.44	0.44
Yamuna Nagar TPS	0.68	8.11	0.09	17.58	0.54	0.49	0.49

Transport

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

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

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 Kilometer 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 18

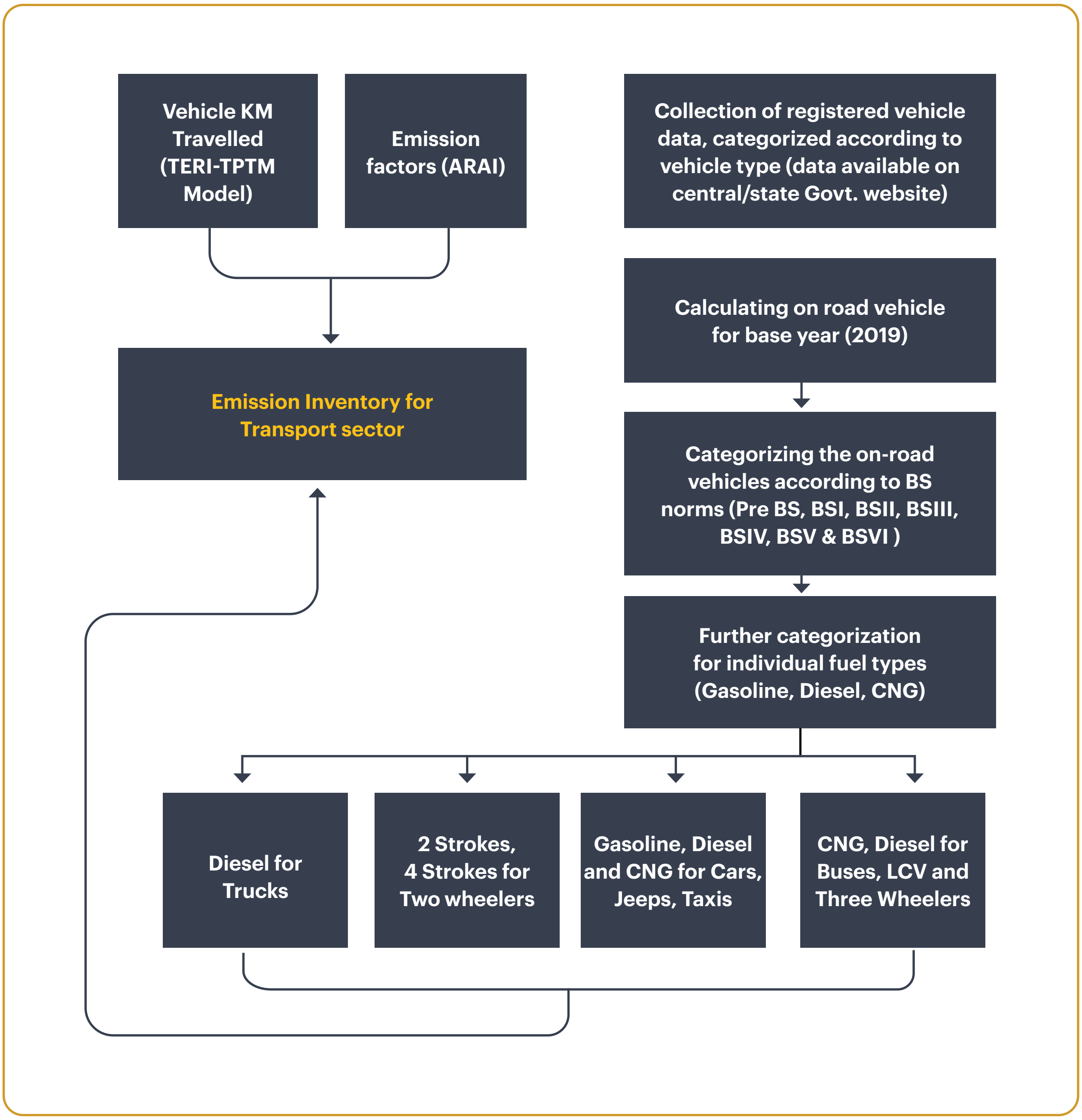


Figure 19: Methodology for estimating emissions from the transport sector

The estimated state level annual Vehicle Kilometer Travelled (VKT) of different categories of vehicle during 2019 was adopted from the TERI-Transport Model (TERI-TPTM) (Table 44). The model first estimates the total transport demand in Haryana, 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 utilization 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 44: 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 Haryana. The emission factors (EF) of PM_{10}, $PM_{2.5}$, NO_x, SO_x, hydrocarbon, CO, BC, and CH_4 for this exercise were adopted from ARAI (2008) and IPCC (2006).

Table 45: Emission Estimates in kt/yr from the Transport Sector in Haryana

Vehicle Type	PM_{10}	$PM_{2.5}$	BC	NO_x	SO_2	CO	NMVOCs
Truck	6.3	6.1	0.9	86.9	0.1	55.7	38.9
Tractor/Trailer	2.4	2.3	0.3	21.6	0.0	8.6	3.9
Bus	1.2	1.2	0.2	13.7	0.0	12.9	6.3
Cars	0.4	0.4	0.1	11.4	0.2	38.6	5.5
MUVs	0.4	0.3	0.1	4.6	0.0	4.3	0.3
2 wheelers	5.6	5.4	0.8	45.7	0.2	248.7	86.2
3 wheelers	0.6	0.5	0.1	4.2	0.0	8.6	1.4
LCVs	4.4	4.3	0.6	41.2	0.3	51.5	3.4
Total	21.2	20.5	3.1	229.3	1.0	428.8	145.9
	CH_4						
Transport	1.56						

Road Dust Resuspension

The dust lying on roads gets re-suspended in air when vehicles move on it. The rate of re-suspension is dependent on the weight of the vehicles and quantity of silt lying on the road. Fugitive emission of particulate matter from re-suspension of road dust due to movement of vehicles on paved roads is calculated using following equation as provided in AP-42,

$$[E_p]_t = \sum VKT_r \times k \times w^{1.02} \times Mo^{0.91}$$

Where, [Ep]t is the fugitive emission of particulates (p) from the transport sector; r is the type of road (arterial, sub-arterial and local); k is function of particle size (0.62 for PM_{10} and 0.15 for $PM_{2.5}$); w is the average weight of vehicle travelling on the road and Mo is road surface silt (≤ 75 µm in physical diameter) loading in unit area. The $[E_p]$t is directly proportional to the silt loading on the road surface and average weight of the vehicles plying on the road. 15% of the [Ep]t is considered as $PM_{2.5}$, while 62% is considered as PM_{10}. After estimating $[E_p]_t$ using the above equation the effect of rainy days was considered to finalize the fugitive emission (f[Ep]t) from road dust re-suspension using the equation below, where Dp is the number of rainy days in a year. Please note that the standardized composition assumptions in the AP-42 methodology may not accurately reflect the specific characteristics of Indian road dust, which can influence the accuracy of emission estimates.

$$f_{[E_P]_t} = [E_P]_t \times (1 - D_P) / (4 \times 365)$$

Based on silt loadings experiments carried out by TERI in past in various regions of India (TERI, 2019), we have assumed an averaged silt load of all highways as 0.3% m-2 in Haryana. However, it is not yet possible to incorporate variations of silt loads on different road types. With more surveys in future, the framework will be able to account for this information. 'w' values are derived based on vehicle type distribution in a particular year.

