# INTEGRATED SECTORAL EMISSIONS SYNTHESIS REPORT

# ROYAL SOCIETY FOR PROTECTION OF NATURE

# Table of Contents

## Table List

# Figure List

## List of Acronyms

| Acronym | Full form /meaning |
|---|---|
| AFOLU | Agriculture, Forestry and Other Land Use |
| BAU | Business-as-Usual |
| BTR | Biennial Transparency Report |
| $CH_4$ | Methane |
| $CO_2$ | Carbon Dioxide |
| $CO_2e$ | Carbon Dioxide Equivalent |
| CRT | Common Reporting Table |
| DECC | Department of Environment and Climate Change |
| EV | Electric Vehicle |
| FMID | Forest Monitoring and Information Division |
| FOLU | Forest and Other Land Use |
| Gg | Gigagram |
| Gg $CO_2e$ | Gigagrams of Carbon Dioxide Equivalent |
| GHG | Greenhouse Gas |
| GNH | Gross National Happiness |
| HDPE | High-Density Polyethylene |
| IPCC | Intergovernmental Panel on Climate Change |
| IPPU | Industrial Processes and Product Use |
| kL | Kilolitre |
| LEDS | Low-Emission Development Strategy |
| LULUCF | Land Use, Land-Use Change and Forestry |
| MRV | Monitoring, Reporting and Verification |
| $N_2O$ | Nitrous Oxide |
| NDC | Nationally Determined Contribution |
| NFI | National Forest Inventory |
| NGO | Non-Governmental Organization |
| NMT | Non-Motorized Transport |
| PET | Polyethylene Terephthalate |
| POL | Petroleum, Oil and Lubricants |
| REDD+ | Reducing Emissions from Deforestation and Forest Degradation, plus conservation, sustainable management of forests and enhancement of forest carbon stocks |
| RSPN | Royal Society for Protection of Nature |
| t C / ha | Tonnes of Carbon per Hectare |
| UNFCCC | United Nations Framework Convention on Climate Change |
| yr | Year |

# Foreword

This report is commissioned by The Royal Society for Protection of Nature (RSPN). Established in 1987 under the Royal Command of His Majesty the Fourth King of Bhutan as a citizen-based non-governmental organization (NGO), RSPN is devoted to the conservation of the Kingdom's environment. RSPN is Bhutan's leading and oldest NGO that contributes to environmental conservation through natural resources management and development of sustainable livelihood approaches, increases environmental awareness through education, advocacy and public participation in conservation, and enhances the knowledge on the environment and sustainable livelihoods in Bhutan.

This report is prepared by Hira Global Co. Ltd. and Pem Nor Consulting, who would like to thank the RSPN Executive Director, Dr. Kinley Tenzin, and the RSPN Director, Mr. Wangchuk Namgay, and RSPN colleagues for their support and guidance in the formulation and finalization of the report.

# 1. Executive Summary

This report is an analysis of the historical trends, projections, mitigation scenarios and sustainability pathways for six sectors of Bhutan's economy: waste, transport, industry, agriculture, forestry, and livestock. It draws on Bhutan's First Biennial Transparency Report (BTR), the accompanying Common Reporting Table (CRT) data, and the National Forest Inventory Volume II: State of Forest Carbon Report (Department of Environment and Climate Change [DECC], 2024; Forest Monitoring and Information Division [FMID], 2023). The projections and scenarios are analytical estimates derived from these official sources and should be interpreted as planning tools rather than official Government projections.

The central finding is that Bhutan's climate strategy must be understood as a dual agenda: reducing rising or persistent emissions in priority emitting sectors while protecting and enhancing very large forest removals. The sectoral evidence shows that IPPU and transport are the most important sources for near-term fossil and process related mitigation, while agriculture and livestock require a package of productivity, soil, rice, manure and feeding interventions. Waste emissions are smaller in absolute magnitude but have strong urban, health and circular economy co-benefits. Forestry is the dominant national sink and therefore the strategic foundation of Bhutan's carbon-negative position. The BTR confirms Bhutan's continued commitment to carbon-neutrality, and the NFI demonstrates the importance of forest carbon stocks and sequestration in delivering that commitment (DECC, 2024; FMID, 2023).

The most important policy conclusion is that Bhutan should not approach these sectors as isolated mitigation silos. Industrial transformation can reduce the country's largest process emission source; electric mobility can reduce growing petroleum dependence; climate-smart agriculture and livestock systems can improve rural productivity while reducing biological emissions; and forest conservation, restoration and REDD+ readiness can maintain the sink that offsets the economy's residual emissions. A coordinated national low-emission investment programme would therefore combine industrial efficiency, low-carbon cement, ferroalloy technology options, electric vehicle infrastructure, public transport, waste diversion, wastewater treatment, manure management, climate-smart rice practices, resilient agroforestry and strengthened forest monitoring. Such a portfolio would also support Bhutan's Gross National Happiness approach by linking emissions reduction with clean cities, soil health, biodiversity, livelihoods, water security and resilience.

## 1.1. National emissions profile and trend message

The national emissions profile shows a clear contrast between positive-emissions sectors and the large negative balance provided by forests and land-use removals. Waste, transport, IPPU, agriculture and livestock are positive-emissions sectors, while forestry/LULUCF provides net removals. This distinction is important because Bhutan's carbon-negative position depends not only on keeping gross emissions low, but also on maintaining the forest sink at a scale that remains larger than national emissions. The updated national profile therefore needs to be interpreted through both gross-emissions management and sink-protection lenses.

Among the emitting sectors, IPPU has the largest gross-emissions profile and the largest emissions growth risk. In 2022, IPPU emissions were about 673.93 Gg CO2e and were dominated by cement/mineral industry and ferroalloy/metal industry emissions. The BAU projection for IPPU reaches 1,303.78 Gg CO2e by 2030. Transport is also a major strategic sector. The updated transport BAU projection rises from 362.78 Gg CO2e in 2024 to 445.95 Gg CO2e in 2030, reflecting a 3.5% annual growth assumption from the 2023 calculated road-emissions baseline. Waste emissions are smaller, rising to 124.26 Gg CO2e under BAU by 2030, but they are important because they are linked to wastewater, solid waste, city management and public health.