Diesel Generator Operation

The emission inventory for DG sets for 2019 is calculated based on diesel consumption in DG sets (activity data) and emission factor (adopted from AP-42, USEPA). Sector-specific fuel consumption is derived using total annual diesel consumption in India and the percentage share of each sector in total fuel usage. Annual diesel consumption in India is taken from Ministry of Petrolium and Natural Gas (MoPNG's) annual reports, and sector-specific fuel consumption percentage share is used from the PPAC report 2021 . Further, emissions are estimated using equations below:

$$\mathbf{E_d = F_d \times Cal_d}$$

$$\mathbf{E_{DG} = E_d \times EF}$$

Where E_d is the total energy equivalent of the diesel fuel consumed by DG sets annually, F_d is the total fuel consumed by DG sets annually, and Cald 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. Pollutant-wise emission factors are taken from AP-42, USEPA, provided in Table 46.

Table 46: Emission Factor for DG sets as per AP-42, USEPA

Pollutants	Emission Factor (g/kwh)
PM_{10}	0.5
$PM_{2.5}$	0.4
SO2	0.4
NO_x	6.8
CO	1.5

**Conversion of ng/J -> g/Kg = 0.0036*

Emissions for various pollutants in the state of Haryana are shown in Table 47.

Table 47: Emissions (kt/yr) from the Operation of Diesel Generators in Different Sectors in Haryana in 2019

	PM_{10}	$PM_{2.5}$	BC	NO_x	SO_2	CO
Agri Pump sets	0.17	0.15	0.06	2.44	0.16	0.53
Mobile towers DG sets	0.09	0.07	0.03	1.22	0.08	0.26
Power generation						
Industrial DG sets	0.26	0.22	0.09	3.66	0.24	0.79
Commercial DG sets	0.14	0.12	0.05	2.03	0.13	0.44
Residential DG sets	0.06	0.05	0.02	0.81	0.05	0.18
Total	**0.72**	**0.61**	**0.24**	**10.17**	**0.67**	**2.19**

Construction and demolition sector

The emissions from the construction sector are estimated based on the area allocated for construction or demolition activities. For this assessment, Gross State Value Added (GSVA) of construction in Haryana, along with the cost of per acre land is incorporated to determine an estimated area under development to further develop the emission inventory. The average construction cost per acre of land in 2016, as determined through expert consultations, is Rs. 984 lakhs. In addition, the construction cost index (with a base year of 2007 and a base price of 100 Rupees, obtained from CIDC, India) is applied to determine the inflation rate, which is subsequently used to estimate the average construction cost per acre of land for the years 2019, 2030, 2040 and 2047, respectively.

Following the estimation of the construction cost per acre, the Gross State Value Added (GSVA) from construction is divided by this cost to calculate the total constructed area for the respective years.

The mathematical expression used for the area calculation is described below:

$$A_{ST} = GSVA_{ST} \qquad Ca$$

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.

Table 48: Construction Cost, Estimated Area Under Construction, and Emission Factors for the Year 2019

Year	2019	Emission Factor	SPM	PM_{10}	$PM_{2.5}$
Construction cost (INR Lakhs)	1000	1.2tons/acre/ month	44.6	15.6	2.6
Estimated area under construction (Acre)	3718				

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

$$E_p = Ac * T * Ef$$

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 SPM from construction activities are estimated using emission factor (1.2 tons/acre/month) (source: EPA). According to USBR (2002)[30], PM_{10} emission from overburden removal and bulldozing activities during construction activity is 35% of total particulate matter emission, while $PM_{2.5}$ is 6% of SPM[131 132]

Residential

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

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

Where, $[E_p]_R$ is the emission of a particular pollutant (p) from the residential sector, $Pop_{(s,f)}$ is the population of a state using a particular fuel (f), $C_{(s,f)}$ = State specific per capita consumption of a particular fuel, $EF_{(f,p)}$ = Emission factor of the particular pollutant (p) of the particular fuel type (f). Six major fuels those are used in the residential households for cooking, heating and lighting purposes is included in this emission inventory estimation – a) Fuel wood, b) dung cake, c) crop residue, d) coal, e) kerosene and f) LPG. State specific population of Haryana during 2019 was taken population projection report for India and states.

State specific monthly per capita consumption of different fuels ($C_{s,f}$) in the rural and urban areas for Haryana 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. On the other side, emissions from the PNG and gobar gas uses in residential sector are not considered owing to their very low usages.

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

Indian Petroleum and Natural Gas Statistics report has been referred to estimate the growth trend of LPG consumption in residential households. MoPNG reports LPG consumption information at state level and therefore for present estimation we have considered LPG consumption data of Haryana for the years 2016 to 2019 to estimate the LPG growth at district level. Accordingly, an annual LPG consumption growth of 8.35% has been considered for Haryana. The increase of numbers of households using LPG is then uniformly distributed to adjust the number of fuelwoods, crop residue, and dung cake-using households during 2019.

The activity data of different fuels was fed into above equation along with the fuel specific emission factors of different pollutants ($EF_{(f,p)}$) (Table 49) to calculate the emission of different pollutants from the use of different fuel types in residential sector.

Table 49: Emission factors (g/Kg) of Different Pollutants from Different Fuel Types used in the Residential Sector

Pollutant	FW	CR	CDC	COAL	KEROSENE_C	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_x	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	

FW: Fuel wood; CR: Crop residue; DC: Dung cake; K: Kerosene; LPG: Liquid Petroleum Gas

Table 50: Total emissions (kt) of Different Pollutants from The Residential Sector in Haryana in 2019

	FW	CR	DC	Coal	K	LPG	Total
PM2.5	3.05	0.46	0.76	0.00002	0.00015	0.14	4.41
PM10	4.50	0.70	1.81	0.00003	0.00018	0.14	7.14
SO2	0.53	0.06	0.10	0.00006	0.00002	0.16	0.85
NO2	1.13	0.15	0.17	0.00001	0.00007	1.13	2.57
CO	44.15	5.18	13.58	0.00025	0.00217	0.78	63.69
NMVOC	10.55	0.69	4.16	0.00004	0.00086	7.38	22.78
BC	0.27	0.02	0.07	0.00000	0.00003	0.00	0.36

FW: Fuel wood; CR: Crop residue; DC: Dung cake; K: Kerosene; LPG: Liquid Petroleum Gas

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,

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

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 Haryana 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 Jain et al. (2014). The combustion efficiency (fBa) of different crop residues is used as reported in Turn et al. (1997) (Table 51).