Agriculture and livestock are presented separately in the updated structure. Agriculture covers crop- and soil-related sources only: rice cultivation, agricultural soils and urea application. On this revised basis, agriculture emissions were 38.94 Gg CO2e in 2022 and reach 47.02 Gg CO2e under BAU by 2030. Livestock is treated as a separate food-system source with a 2022 BTR-anchored total of 365.00 Gg CO2e and a BAU projection of 379.86 Gg CO2e by 2030. Forestry/LULUCF remains the dominant national sink, with 2022 net removals of about -11,330.52 Gg CO2e and a 2030 BAU net balance of about -9,506.22 Gg CO2e. Figure 1 shows all six analyzed sectors, separating the large forestry/LULUCF net removals from positive emitting sectors so that the trend can be interpreted clearly.

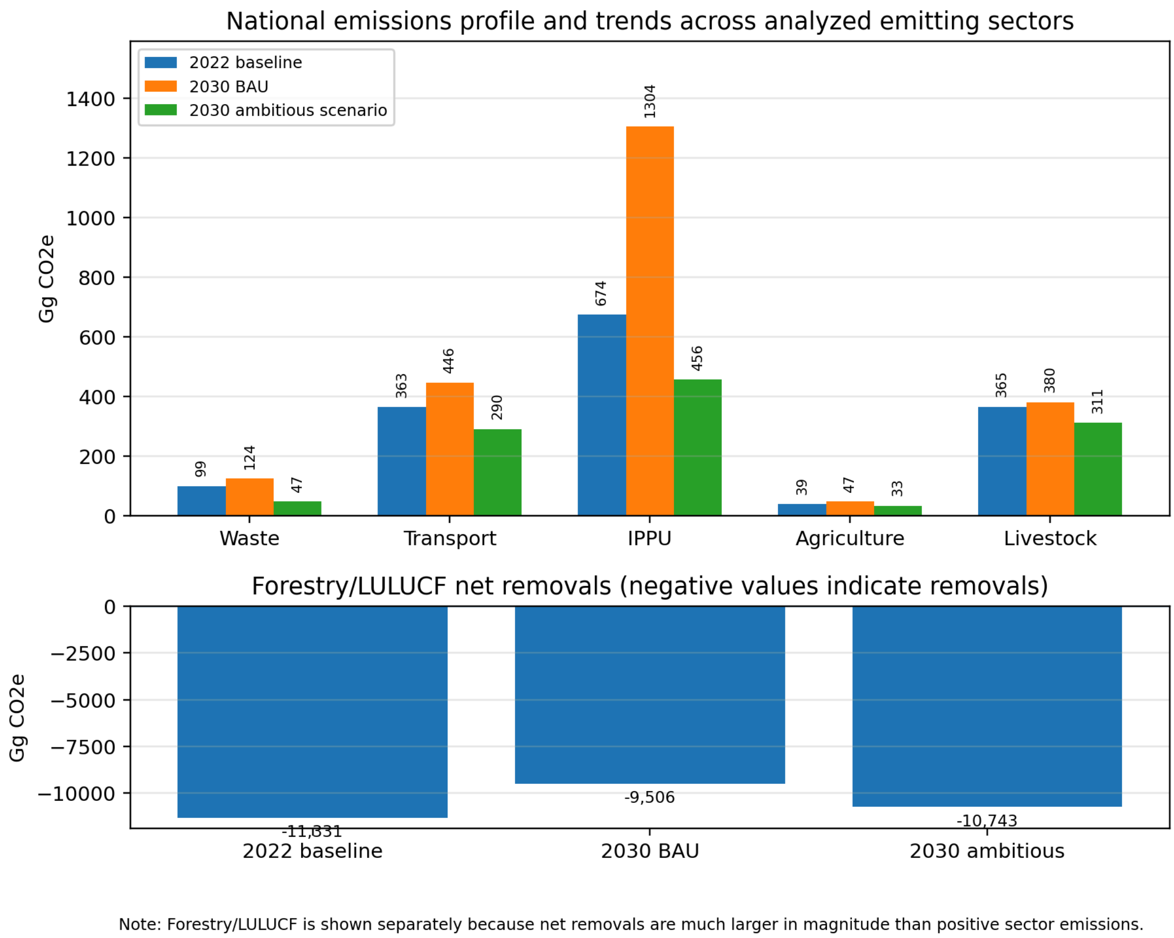


*Figure 1. National emissions profile across the six analyzed sectors.*

## 1.2. Waste sector recommendations

The waste sector should be treated as a high co-benefit mitigation sector. Although total waste emissions are far smaller than IPPU, agriculture or transport, they are closely linked to public health, urban management, groundwater protection, tourism, circular economy development and local environmental quality. The sector's emissions increased from 93.58 Gg CO2e in 2019 to 99.01 Gg CO2e in 2022. Wastewater treatment and discharge accounted for more than 80% of waste-sector emissions in 2022, while solid waste disposal was the second-largest source. This means that a waste-sector mitigation programme must address both solid-waste and wastewater systems. The BTR also indicates that Bhutan's waste estimates rely on population data, per capita waste generation assumptions and IPCC default factors, which highlights the need for better data and more disaggregated monitoring (DECC, 2024; IPCC, 2006).

The preferred waste strategy should combine three intervention clusters. First, Bhutan should accelerate organic waste diversion through source separation, decentralized composting, municipal composting facilities, community-level biodegradable waste management and institutional procurement of compost for landscaping, agriculture and public works. Organic waste diversion has the advantage of reducing methane formation in disposal sites while generating soil and circular economy benefits. Second, Bhutan should upgrade solid waste infrastructure by developing material recovery facilities, recycling hubs, waste banks, sanitary landfill improvements, and landfill gas management where technically and economically justified. Third, Bhutan should prioritize wastewater treatment because wastewater is the largest waste emission source in the BTR based data. Better sewerage coverage, improved treatment operations, sludge management and methane capture at larger facilities would deliver both mitigation and water quality benefits.

The most ambitious waste emissions mitigation scenario in the analysis is a Zero Waste and wastewater transformation pathway that reduces emissions to about 47.2 Gg $CO_2$e by 2030 and yields cumulative mitigation of about 299.3 Gg $CO_2$e over 2023-2030 relative to business as usual (BAU). This pathway requires strong national-local coordination, municipal performance indicators, investment in infrastructure, digital waste and wastewater MRV, private-sector participation and behavioral change at household and institutional levels. It would also provide benefits beyond mitigation, including cleaner rivers, improved public health, reduced plastic leakage, lower open-burning risks and new green jobs in waste collection, sorting, composting and recycling. The immediate recommendation is to create an integrated Waste and Wastewater Mitigation Programme for Thimphu and other urban centers, with clear annual targets for organic waste diversion, recycling recovery rates, wastewater treatment efficiency and landfill emissions monitoring.