Table 51: 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 (*f*Da)[b]	0.86	0.88	0.80	0.90	0.90
Combustion efficiency (*f*Ba)[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.

Cultivation-related Emissions: Space Application Centre, Ahemdabad reported state specific methane emission factors from rice crop land. Following the report, the Haryana state specific methane emission factors were used to estimate the methane emissions from rice crop lands. IPCC default emission factor for direct nitrous oxide emission estimation from crop land was used during the estimation of nitrous oxide emission from different crop land. However, upper Indo-Gangetic Plain specific emission factors were used to estimate nitrous oxide emissions from wheat and maize crops.

Estimated methane emissions from rice crop land of Haryana during 2019-20 were 50 kt (Table 52). 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. Average N-fertilizer application to wheat, maize, cotton and Sugarcane crops were taken as 120, 156, 250 and 250 Kg/ha in Haryana.

Table 52: Total Agriculture-related Emissions in Haryana in 2019 (kt/yr)

District	PM_{10}	$PM_{2.5}$	BC	SO_2	NO_x	CO	NMVOC	CH_4
Ambala	3.4	2.5	0.4	0.7	0.3	25.3	1.2	3.1
Bhiwani	3.7	2.3	0.2	0.4	0.5	19.9	3.9	0.9
Charki Dadri	1.5	0.9	0.1	0.2	0.2	8.8	1.2	0.4
Faridabad	0.6	0.4	0.1	0.1	0.0	4.9	0.2	0.6
Fatehabad	9.7	6.4	0.8	1.7	0.9	65.0	7.4	4.4
Gurgaon	0.4	0.3	0.0	0.1	0.0	3.2	0.2	0.2
Hisar	8.4	5.3	0.6	1.1	0.9	48.8	8.0	2.9
Jhajjar	2.4	1.6	0.2	0.4	0.2	18.0	1.0	1.8
Jind	9.1	6.0	0.8	1.6	0.8	61.9	5.9	5.0
Kaithal	7.4	5.3	0.8	1.7	0.5	58.5	2.9	6.0
Karnal	8.0	5.8	0.9	1.8	0.6	62.6	2.9	6.2
Kurukshetra	4.9	3.6	0.5	1.1	0.4	37.4	1.9	4.2
Mahendragarh	0.2	0.1	0.0	0.0	0.0	0.9	0.1	0.0
Mewat	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.4
Palwal	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.3
Panchkula	0.2	0.1	0.0	0.0	0.0	1.2	0.1	0.4
Panipat	2.8	2.0	0.3	0.6	0.2	21.5	0.9	3.0
Rewari	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Rohtak	3.1	2.1	0.3	0.6	0.3	21.7	1.3	2.3
Sirsa	15.1	9.3	0.9	1.9	1.8	82.1	16.0	3.6
Sonipat	4.7	3.3	0.5	1.0	0.4	36.5	1.4	4.0
Yamunanagar	3.4	2.5	0.4	0.7	0.3	24.5	1.1	2.9
Total	**88.9**	**59.8**	**7.8**	**15.9**	**8.5**	**602.9**	**57.4**	**53.9**

Refuse Burning

The emissions from the construction sector are estimated based on the area allocated for construction or demolition activities. For this assessment, Gross State Value Added (GSVA) of construction in Haryana, along with the cost of per acre land is incorporated to determine an estimated area under development to further develop the emission inventory. The average construction cost per acre of land in 2016, as determined through expert consultations, is Rs. 984 lakhs. In addition, the construction cost index (with a base year of 2007 and a base price of 100 Rupees, obtained from CIDC, India) is applied to determine the inflation rate, which is subsequently used to estimate the average construction cost per acre of land for the years 2019, 2030, 2040 and 2047, respectively.

Following the estimation of the construction cost per acre, the Gross State Value Added (GSVA) from construction is divided by this cost to calculate the total constructed area for the respective years.

The mathematical expression used for the area calculation is described below:

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

Where, AST represents the total area under construction during a year, GSVAST 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.

Table 53: Construction cost and area taken for estimation

Year	2019	2030	2040	2047
Construction cost (INR Lakhs)	1000	1076	1145	1194
Estimated area under construction (Acre)	3718	5243	6587	7744

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

$$E_p = Ac * T * Ef$$

Where, Ep 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 SPM from construction activities are estimated using emission factor (1.2 tons/acre/month) (source: EPA). According to USBR (2002), PM_{10} emission from overburden removal and bulldozing activities during construction activity is 35% of total particulate matter emission, while $PM_{2.5}$ is 6% of SPM (Ahuja et al. 1989; Houck et al., 1989, 1990). Emissions factors and emissions are represented in below Table 54**.**

Table 54: Emissions factors and emissions of Construction Sector

Pollutant	Emission Factor	Year wise Emissions (kt/yr)			
		2019	2030	2040	2047
SPM	**1.2tons/acre/month**	44.6	62.9	79.0	92.9
PM_{10}		15.6	22.0	27.6	32.5
$PM_{2.5}$		2.6	3.7	4.7	5.5

Livestock and Manure Management

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

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

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 55). And in Figure 19 highlighted Methane Emissions from Livestock and Manure Management in Haryana in 2019

Table 55: 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

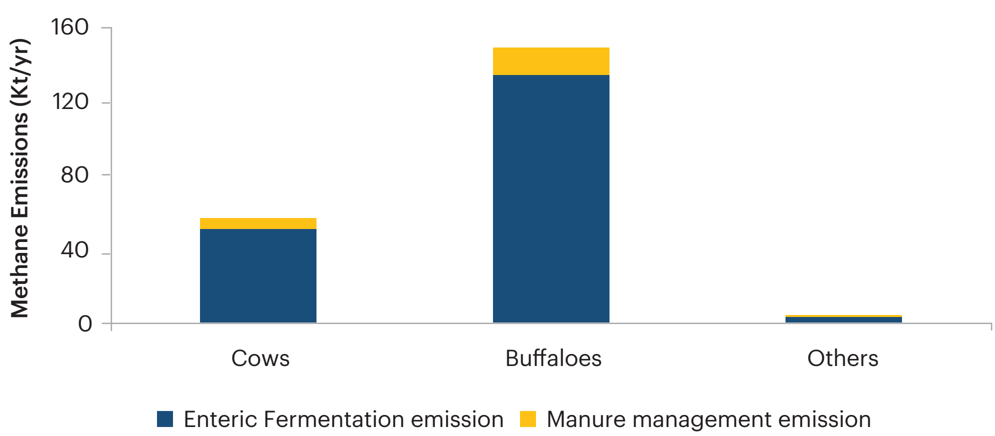


Figure 20: Methane Emissions from Livestock and Manure Management in Haryana in 2019

**Others include Sheep, Goats, Horses & Ponies, Donkeys, Pigs, and Camels.*

1. Li, C. (2020). Space-borne estimation of volcanic sulfate aerosol lifetime. *Journal of Geophysical Research: Atmospheres*, 125(22), e2020JD033883. https://doi.org/10.1029/2020JD033883
2. Andreae MO. The dark side of aerosols. Nature. 2001 Feb 8;409(6821):671-2. doi: 10.1038/35055640. PMID: 11217841.
3. Zare, A., Romer, P. S., Nguyen, T., Keutsch, F. N., Skog, K., & Cohen, R. C. (2018). A comprehensive organic nitrate chemistry: insights into the lifetime of atmospheric organic nitrates. *Atmospheric Chemistry and Physics*, 18(20), 15419-15436. https://doi.org/10.5194/acp-18-15419-2018
4. National Aeronautics and Space Administration. (2025, February 14). *Temperatures rising: NASA confirms 2024 warmest year on record*. Retrieved from https://www.nasa.gov/news-release/temperatures-rising-nasa-confirms-2024-warmest-year-on-record/
5. Haryana Department of Environment and Climate Change. (n.d.). *Revised State Action Plan on Climate Change*. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf
6. India State-Level Disease Burden Initiative Air Pollution Collaborators. (2020). *Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019*. *The Lancet Planetary Health*. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196
7. Climate & Clean Air Coalition. (n.d.). *Short-lived climate pollutants*. Retrieved April 10, 2025, from https://www.ccacoalition.org/content/short-lived-climate-pollutants
8. Xu, Y., Ramanathan, V., & Victor, D. G. (2022). Global warming will happen faster than we think. *Proceedings of the National Academy of Sciences, 119*(3), e2123536119. https://pubmed.ncbi.nlm.nih.gov/30518902/
9. J. Rogelj, M. Schaeffer, M. Meinshausen, D.T. Shindell, W. Hare, Z. Klimont, G.J.M. Velders, M. Amann, & H.J. Schellnhuber. (2014). Disentangling the effects of CO2 and short-lived climate pollutant mitigation, Proc. Natl. Acad. Sci. U.S.A. 111 (46) 16325-16330, https://doi.org/10.1073/pnas
10. State Action Plan on Climate Change. (n.d.). *State Action Plan on Climate Change*. Department of Environment and Climate Change Government of Punjab. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf
11. Haryana State Pollution Control Board. (2024). *Winter Action Plan for Air Pollution Control 2024-25*. https://hspcb.org.in/uploads/modules/hspcb_winter_action_plan__2024-25_66f1210826d53.pdf
12. ICAR-Central Research Institute for Dryland Agriculture. (2022). *Heat wave 2022: Causes, impacts, and way forward for Indian agriculture*. Indian Council of Agricultural Research (ICAR). https://www.icar-crida.res.in/assets/img/Technicalblletins/Heat%20wave%202022%20-%20Causes%20Impacts%20and%20way%20forward%20for%20Indian%20Agriculture.pdf
13. Fuller, T. K., & White, J. R. (2011). The effects of ambient temperature on coal-fired power plant performance. *International Journal of Energy Research, 35*(2), 162–170.
14. Ninaniya, K., Shekhar, C., Chahal, D., & Bishnoi, N. S. (2024). Relationship between paddy cultivation and methane emission rate (XCH4) in Haryana. *Journal of Agrometeorology, 26*(4), 491–493. https://doi.org/10.54386/jam.v26i4.259
15. Times of India. (2024, March 8). *Haryana wants civic bodies to ramp up cleanliness drives before Swachh survey*. https://timesofindia.indiatimes.com/city/gurgaon/haryana-wants-civic-bodies-to-ramp-up-cleanliness-drives-before-swachh-survey/articleshow/118718056.cms
16. Central Pollution Control Board. (n.d.). *Continuous ambient air quality monitoring stations (CAAQMS) data*. Government of India. https://prana.cpcb.gov.in/#/air-quality-data
17. Haryana Pollution Control Board. (2018). *Emission inventory report: Transport sector emissions in Haryana*. Government of Haryana.
18. Monks, P. S., Archibald, A. T., Coe, H., Cooper, O., Coyle, M., Derwent, R., ... & Williams, M. L. (2015). Atmospheric composition change – global and regional air quality. *Atmospheric Environment, 124*, 235–253. https://doi.org/10.1016/j.atmosenv.2015.02.067
19. Haryana Pollution Control Board. (2018). *Solid waste management and emission inventory report for Haryana*. Government of Haryana. https://www.hpcb.gov.in
20. Central Pollution Control Board. (2021). *Annual report 2020-21 on implementation of solid waste management rules, 2016*. https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf
21. Haryana Pollution Control Board. (2018). *Emission inventory report: Industrial sector emissions in Haryana*. Government of Haryana.

22. Mahajan, S., Papang, J. S., Ghule, A., Arora, S., & Indu. (2019). Analysis of dairy cooperative movement in Haryana. *Indian Journal of Dairy Science*, 72(5), 554–561. https://doi.org/10.33785/IJDS.2019.v72i05.014

23. Government of Haryana, Department of Animal Husbandry & Dairying. (2023). *Gausamvardhan Initiative: Strategic targets for cattle population improvement*.https://www.haryana.gov.in

24. *7 January 2025*. (n.d.). Haryana Chief Minister's Office. https://haryanacmoffice.gov.in/7-january-2025

25. Haryana to provide lands to gaushalas for grazing cows. *The Statesman*. https://www.thestatesman.com/cities/haryana-to-provide-lands-to-gaushalas-for-grazing-cows-1501756710.html

26. Pathak, H., Tripathi, R., Jambhulkar, N. N., Bisen, J. P., & Panda, B. B. (2020). *Eco-regional-based Rice Farming for Enhancing Productivity, Profitability and Sustainability* (NRRI Research Bulletin No. 22). ICAR-National Rice Research Institute. https://icar-nrri.in/wp-content/uploads/2020/05/NRRI-Research-Bulletin-22.pdf

27. Department of Economic and Statistical Analysis, Government of Haryana. (2023). *Haryana economic survey 2023*. Government of Haryana. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf

28. Haryana State Action Plan on Climate Change. https://moef.gov.in/uploads/2017/09/Haryana.pdf

29. Haryana Department of Environment and Climate Change. (n.d.). *Revised State Action Plan on Climate Change*. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf

30. Intergovernmental Panel on Climate Change. (2022, April 4). *Summary for policymakers of IPCC report on mitigation of climate change approved by governments*. IPCC. https://www.ipcc.ch/2022/04/04/ipcc-ar6-wgiii-pressrelease/.