### 1.3. Transport sector recommendations

Transport is one of Bhutan's most visible low-emission development opportunities because the sector combines fuel import reduction, air quality benefits, mobility improvement and clean electricity use. The transport related data shows strong growth in petroleum-related transport emissions over the historical period to 2020. The projection in the sector report indicates that, under BAU, transport emissions could rise from about 362.78 Gg $CO_2$e in 2024 to 445.95 Gg $CO_2$e in 2030. The vehicle-registration evidence confirms the need for an integrated mobility strategy. Registered vehicles increased from 112,058 in December 2020 to 128,237 by March 2026. Electric vehicles (EVs) increased from 133 to 1,252 over the same period, but EVs still represented less than 1% of the total vehicle stock by March 2026. The EV projection reaches 2.25% of total registered vehicles by 2030, which shows that EV adoption is accelerating but not yet sufficient to transform the sector on its own. High-utilization fleets such as buses, taxis, government fleets and municipal vehicles should therefore be early electrification targets.

The transport strategy should be designed as a complete mobility transition rather than a narrow vehicle replacement programme. Electric vehicle adoption is important, but the largest benefits will come from combining EVs with electric buses, public transport reform, route optimization, parking and congestion management, non-motorized transport, road safety, charging infrastructure, and vehicle efficiency standards. Urban mobility should be planned around reliable public transport, pedestrian friendly streets and cycling corridors, especially in Thimphu and growing regional towns. Freight and intercity transport should be addressed through route efficiency, vehicle standards, fleet renewal and future options for low-carbon fuels or electrified freight where feasible.

The most ambitious transport emissions mitigation scenario in the analysis is an integrated low-carbon mobility transition that reduces projected 2030 emissions from about 445.95 Gg $CO_2e$ under BAU to about 289.87 Gg $CO_2e$. It delivers cumulative mitigation of about 543.44 Gg $CO_2e$ over 2024-2030. The scenario is ambitious but credible if implementation is phased: public fleet electrification and bus investment first, followed by private EV market support, urban transport demand management, and long-term standards for vehicles and fuels. The key recommendation is to establish a National Electric and Integrated Mobility Programme that aligns import policy, fiscal incentives, charging infrastructure, urban planning, public transport investment and MRV. This programme should be designed to protect equity by improving affordable mobility options, not only by subsidizing private vehicles.

### 1.4. IPPU sector recommendations

IPPU is the highest priority sector for absolute emissions reduction because it is the largest positive-emissions source among the six sectors. In 2022, IPPU emissions were about 673.93 Gg $CO_2e$. The BTR BAU projection rises sharply, reaching 1,303.78 Gg $CO_2e$ by 2030, indicating that industrial output and process emissions could become a major pressure on Bhutan's carbon-negative position if mitigation is delayed. Cement/mineral industry and ferroalloys/metals dominate the sector, while lubricant use is small. The BTR and CRT data therefore point to an industrial mitigation strategy centered on cement and metal production rather than dispersed minor sources (DECC, 2024).

The IPPU mitigation package should be implemented in two time horizons. In the near term, Bhutan should pursue industrial energy efficiency, clinker optimization, alternative raw materials where technically feasible, improved kiln performance, waste heat recovery, better process control, emissions monitoring, and industrial energy management systems. These are practical measures that can reduce emissions without requiring a full transformation of industrial processes. In the medium to long term, Bhutan should assess deeper low-carbon industrial technologies, including lower clinker cement, supplementary cementitious materials, alternative binders, electrification where feasible, cleaner ferroalloy production, material efficiency, circular use of industrial by-products, and procurement standards for low-carbon construction materials. The sector should also assess competitiveness risks and opportunities, including future carbon-related trade measures and demand for low-carbon materials.

The most ambitious IPPU emissions mitigation scenario in the sector report is a full LEDS industries transformation that reduces projected 2030 emissions from about 1,303.78 Gg $CO_2e$ under BAU to about 456.32 Gg $CO_2e$ and delivers about 4,000.69 Gg $CO_2e$ cumulative mitigation over 2023-2030. This is the largest positive-emissions mitigation potential among the emitting sectors assessed. The priority recommendation is therefore to create a Low-Carbon Industry Roadmap for cement and ferroalloys, backed by plant-level audits, performance benchmarks, technology feasibility studies, concessional finance, MRV requirements, and a pipeline of investable industrial decarbonization projects. Because deep industrial mitigation is capital intensive, this roadmap should be linked to climate finance and concessional industrial transformation facilities.

## 1.5. Agriculture sector recommendations

Agriculture is important because it is closely connected to livelihoods, food security, soil health, rural resilience, biodiversity and climate adaptation. The agriculture analysis covers crop- and soil-related sources only – rice cultivation, agricultural soils and urea application – while livestock is treated separately. Rice cultivation was the dominant source of emissions, accounting for about 72.3% of agriculture emissions in 2022, while agricultural soils accounted for 25.8 % and urea application for 1.9% agriculture emissions.

The BAU projection is anchored in the BTR's non-livestock agriculture estimate of 45.18 Gg $CO_2$e in 2022 and applies a conservative 0.5% annual growth assumption. Under this pathway, agriculture emissions reach 47.02 Gg $CO_2$e by 2030. The high-ambition agriculture scenario of integrated climate-smart crop systems reduces projected 2030 emissions to 32.91 Gg CO2e and provides 62.74 Gg CO2e of cumulative mitigation over 2023-2030. The relatively modest absolute mitigation volume should not obscure the sector's importance for food security, water efficiency, soil health and rural resilience.

Agriculture mitigation should focus on low-methane rice cultivation, better water scheduling, alternate wetting and drying where feasible, residue management, soil testing, nutrient efficiency, organic and biofertilizer systems with safeguards, perennial crops, agroforestry and climate-smart restoration. These interventions must be implemented through farmer-centered extension rather than narrow emissions targets. The recommended programme is a Crop-Based Climate-Smart Agriculture Programme that links mitigation with improved productivity, water management, soil fertility, food security and adaptation.

## 1.6. Forestry and land use recommendations

Forestry is the foundation of Bhutan's carbon-negative status and must be treated as a strategic national asset. The NFI reports that Bhutan's forests constitute about 86% of the national carbon stock, with 521.16 million tonnes of carbon and a forest carbon density of 194.72 tonnes per hectare. It also reports total carbon stock including non-forest areas of about 606.31 million tonnes of carbon and forest sequestration potential of about 11 million tonnes $CO_2$ per year (FMID, 2023). The CRT data confirm that LULUCF is a very large net sink, with net removals of about -11,330.52 Gg $CO_2$e in 2022. These removals far exceed the positive-emissions of any individual emitting sector in the six-sector analyses.

The forestry strategy should therefore focus on avoiding loss of sink capacity while increasing resilience and restoration potential. The first priority is to protect existing forests from conversion, fragmentation, unsustainable extraction, wildfire, pests and climate-related degradation. The second priority is to enhance forest quality through sustainable forest management, assisted natural regeneration, enrichment planting, restoration of degraded areas, climate resilient species selection, fire management and watershed protection. The third priority is to expand trees outside forests through agroforestry, urban greening, riparian restoration and community based landscape restoration. The fourth priority is to strengthen forest MRV using repeated NFI, remote sensing, disturbance monitoring, permanent plots, carbon pool assessment and integration with national GHG inventory systems.

The integrated REDD+ and resilient landscape transformation scenario in the forestry report would increase additional net removals by about 5,200.68 Gg $CO_2$e cumulatively over 2023-2030 relative to BAU and improve the 2030 net forestry balance to about -10,742.91 Gg $CO_2$e. The recommendation is to establish a National Forest Sink Protection and Enhancement Programme that combines REDD+ readiness, forest landscape restoration, climate-resilient watershed management, carbon finance readiness, community forestry incentives and biodiversity safeguards. This should not be seen merely as a carbon programme; it is also a water, biodiversity, disaster risk reduction and livelihood programme.

## 1.7. Livestock sector recommendations

Livestock is presented as a separate analytical and programme area because its emissions profile and mitigation options are distinct from crop-based agriculture. Livestock emissions are driven mainly by methane from enteric fermentation, with manure management as a secondary but practical mitigation entry point. The BTR reports livestock-sector emissions of 365.00 Gg $CO_2$e in 2022. The livestock BAU projection in the report applies a conservative 0.5 percent annual increase from the 2022 anchor and reaches 379.86 Gg $CO_2$e by 2030.

The high-ambition livestock scenario of integrated low-carbon livestock transformation reduces 2030 emissions to 311.48 Gg $CO_2$e and provides cumulative mitigation of 304.14 Gg $CO_2$e over 2023-2030. The pathway combines improved feed quality, fodder systems, dairy productivity, breed improvement, animal health, manure collection, covered storage, composting, biogas, digestate use and stronger livestock MRV. The largest gains are expected from reducing emissions intensity through better productivity and feed digestibility rather than from reducing livestock activity in ways that could harm food security or rural livelihoods.

The recommended intervention is an Integrated Low-Carbon Livestock Programme implemented through extension services, farmer groups, dairy cooperatives, local governments and targeted finance. The programme should support feed and fodder development, animal-health services, selective breeding, stall feeding where appropriate, manure management and biogas systems. A parallel inventory improvement effort is needed to strengthen future Tier 2 livestock estimates using better data on herd composition, animal productivity, feed quality, manure systems and geographic production patterns.

## 1.8. Integrated scenario implications

Across the six sector analyses, the most ambitious scenarios point toward a coherent national mitigation portfolio. IPPU offers the largest positive-emissions reduction opportunity, with about 4,000.69 Gg $CO_2e$ cumulative mitigation by 2030 under the full industrial transformation scenario. Transport offers about 543.44 Gg $CO_2e$ cumulative mitigation under the integrated low-carbon mobility scenario. Waste offers about 299.3 Gg $CO_2e$ cumulative mitigation under the Zero Waste and wastewater transformation scenario. Agriculture provides 62.74 Gg CO2e of cumulative mitigation, while livestock provides 304.14 Gg CO2e under the integrated low-carbon livestock pathway.

Forestry is the dominant removal opportunity. The integrated REDD+ and resilient landscape transformation scenario adds about 5,200.68 Gg $CO_2e$ in cumulative net removals relative to BAU by 2030. This does not substitute for emissions reduction in other sectors; rather, it protects Bhutan's national carbon balance while the economy develops. The most robust national strategy is therefore a balanced portfolio with two pillars: aggressive reduction of gross emissions from IPPU, transport, waste, agriculture and livestock; and strong protection and enhancement of forest removals. This dual approach reduces dependence on a single sink, manages future uncertainty, and helps ensure that economic growth does not erode carbon-negative status.

The synthesis also shows that mitigation options differ in cost, maturity and co-benefits. Waste and transport interventions can deliver visible urban benefits and are suitable for early implementation. Agriculture and livestock interventions require farmer centered design and extension systems. IPPU requires capital intensive technology and policy support. Forestry requires long-term institutional continuity, robust safeguards and sustained finance. The implementation strategy should therefore sequence actions by readiness: immediate measures such as data systems, audits, source separation, public fleet electrification and forest disturbance monitoring should begin now; infrastructure and technology investments should follow through structured project pipelines; and deeper industrial and landscape transformation should be supported by climate finance, carbon finance and concessional investment (DECC, 2024; FMID, 2023).

## 1.9. Key recommendations for policy and investment

The first recommendation is to establish an integrated national mitigation investment pipeline rather than a list of disconnected sector actions. The pipeline should be grouped into bankable programme areas: low-carbon industry, electric and integrated mobility, zero waste and wastewater transformation, climate-smart food systems, low-emission livestock, and forest sink protection and landscape restoration. Each programme area should include a results framework, investment needs, implementation entities, MRV indicators, readiness gaps and financing options.

The second recommendation is to prioritize IPPU and transport for near-term gross emission reductions. IPPU is the largest positive-emissions source and should be addressed through a Low-Carbon Industry Roadmap, plant audits, clinker reduction strategies, efficiency standards, cleaner ferroalloy options and concessional technology finance. Transport should be addressed through EV and bus electrification, charging infrastructure, public transport improvement, urban planning and demand management. These two sectors are likely to determine whether gross emissions rise significantly over the next decade (DECC, 2024).

The third recommendation is to implement a national organic waste, wastewater and resource recovery programme. Waste mitigation has modest carbon volume but high environmental and public health benefits. Bhutan should scale source separation, composting, recycling, sanitary disposal and wastewater treatment upgrades, with clear municipal performance indicators and digital monitoring. The fourth recommendation is to implement a climate-smart agriculture and low-emission livestock programme that supports farmers through extension, incentives and access to technology rather than imposing emission targets in isolation. Measures should include improved rice-water management, nutrient efficiency, soil carbon practices, agroforestry, feed improvement, dairy productivity, manure management and biogas.