31. Xu, Y., Ramanathan, V., & Victor, D. G. (2022). Global warming will happen faster than we think. *Proceedings of the National Academy of Sciences, 119*(3), e2123536119. https://doi.org/10.1073/pnas.2123536119

32. Institute for Governance & Sustainable Development (IGSD). (2013). *Primer on Short-Lived Climate Pollutants*. https://www.igsd.org/documents/PrimeronShort-LivedClimatePollutantsElectronicVersion.pdf

33. Intergovernmental Panel on Climate Change. (2021). Short-lived climate pollutants. In *Climate Change 2021: The Physical Science Basis. Contribution of Working Group I to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Masson-Delmotte, V., Zhai, P., Pirani, A., Connors, S. L., Péan, C., Berger, S., Caud, N., Chen, Y., Goldfarb, L., Gomis, M. I., Huang, M., Leitzell, K., Lonnoy, E., Matthews, J. B. R., Maycock, T. K., Waterfield, T., Yelekçi, O., Yu, R., & Zhou, B. (eds.)]. Cambridge University Press. https://www.ipcc.ch/report/ar6/wg1/chapter/chapter-6/

34. Szopa, S., & Naik, V. (2023). Short-lived Climate Pollutants. In: *IPCC: Sixth Assessment Report*. The Intergovernmental Panel on Climate Change (IPCC).https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter06.pdf

35. Mar, K. A., Unger, C., Walderdorff, L., & Butler, T. (2022). Beyond CO2 equivalence: The impacts of methane on climate, ecosystems, and health. *Environmental Science & Policy, 134*, 127 136. https://doi.org/10.1016/j.envsci.2022.03.027

36. Szopa, S., & Naik, V. (2023). *IPCC: Sixth assessment report*. Intergovernmental Panel on Climate Change (IPCC). https://www.ipcc.ch/report/ar6/

37. Solomon S. et al. (2007) Climate Change 2007: Physical Science Basis, Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, 129, 132.p https://www.ipcc.ch/report/ar4/wg1/

38. Isaksen, I. S., Berntsen, T. K., Dalsøren, S. B., Eleftheratos, K., Orsolini, Y., Rognerud, B., & Holmes, C. D. (2014). Atmospheric ozone and methane in a changing climate. Atmosphere, 5(3), 518-535. https://doi.org/10.3390/atmos5030518

39. NASA. (2011, April). *The greenhouse effect of tropospheric ozone*. NASA Aura. https://aura.gsfc.nasa.gov/science/feature-20110403.html

40. Rowlinson, M. J., Rap, A., Hamilton, D. S., Pope, R. J., Hantson, S., Arnold, S. R., ... & Nieradzik, L. (2020). Tropospheric ozone radiative forcing uncertainty due to pre-industrial fire and biogenic emissions. Atmospheric Chemistry and Physics, 20(18), 10937-10951

41. Bond, T.C., Doherty, S.J., Fahey, D.W., Forster, P.M., Bernsten, T., DeAngelo, B.J. et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. *Journal of Geophysical Research: Atmospheres*; 118(11):5380-5552. doi:10.1002/jgrd.5017

42. Venkataraman, C., Brauer, M., Cropper, M. L., Apte, J. S., Bonjour, S., Balakrishnan, K., ... & Dandona, L. (2020). How Air Pollution Affects the Indian Economy. *The Lancet Planetary Health, 5*(1), E26-E38. https://doi.org/10.1016/S2542-5196(20)30298-4

43. Venkataraman, C., Brauer, M., Cropper, M. L., Apte, J. S., Bonjour, S., Balakrishnan, K., ... & Dandona, L. (2021). How air pollution affects the Indian economy. *The Lancet Planetary Health, 5*(1), E26-E38. https://doi.org/10.1016/S2542-5196(20)30298-4

44. United States Environmental Protection Agency. (2024, April 16). *Understanding global warming potentials*. https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

45. Department of Agriculture, Government of Haryana. (n.d.). *Vital of agriculture*. Government of Haryana. https://agriharyana.gov.in/data/AYP_MSP_VitalOfAgriDoc/Vital_of_Agriculture.pdf

46. Haryana Government, Department of Economic and Statistical Analysis. (2024). *Economic Survey of Haryana (2023-2024)*. https://esaharyana.gov.in/document-category/economic-survey-of-haryana-english/

47. Department of Economic and Statistical Affairs, Haryana. (2024). *Economic Survey of Haryana 2023-24*. https://cdnbbsr.s3waas.gov.in/s32b0f658cbffd284984fb11d90254081f/uploads/2024/02/202402271962653454.pdf

48. ICAR-Central Research Institute for Dryland Agriculture. (2022). *Heat wave 2022: Causes, impacts, and way forward for Indian agriculture*. Indian Council of Agricultural Research (ICAR). https://www.icar-crida.res.in/assets/img/Technicalblletins/Heat%20wave%202022%20-%20Causes%20Impacts%20and%20way%20forward%20for%20Indian%20Agriculture.pdf

49. Haryana Department of Environment and Climate Change. (n.d.). *Revised State Action Plan on Climate Change*. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf

50. Ninaniya, K., Shekhar, C., Chahal, D., & Bishnoi, N. S. (2024). Relationship between paddy cultivation and methane emission rate (XCH4) in Haryana. *Journal of Agrometeorology, 26*(4), 491–493. https://doi.org/10.54386/jam.v26i4.259

51. Times of India. (2024, March 8). *Haryana wants civic bodies to ramp up cleanliness drives before Swachh survey*. https://timesofindia.indiatimes.com/city/gurgaon/haryana-wants-civic-bodies-to-ramp-up-cleanliness-drives-before-swachh-survey/articleshow/118718056.cms

52. Bureau of Energy Efficiency. (2020). *State Energy Efficiency Index 2020*. Ministry of Power, Government of India. https://cdnbbsr.s3waas.gov.in/s3f80ff32e08a25270b5f252ce39522f72/uploads/2021/12/2021120165.pdf

53. Department of Economic and Statistical Analysis, Government of Haryana. (2023). *Haryana economic survey 2023*. Government of Haryana. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf

54. Haryana Kisan Kalyan Parishad. (n.d.). *Task Force Report*. https://hkkp.org.in/Reports/Task%20Force.pdf

55. Central Pollution Control Board. (n.d.). *Continuous ambient air quality monitoring stations (CAAQMS) data*. Government of India. https://prana.cpcb.gov.in/#/air-quality-data

56. India State-Level Disease Burden Initiative Air Pollution Collaborators. (2020). *Health and economic impact of air pollution in the states of India: The Global Burden of Disease Study 2019. The Lancet Planetary Health*. https://www.thelancet.com/journals/lanplh/article/PIIS2542-5196

57. Hindustan Times. (2023, November 7). *38% drop in farm fire cases in Haryana in 2023: Govt to Centre*. Hindustan Times. https://www.hindustantimes.com/cities/chandigarh-news/38-drop-in-farm-fire-cases-in-haryana-in-2023-govt-to-centre-101699470402140.html

58. The Hindu. (2024, February 15). *With farm fires declining in Punjab and Haryana, Delhi's pollution woes need other solutions*. The Hindu. https://www.thehindu.com/data/with-farm-fires-declining-in-punjab-and-haryana-delhis-pollution-woes-need-other-solutions/article68791190.ece

59. Government of Haryana. (2024). *Extraordinary Gazette Notification No. 162-2024-Ext*. Haryana Gazette. https://www.egazetteharyana.gov.in/Gazette/Extra-Ordinary/2024/162-2024-Ext/20682.pdf

60. Haryana Government. (2024). *[Gazette Notification, Extra-Ordinary, 2024/162-2024-Ext/20682]*. eGazette Haryana. Retrieved from https://www.egazetteharyana.gov.in/Gazette/Extra-Ordinary/2024/162-2024-Ext/20682.pdf

61. Government of Haryana. (2024). *Haryana electric vehicle policy 2024*. Department of Transport, Haryana. https://haryanatransport.gov.in/sites/default/files/Electric%20Vehicle%20Policy_2.pdf

62. Iimont, Z., Cofala, J., Bertok, I., Amann, M., Heyes, C., & Gyarfas, F. (2002). *Modelling Particulate Emissions in Europe. A Framework to Estimate Reduction Potential and Control Cost.*Interim Report.

63. Ministry of Road Transport and Highways. (n.d.). *Bharat Stage Emission Norms*.https://morth.nic.in

64. Government of India, Ministry of Road Transport and Highways. (2023). Vehicle Registration Statistics. https://morth.nic.in

65. Ministry of Road Transport and Highways. (n.d.). VAHAN Database. https://vahan.nic.in

66. Haryana State Pollution Control Board. (2020). *Emission Inventory and Source Apportionment Study for Haryana*. Government of Haryana. https://moef.gov.in/uploads/2017/09/Haryana.pdf

67. GIZ & Haryana State Pollution Control Board. (2020). *Air Quality Management Plan for Haryana*. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ). https://www.ghgplatform-india.org/wp-content/uploads/2022/09/GHGPI_Trend-Analysis_2005-to-2018_Haryana_Sep22.pdf

68. GHG Platform India. (2022). *Trend Analysis of Greenhouse Gas Emissions in Haryana (2005–2018)*. Climate Trends. https://www.ghgplatform-india.org/wp-content/uploads/2022/09/GHGPI_Trend-Analysis_2005-to-2018_Haryana_Sep22.pdf

69. Ministry of Environment, Forest and Climate Change. (2017). *Haryana State Action Plan on Climate Change*. Government of India. https://moef.gov.in/uploads/2017/09/Haryana.pdf

70. Ministry of Petroleum and Natural Gas. (n.d.). *Hydrogen initiatives of the Ministry of Petroleum & Natural Gas*. Retrieved February 24, 2025, from https://mopng.gov.in/en/page/12

71. New and Renewable Energy Department, Haryana. (2024). *Draft Haryana Green Hydrogen Policy 2024*. https://cdnbbsr.s3waas.gov.in/s3f80ff32e08a25270b5f252ce39522f72/uploads/2024/02/20240215954959595.pdf

72. Central Electricity Authority. (2020). *Growth of electricity sector in India from 1947–2020*. Ministry of Power, Government of India. https://cea.nic.in/wp-content/uploads/pdm/2020/12/Growth_1947-2020.pdf

73. Department of Economic and Statistical Affairs, Haryana. (2024). *Economic Survey of Haryana 2023-24*. Government of Haryana. https://cdnbbsr.s3waas.gov.in/s386e78499eeb33fb9cac16b7555b50767/uploads/2024/02/202402231931158089.pdf

74. National Academy of Sciences. (2001). *Growing Populations, Changing Landscapes: Studies from India, China, and the United States*. Washington, DC: The National Academies Press. https://nap.nationalacademies.org/read/10144/chapter/11

75. National Dairy Development Board. (2019). *Study on Demand of Milk and Milk Products in India*. Anand, India: National Dairy Development Board. https://www.nddb.coop/sites/default/files/pdfs/baseline/14_Estimation_of_demand_of_mik_and_milk_products_in_India.pdf

76. Invest India. (n.d.). *Catalysing India's bovine population through technology intervention*. https://www.investindia.gov.in/team-india-blogs/catalysing-indias-bovine-population-through-technology-intervention

77. Department of Animal Husbandry, Haryana. (n.d.). *Gaushala Development Programme*. Pashudhan Haryana. https://www.pashudhanharyana.gov.in/9-gaushala-development-programme

78. *13. Haryana livestock development board | department of animal husbandry & dairying, government of haryana*. (n.d.). https://www.pashudhanharyana.gov.in/13-haryana-livestock-development-board

79. Pune, B. (2023, July 17). *Methane emission mitigation strategies in livestock*. BAIF. https://baif.org.in/livestock-strategies/

80. ICAR-National Rice Research Institute. (2020). *Rice Research for Enhancing Productivity, Profitability and Climate Resilience*. https://icar-nrri.in/wp-content/uploads/2019/02/Rice_Research_book_nrri.pdf

81. ICAR-National Rice Research Institute. (2020). *Rice Research for Enhancing Productivity, Profitability and Climate Resilience*. https://icar-nrri.in/wp-content/uploads/2019/02/Rice_Research_book_nrri.pdf

82. ICAR-National Rice Research Institute. (2020). *Rice Research for Enhancing Productivity, Profitability and Climate Resilience*. https://icar-nrri.in/wp-content/uploads/2019/02/Rice_Research_book_nrri.pdf

83. Department of Agriculture & Farmers Welfare. (2024). Annual Report 2024. Government of India. http://www.exampleurl.gov.in/annualreport2024

84. Ministry of Petroleum and Natural Gas. (2021). *Pradhan Mantri Ujjwala Yojana (PMUY): Scheme overview and progress report*. Government of India. https://www.pmuy.gov.in