The fifth recommendation is to protect and enhance forest sinks as a national priority. This requires repeated forest inventory, remote sensing monitoring, forest fire and pest management, watershed restoration, community forestry support, safeguards and carbon finance readiness. The sixth recommendation is to strengthen national MRV systems. Bhutan should build integrated data pipelines linking sector activity data, inventory methodologies, mitigation project monitoring and finance tracking. This will improve future BTR reporting and help convert mitigation ideas into fundable programmes.

The final recommendation is to create a governance mechanism that can coordinate across sectors without weakening sector ownership. A national low-emission development coordination platform could bring together the Department of Environment and Climate Change, sector ministries, municipalities, public utilities, industry, financial institutions, research institutions and development partners. The platform should review annual emissions and removals data, maintain a pipeline of mitigation investments, monitor implementation progress, and support reporting under the Enhanced Transparency Framework. The BTR already demonstrates Bhutan's commitment to transparency; the next step is to turn that reporting system into a management system for mitigation implementation.

Monitoring, Reporting, and Verification (MRV) should be improved in all six sectors. Waste requires better data on waste generation, composition, disposal pathways, recycling, composting, wastewater treatment and sludge. Transport requires fuel, vehicle kilometer, EV, charging and public transport data. IPPU requires facility level production and process data, while protecting confidential business information. Agriculture and livestock require better activity data on livestock populations, feed, manure systems, rice-water regimes, fertilizer use and soil practices. Forestry requires continuity of NFI, remote sensing, forest disturbance monitoring and carbon pool assessment (DECC, 2024; FMID, 2023). Improved MRV is not just a reporting obligation; it is essential for designing climate finance proposals and tracking results.

Finance should be structured by readiness and investment type. Early stage grants can support data systems, feasibility studies, policy design and capacity building. Concessional loans and guarantees can support industrial upgrades, electric buses, charging infrastructure, wastewater treatment and recycling facilities. Results based finance and carbon finance can support forest conservation, restoration, agroforestry and possibly methane or waste reduction projects where methodologies are feasible. Public finance should be used to de-risk investments that generate broad social benefits but limited short-term revenue. Private finance should be mobilized where there are viable business models, such as industrial efficiency, recycling, EV charging, fleet electrification and biogas.

## 1.10. Executive summary: priority mitigation portfolio

The priority mitigation portfolio summarizes the programme areas that should guide policy and investment. Figure 2 and Table 1 present the cumulative mitigation or additional removals under ambitious scenarios. The forestry/LULUCF value represents additional net removals relative to BAU, while the other values represent cumulative reductions in positive emissions. Livestock is marked with an asterisk because it should be interpreted as a food-system sub-sector lens and should not be double counted with agriculture in economy-wide aggregation.

The table following the figure translates the scenario results into actionable programme areas. It emphasizes that each sector requires a different implementation strategy. IPPU requires technology audits, industrial finance and MRV. Transport requires mobility-system planning and electrification. Waste requires municipal service reform and wastewater investment. Agriculture requires farmer-centered crop and soil management. Livestock requires productivity, feed and manure interventions. Forestry requires long-term protection, restoration, safeguards and finance. Together, these actions form an integrated mitigation portfolio that can support Bhutan’s carbon-negative pathway while strengthening environmental sustainability and resilience.

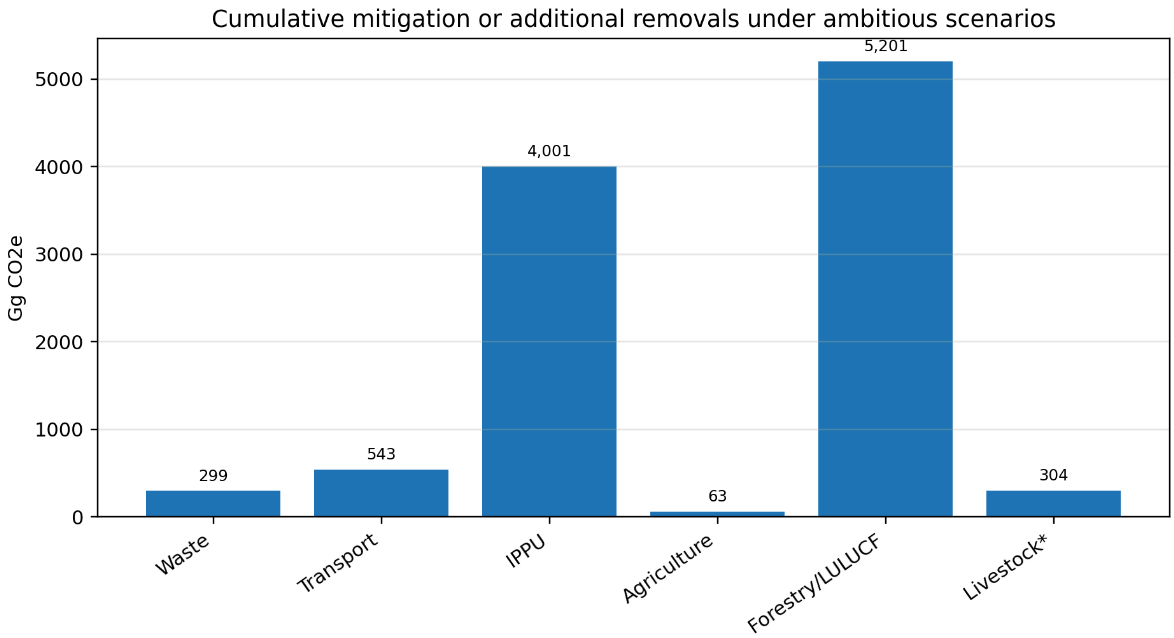


*Figure 2. Cumulative mitigation or additional removals under ambitious scenarios.*

*Table 1. Recommended areas and actions for emissions reductions.*

| Recommendation area | Priority action | Cumulative mitigation or additional net removals (Gg $CO_2e$) |
|---|---|---|
| Low-carbon industry | Prepare plant-level audits, clinker optimization, low-carbon cement and ferroalloy transformation pathways. | 4,000.69 |
| Integrated mobility | Scale EVs, electric buses, public transport, NMT, freight efficiency and charging infrastructure. | 543.44 |
| Zero waste and wastewater | Scale source separation, composting, recycling, sanitary disposal and wastewater treatment upgrades. | 299.32 |
| Climate-smart agriculture | Scale rice-water management, nutrient efficiency, soil health, agroforestry and organic manure systems. | 62.74 |
| Integrated low-carbon livestock | Improve feed, dairy productivity, breeding, manure management and biogas with stronger Tier 2 inventory data. | 304.14 |
| Forest sink protection | Maintain and enhance forest carbon stocks through conservation, restoration, REDD+ readiness and monitoring. | 5,200.68 |

*Note: Forestry/LULUCF represents additional net removals relative to BAU; all other sectors represent emissions reductions relative to BAU.*

## 2. Introduction and national mitigation context

Bhutan's national mitigation context is shaped by the relationship between gross emissions and forest removals. The country's carbon-negative status depends on a large and continuing forest sink that offsets positive emissions from energy, industry, agriculture, livestock and waste. This is a strong national advantage, but it also creates a strategic responsibility: Bhutan must protect and enhance its sink while preventing gross emissions from rising unnecessarily. The purpose of this insert is therefore to provide a clearer and more detailed executive summary, introduction, methodology and national trajectory narrative for the integrated sectoral emissions synthesis report.

The six sectors analyzed in the report represent different parts of Bhutan's development pathway. IPPU is linked to industrial growth, construction materials, cement, ferroalloys and future economic diversification. Transport is linked to connectivity, trade, urbanization, mobility and imported petroleum. Waste is linked to urban management, public health, sanitation, wastewater and circular economy. Agriculture and livestock are linked to food security, rural livelihoods, soil health and farmer income. Forestry/LULUCF is linked to national carbon neutrality, biodiversity, watershed protection, slope stability and rural ecosystem services. A coherent national mitigation strategy must therefore recognize the different roles that each sector plays.

The report is built around three core questions: what are the historical emissions and removals trends; what could happen under BAU projections to 2030; and what mitigation and sustainability strategies can alter the trajectory. These questions are answered for each of the six sectors. The synthesis then compares the results and identifies cross-cutting priorities such as MRV, climate finance, institutional coordination and environmental safeguards.

This synthesis is especially useful because it distinguishes between sectors that are important for volume-based emissions reduction and sectors that are important for co-benefits, resilience and long-term sustainability. IPPU and forestry dominate the quantitative mitigation and removal picture. Transport is strategically important because it connects fossil-fuel use with clean electricity. Waste, agriculture and livestock are comparatively smaller in carbon volume, but they deliver essential benefits for health, livelihoods, soil, sanitation, local environmental quality and rural resilience. The national mitigation context therefore calls for an investment portfolio rather than a single-sector approach.

## 3. Methodological approach

The methodology combines official inventory and projection information with analytical scenario development. The principal source is Bhutan's First BTR and accompanying CRT. Historical values are drawn from the CRT trend data wherever available. The BTR's

national projection table is used for the national emissions, sink capacity and net balance pathway. The National Forest Inventory Volume II is used to interpret forest carbon stock, forest carbon density, sequestration potential and the importance of forestry/LULUCF as the national sink.
Sector methods are tailored to the available data. Waste uses historical CRT emissions and the BTR waste BAU pathway. Transport uses fuel-import-based emissions estimates and an analytical BAU pathway applying 3.5% annual growth from the 2023 calculated road-emissions baseline, supported by vehicle-registration trends. IPPU uses CRT historical emissions and the BTR IPPU BAU projection. Agriculture uses crop- and soil-related CRT categories and a separate analytical BAU projection anchored to the BTR's non-livestock agriculture estimate. Livestock is analyzed separately using the BTR 2022 livestock total as the anchor and a conservative BAU projection. Forestry/LULUCF uses CRT historical net removals, BTR FOLU gross emissions and sink capacity, and NFI forest-carbon evidence.

The mitigation scenarios are planning scenarios rather than official government projections. Each sector has a low-, medium- and high-ambition scenario, with the high-ambition scenario used in the executive summary to compare cumulative mitigation or additional removals. The results should be interpreted as decision-support estimates that show direction and scale. They are useful for prioritizing policy, investment and MRV improvements, and should be refined through future sector-specific studies, feasibility assessments, cost-benefit analysis and stakeholder consultation before being used as formal targets.

## 4. National emissions profile and projected trajectory

The BTR national projection provides the basis for understanding Bhutan's overall emissions trajectory. Gross emissions are projected to rise over time, but the net balance remains negative because sink capacity is larger than total gross emissions. This is a favorable national position, but it should not be interpreted as a reason to delay mitigation in positive-emissions sectors. A rising gross-emissions trajectory can narrow the safety margin provided by forest removals, especially if future land-use pressures or climate-related disturbances reduce sink performance.

Within the six-sector analytical profile, total positive emissions increase from 1,552.05 Gg $CO_2e$ in 2020 to 2,300.87 Gg $CO_2e$ in 2030, while the six-sector net balance remains negative but weakens from -8,774.92 Gg $CO_2e$ in 2020 to -6,452.28 Gg $CO_2e$ in 2030. This indicates that Bhutan remains carbon-negative under the projection, but the magnitude of the net sink declines compared with 2020.

The implication is that Bhutan's long-term carbon-negative position should be managed actively. Gross-emission reductions in IPPU, transport, waste, agriculture and livestock can reduce future pressure on the sink. Forestry/LULUCF protection and enhancement can maintain the removal foundation of the national balance. Figure 3 shows the 2022 cross-sector profile, while Figure 4 shows the projected six-sector trajectory to 2030, and Table 2 present the national projection for total gross emissions, sink capacity and net balance from 2020 to 2030.