85. Government of India, Ministry of Petroleum and Natural Gas. (2022). *Indian petroleum and natural gas statistics 2021–22*. from https://www.mopng.gov.in/publications

86. National Biomass Cookstoves Programme. (n.d.). *National Biomass Cookstoves Programme*. Ministry of New and Renewable Energy, Government of India. https://policy.thinkbluedata.com/sites/default/files/National%20Biomass%20Cookstoves%20Programme.pdf

87. *Short-lived climate pollutants and health | Climate & Clean Air Coalition*. (n.d.). Retrieved from https://www.ccacoalition.org/content/short-lived-climate-pollutants-and-health

88. Venkataraman, C., Brauer, M., Cropper, M. L., Apte, J. S., Bonjour, S., Balakrishnan, K., ... & Dandona, L. (2021). How air pollution affects the Indian economy. *The Lancet Planetary Health, 5*(1), E26-E38. https://doi.org/10.1016/S2542-5196(20)30298-4

89. Venkataraman, C., Brauer, M., Cropper, M. L., Apte, J. S., Bonjour, S., Balakrishnan, K., ... & Dandona, L. (2021). How air pollution affects the Indian economy. *The Lancet Planetary Health, 5*(1), E26-E38. https://doi.org/10.1016/S2542-5196(20)30298-4

90. *Short-lived climate pollutants and health | Climate & Clean Air Coalition*. (n.d.). Retrieved from https://www.ccacoalition.org/content/short-lived-climate-pollutants-and-health

91. Haryana Department of Environment and Climate Change. (n.d.). *Revised State Action Plan on Climate Change*. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf

92. Haryana Department of Environment and Climate Change. (n.d.). *Revised State Action Plan on Climate Change*. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf

93. Mazdiyasni, O., AghaKouchak, A., Davis, S. J., Madadgar, S., Mehran, A., Ragno, E., Sadegh, M., Sengupta, A., Ghosh, S., Dhanya, C. T., & Niknejad, M. (2017). Increasing probability of mortality during Indian heat waves. *Science Advances, 3*(6), e1700066. https://doi.org/10.1126/sciadv.1700066

94. Yu, W., Mengersen, K., Wang, X., Ye, X., Guo, Y., Pan, X., & Tong, S. (2012). Daily average temperature and mortality among the elderly: A meta-analysis and systematic review of epidemiological evidence. *International Journal of Biometeorology, 56*(4), 569–581. https://doi.org/10.1007/s00484-011-0497-3

95. Maharana, P., Kumar, D., Das, S., Tiwari, P. R., Norgate, M., & Raman, V. A. V. (2024). Projected changes in heatwaves and its impact on human discomfort over India due to global warming under the CORDEX-CORE framework. *Theoretical and Applied Climatology, 155*(4), 2775–2786. https://doi.org/10.1007/s00704-023-04788-4

96. *Climate change: Implications for the energy sector*. (n.d.). Retrieved from https://climate-adapt.eea.europa.eu/en/metadata/publications/climate-change-implications-for-the-energy-sector

97. Grid Controller of India Limited (GRID-INDIA). (2024, February 13). *Impact of Heat Wave on Power System*. National Disaster Management Authority (NDMA). https://ndma.gov.in/sites/default/files/PDF/Heatwave-workshop/13012024/session3/Grid_India.pdf

98. Mathew, A., Khandelwal, S., & Kaul, N. (2016). Spatial and temporal variations of urban heat island effect and the effect of percentage impervious surface area and elevation on land surface temperature: Study of Chandigarh city, India. *Sustainable Cities and Society, 26*, 264–277. https://doi.org/10.1016/j.scs.2016.06.018

99. Bala, S., & Dar, S. N. (2024). Dynamics of land use land cover and its impact on land surface temperature: A study of Faridabad District, India. *GeoJournal, 89*(1), 30. https://doi.org/10.1007/s10708-024-11011-y

100. Kushwaha, S., & Nithiyanandam, Y. (2019). The study of heat island and its relation with urbanization in gurugram, delhi ncr for the period of 1990 to 2018. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, XLII-5/W3*, 49–56. https://doi.org/10.5194/isprs-archives-XLII-5-W3-49-2019

101. US EPA, O. (2015, October 1). *Reduce heat islands* [Overviews and Factsheets]. https://www.epa.gov/green-infrastructure/reduce-heat-islands

102. Li, X., Zhou, Y., Yu, S., Jia, G., Li, H., & Li, W. (2019). Urban heat island impacts on building energy consumption: A review of approaches and findings. *Energy, 174*, 407–419. https://doi.org/10.1016/j.energy.2019.02.183

103. Islam, S., Karipot, A., Bhawar, R., Sinha, P., Kedia, S., & Khare, M. (2024). Urban heat island effect in India: A review of current status, impact and mitigation strategies. *Discover Cities, 1*(1), 34. https://doi.org/10.1007/s44327-024-00033-3

104. Li, X., Zhou, Y., Yu, S., Jia, G., Li, H., & Li, W. (2019). Urban heat island impacts on building energy consumption: A review of approaches and findings. *Energy, 174*, 407–419. https://doi.org/10.1016/j.energy.2019.02.183

105. Haryana Department of Environment and Climate Change. (n.d.). *Revised State Action Plan on Climate Change*. https://cdnbbsr.s3waas.gov.in/s3d8330f857a17c53d217014ee776bfd50/uploads/2023/04/2023041994.pdf

106. *The economic benefits of reducing short-lived climate pollutants | Climate & Clean Air Coalition*. (n.d.). Retrieved from https://www.ccacoalition.org/content/economic-benefits-reducing-short-lived-climate-pollutants

107. *Tropospheric ozone | climate & clean air coalition*. (n.d.). Retrieved from https://www.ccacoalition.org/short-lived-climate-pollutants/tropospheric-ozone

108. *Short-lived climate pollutants and food security | Climate & Clean Air Coalition*. (n.d.). Retrieved from https://www.ccacoalition.org/content/short-lived-climate-pollutants-and-food-security

109. Büker, P., & Emberson, L. (2009). *Ozone: A threat to food security in South Asia*. https://www.sei.org/publications/ozone-threat-food-security-south-asia/

110. Dewan, S., & Lakhani, A. (2024). Impact of ozone pollution on crop yield, human health, and associated economic costs in the Indo-Gangetic plains. *Science of The Total Environment, 945*, 173820. https://doi.org/10.1016/j.scitotenv.2024.173820

111. Dash, N., & Anup, S. (2024). *India's public EV charging infrastructure readiness – A case study of Haryana state*. International Council on Clean Transportation. https://theicct.org/wp-content/uploads/2024/01/ID-29-%E2%80%93-Haryana-charging_final.pdf

112. Government of Haryana. (2022, July 8). *Haryana Government Gazette (Extraordinary), July 8, 2022*. Government of Haryana.

113. Central Pollution Control Board. (2022). *Annual Report 2020-21 on Implementation of Solid Waste Management Rules, 2016*. Delhi: Author. Retrieved from https://cpcb.nic.in/uploads/MSW/MSW_AnnualReport_2020-21.pdf

114. Sharma, P., Sharma, J., Sharma, D., & Himanshu. (2024). Solid Waste Management-A Case Study of Haryana State. *Journal of Emerging Technologies and Innovative Research (JETIR)*, *11*(4), i599-i602.

115. Ministry of Micro, Small & Medium Enterprises. (n.d.). *MSME (Udyam) registration including Udyam Assist Platform (UAP): State wise details*. Retrieved from https://dashboard.msme.gov.in/Udyam_Statewise.aspx

116. Haryana Government. (2020). *Haryana Enterprises and Employment Policy, 2020*. Department of Industries and Commerce, Government of Haryana. https://investharyana.in/content/pdfs/Draft%20EPP%202020%20chapters_5th%20Sept%202020.pdf

117. '2020-21 Assessment of Livestock Feed and Fodder in Haryana | Official Website of Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India'. https://desagri.gov.in/aer/2020-21-assessment-of-livestock-feed-and-fodder-in-haryana-2/.

118. Haryana Government. (2021). *Purna Gau Charan Bhumi Policy Guidelines*. Government of Haryana.

119. 'Land Use Statistics – At a Glance | Official Website of Directorate of Economics and Statistics, Department of Agriculture and Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India'. https://desagri.gov.in/document-report-category/land-use-statistics-at-a-glance/.

120. Dhall, N., Kaur, B., & Som, B. K. (2020). Crop residue burning in Haryana: Issues & suggestive policy measures. Journal of Management and Public Policy, 11(2), 7-18.

121. Sahu, V., Tripathi, S. N., Sutaria, R., Dumka, N., Kotwal, A., Ghosh, K., & Singh, R. K. (2024). Assessment of a clean cooking fuel distribution scheme in rural households of India – "Pradhan Mantri Ujjwala Yojana (PMUY)". *Energy for Sustainable Development*, *81*, 101492. https://doi.org/10.1016/j.esd.2024.101492

122. GAINS. (2012). *Greenhouse gas and air pollution interactions and synergies South Asia Program*. Laxenburg, Austria: International Institute of Applied Systems Analysis.

123. USEPA. (2015). *AP-42 emission factor database.* Washington, DC: United State Environment Protection Agency

124. Central Electricity Authority. (2020). Annual Coal and Biomass Consumption in Thermal Power Plants (2019). Government of India. https://cea.nic.in

125. Central Electricity Authority. (2019). *Statistical Yearbook 2019*. Government of India. https://cea.nic.in

126. U.S. Environmental Protection Agency. (1995). *AP-42, Fifth Edition, Volume I: Stationary Source Emission Factors* (EPA/600/R-95/060). https://www.epa.gov/air-emissions-factors-and-quantification/ap-42-compilation-air-emissions-factors

127. Ministry of Petroleum and Natural Gas. (2021). *PPAC Report 2021: Sector-Specific Fuel Consumption*. Government of India.

128. Reserve Bank of India. (2023). RBI Handbook. https://www.rbi.org.in

129. Construction Industry Development Council. (n.d.). *Construction cost index* (Base year: 2007; Base price: 100 Rupees)

130. U.S. Bureau of Reclamation. (2002). *Construction site dust emissions and mitigation strategies*. U.S. Department of the Interior.

131. Houck, J. E., Chow, J. C., Watson, J. G., & Simons, C. A. (1990). *PM2.5 emissions from construction activities and related sources*. Atmospheric Environment, 24(5), 1143-1150.

132. Ahuja, M. S., Overcamp, T. J., & Aneja, V. P. (1989). *Emission factors for fugitive dust from construction activities*. Journal of the Air & Waste Management Association, 39(6), 865-870. https://doi.org/[DOI]

133. MoHFW, Government of India. (2020*). Report of the technical group on Population Projections, India. National Commission on Population.* Ministry of Health Family and Welfare. https://main.mohfw.gov.in/sites/default/files/Population%20Projection%20Report%202011-2036%20-%20upload_compressed_0.pdf

134. NSSO [National Sample Survey Organization]. (2014). *Household consumption of various goods and services in India 2011-2012.* NSS 68th round. Report number 558 (68/1.0/2). New Delhi: National Sample Survey Organization, Ministry of Statistics and Program Implementation (MoSPI), Govt. of India.

135. Datta, A., Mohan, I., Sharma, S. (2014). Emission inventory of residential sector. In: Sharma, S., Kumar, A. (eds.) *Air pollution emissions scenario for India.* Ver.1. TERI-Press, The Energy and Resources Insitute, New Delhi. ISBN 978-81-7993-639-9.

136. Jain, N., Bhatia, A., & Pathak, H. (2014). Emission of air pollutants from crop residue burning in India. *Aerosol and Air Quality Research* 14:422–30.

137. Turn, S. Q. Jenkin, B. W, Chow, J.C., Pritchett, L.C., Campbell, D. Cahill, T. Whalen, S.A. (1997). Elemental characterization of particulate matter emitted from Biomass burning: Wind tunnel derived source profile for herbaceous and wood fuel. *Journal of geophysical research.* 102, 3683 3699

138. NASA LP DAAC. (2019). *MODIS Terra and Aqua Fire and Thermal Anomalies Products*. NASA Land Processes Distributed Active Archive Center (LP DAAC). Retrieved [Month Day, Year], from https://lpdaac.usgs.gov/product_search/

139. Giglio, L., Schroeder, W., & Justice, C. O. (2016). The Collection 6 MODIS active fire detection algorithm and fire products. *Remote Sensing of Environment, 178*, 31–41. https://doi.org/10.1016/j.rse.2016.02.054

140. Bouwman, A. F. (1996). *Direct emission of nitrous oxide from agricultural soils. Nutrient cycling in agroecosystems.* 46, 53-70.

141. Fagodiya, R. K., Pathak, H., Bhatia, A., Jain, N., Gupta, D. K., Kumar, A., ... & Tomer, R. (2019). Nitrous oxide emission and mitigation from maize–wheat rotation in the upper Indo-Gangetic Plains. *Carbon Management, 10*(5), 489-499.

142. Reserve Bank of India. (2023). Handbook of Statistics on Indian Economy 2022-23. Reserve Bank of India

For more information:

Reach out to:
Institute for Governance and Sustainable
Development Sector 38A, Opposite 38-D Market
CU-IDC Campus, Chandigarh, 160014 | India