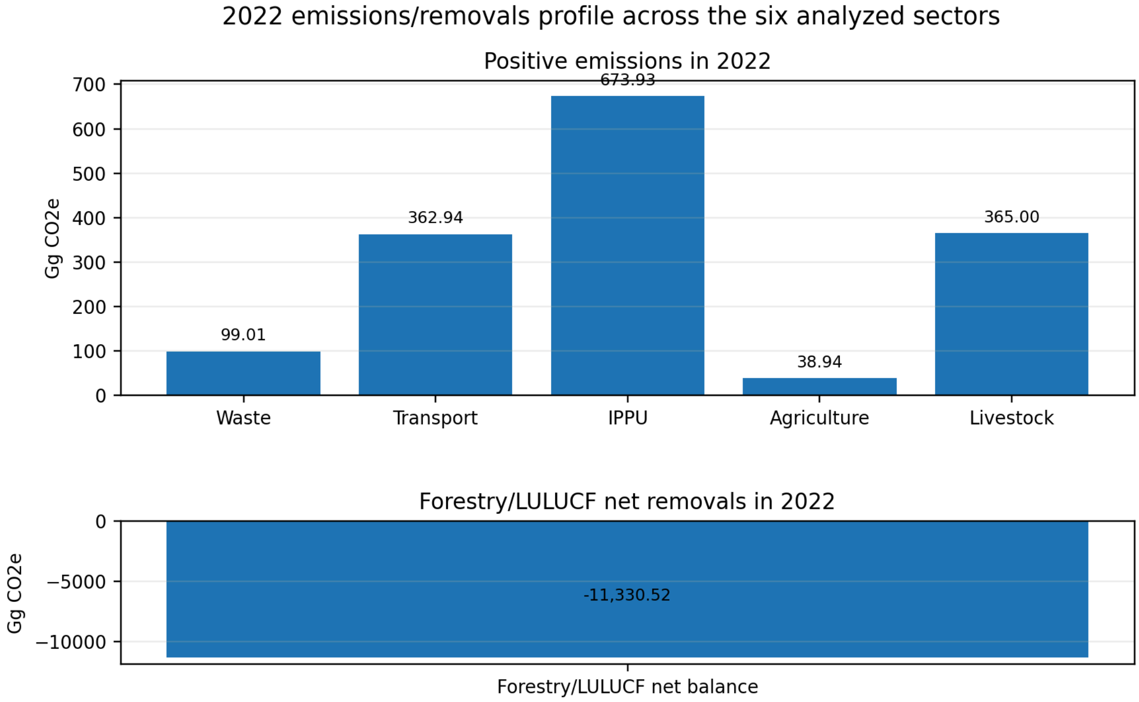


*Figure 3. 2022 emissions/removals profile across the six analyzed sectors.*

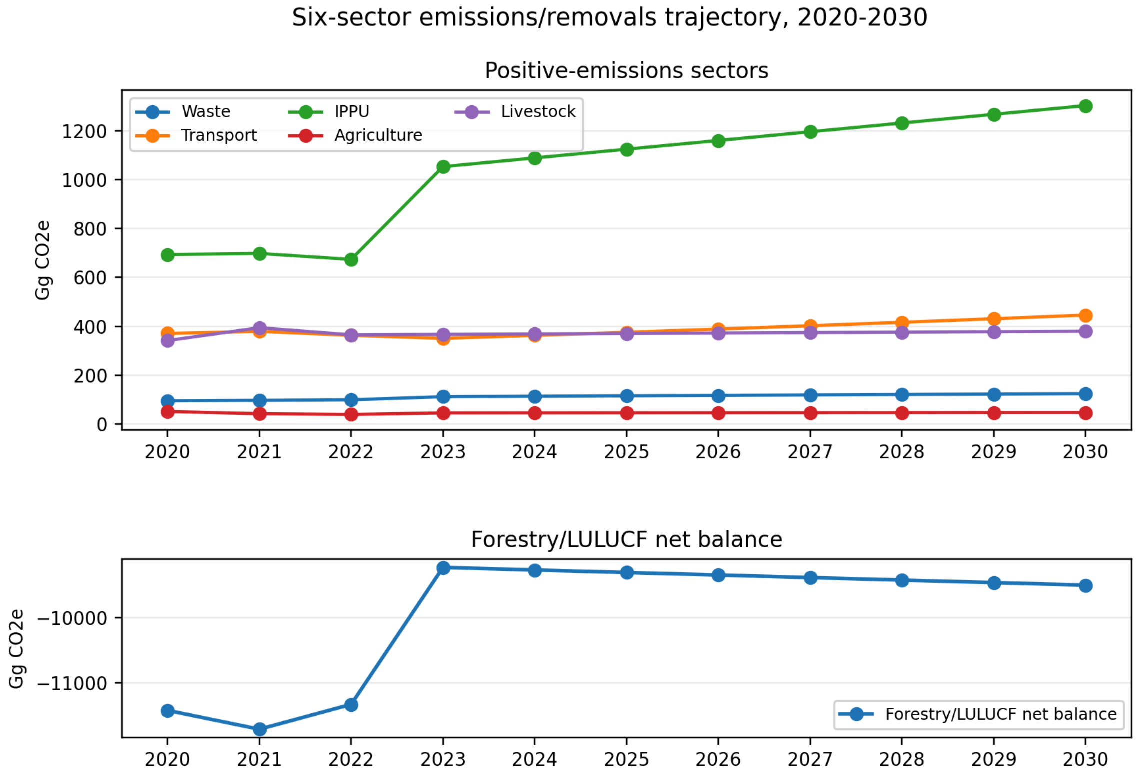


*Figure 4. Six-sector emissions/removals trajectory, 2020-2030.*

*Note: Positive-emissions sectors are shown separately from forestry/LULUCF net removals due to scale difference.*

*Table 2. Six-sector emissions/removals profile and projected trajectory, 2020-2030.*

| Year | Waste (Gg $CO_2$e) | Transport (Gg $CO_2$e) | IPPU (Gg $CO_2$e) | Agriculture (Gg $CO_2$e) | Livestock (Gg $CO_2$e) | Forestry/ LULUCF net balance (Gg $CO_2$e) | Total positive emissions (Gg $CO_2$e) | Six sector net balance (Gg $CO_2$e) |
|---|---|---|---|---|---|---|---|---|
| 2020 | 95.01 | 370.70 | 693.82 | 50.99 | 341.53 | -11,422.90 | 1,552n5 | -9,870.85 |
| 2021 | 96.74 | 379.30 | 698.35 | 42.16 | 394.16 | -11,711.10 | 1,610.71 | -10,100.39 |
| 2022 | 99.01 | 362.94 | 673.93 | 38.94 | 365.00 | -11,330.52 | 1,539.82 | -9,790.70 |
| 2023 | 111.78 | 350.51 | 1,053.77 | 45.41 | 366.82 | -9,235.32 | 1,928.29 | -7,307.03 |
| 2024 | 113.56 | 362.78 | 1,089.48 | 45.63 | 368.66 | -9,274.01 | 1,980.11 | -7,293.90 |
| 2025 | 115.35 | 375.48 | 1,125.20 | 45.86 | 370.50 | -9,312.72 | 2,032.39 | -7,280.33 |
| 2026 | 117.13 | 388.62 | 1,160.92 | 46.09 | 372.35 | -9,351.42 | 2,085.11 | -7,266.31 |
| 2027 | 118.91 | 402.22 | 1,196.63 | 46.32 | 374.22 | -9,390.12 | 2,138.30 | -7,251.82 |
| 2028 | 120.69 | 416.30 | 1,232.35 | 46.55 | 376.09 | -9,428.81 | 2,191.98 | -7,236.83 |
| 2029 | 122.48 | 430.87 | 1,268.07 | 46.79 | 377.97 | -9,467.51 | 2,246.18 | -7,221.33 |
| 2030 | 124.26 | 445.95 | 1,303.78 | 47.02 | 379.86 | -9,506.22 | 2,300.87 | -7,205.35 |

*Notes: 1. Forestry net balance = Forestry/LULUCF gross emissions + forest and land sink capacity/removals; negative forestry/LULUCF values indicate that removals exceed land-use emissions.*
*2. Historical values are used through the latest available year where applicable. Projection methods differ by sector: waste, IPPU and forestry use BTR-based pathways; transport, agriculture and livestock use analytical projections described in the sector specific sections.*

## 5. Waste sector analysis

### 5.1 Introduction

Waste management is closely connected to public health, urban service delivery, river and watershed protection, tourism, urban resilience, land availability, circular economy development and the maintenance of Bhutan's carbon-neutral development pathway. For a country with fragile mountain ecosystems, narrow valleys, dispersed settlements and strong constitutional and policy commitments to environmental stewardship, waste is both a greenhouse gas issue and a broader environmental management priority.

Bhutan's national circumstances are shaped by mountainous terrain, a high dependence on climate-sensitive sectors, extensive forest cover, hydropower resources and strong policy commitments to low-emission and climate-resilient development. These national circumstances are highly relevant to waste management. Settlement patterns and mountainous topography make waste collection and transport more difficult; limited flat land creates pressure on landfill siting and management; and climate-related hazards such as intense rainfall can increase the environmental risks associated with poorly managed waste disposal sites, leachate and wastewater infrastructure (DECC, 2024).

The waste sector also intersects with Bhutan's development transition. Urbanization, tourism recovery, changing consumption patterns, packaged goods, construction, institutional waste and expanding service sectors are likely to increase the volume and complexity of waste. At the same time, Bhutan's population remains relatively small, providing an opportunity to design a system that avoids the high-emission and high-pollution pathways seen in many countries where waste management improvements lag behind urban growth. The policy challenge is therefore not only to reduce methane and nitrous oxide emissions, but to establish a prevention-first waste hierarchy: avoid waste generation where possible, separate waste at source, recover materials, compost organic fractions, treat wastewater effectively, and safely manage residuals.

The Royal Government of Bhutan addressed waste through the National Waste Flagship Programme during the 12th Five Year Plan, with continued sectoral interventions in the 13th Five Year Plan (DECC, 2024). This is an important institutional signal. Waste management cannot be solved only through municipal collection and disposal. It requires coordination across national ministries, thromdes, dzongkhags, gewogs, businesses, households, health facilities, schools, monastic institutions, tourism operators and waste value chain actors. It also requires reliable data systems that convert operational information on waste generation, collection, segregation, recycling, composting, landfill management, sludge handling and wastewater treatment into climate-relevant activity data (DECC, 2024).

The historical time series for waste sector emissions from 2019 to 2022 show a modest upward trend, with the largest absolute contribution coming from wastewater treatment and discharge. Solid waste disposal is the second-largest component and is particularly important because methane generated from decomposing organic matter at disposal sites can persist as a long-term emission source.

Inventory uncertainty is a central theme of the waste sector analysis. In the BTR, the waste category is described as one of the highest-uncertainty areas because disaggregated and annually updated waste data are not consistently available. Population projections and default emission factors are used as surrogates for several components. The solid waste estimate uses population projection data, a per-capita waste generation rate and an assumed organic share based on the 2019 National Waste Inventory Survey. Wastewater emissions are estimated using population data and default parameters for domestic wastewater, while industrial wastewater relies on production data for breweries and distilleries. These methods are consistent with IPCC approaches where direct data are limited, but they reduce the precision of annual trend analysis and make it difficult to separate real changes in emissions from changes caused by assumptions, proxies or data gaps (DECC, 2024).

This analysis evaluates the historical waste sector emissions contained in the CRT table, uses the BTR's projected waste emissions as the BAU trajectory to 2030, and develops three mitigation scenarios for comparison. The scenario analysis highlights the types of measures that would have the strongest mitigation and environmental sustainability benefits. The scenarios are designed around the most important sources identified in the data: wastewater treatment and discharge, solid waste disposal, organic waste management, recycling and residual disposal practices (DECC, 2024).

The first scenario represents incremental reform. It assumes strengthened implementation of existing waste management actions, improved source segregation in urban areas, gradual expansion of composting, better recycling of high-value materials, and improvements in wastewater operation and maintenance. The second scenario represents accelerated circular economy implementation. It assumes that Bhutan's waste management system moves beyond collection and disposal toward coordinated material recovery, organic-waste diversion, improved sludge management and stronger producer and business participation. The third scenario represents a transformational pathway aligned with the aspiration of Zero Waste Bhutan and the BTR's mitigation framing. It assumes that the current pattern of high landfill disposal is reversed by 2030, that source segregation becomes the operational norm, and that wastewater systems are upgraded to reduce methane and nitrous oxide generation while improving water quality.

The mitigation strategies proposed in this analysis therefore combine climate and environmental priorities. Reducing methane from organic waste and wastewater is the direct greenhouse-gas objective. Reducing open dumping and uncontrolled burning improves air quality, reduces plastic leakage and protects landscapes. Increasing composting and anaerobic treatment can recover nutrients and support soil health if quality standards are maintained. Expanding recycling and reuse reduces demand for raw materials and helps create green jobs. Improving wastewater treatment protects rivers, urban water quality and public health. In a Bhutanese context, these outcomes are mutually reinforcing: effective waste management supports carbon-neutrality, Gross National Happiness principles, sustainable tourism, watershed protection and climate-resilient settlement planning.

## 5.2. Analysis of waste emissions: historical trends and projections

The available data indicates that total waste sector emissions increased from 93.58 Gg $CO_2e$ in 2019 to 99.01 Gg $CO_2e$ in 2022. This represents a net increase of 5.43 Gg $CO_2e$, or 5.8%, over the four-year period. The increase was gradual, with annual values of 93.58 Gg $CO_2e$ in 2019, 95.01 Gg $CO_2e$ in 2020, 96.74 Gg $CO_2e$ in 2021 and 99.01 Gg $CO_2e$ in 2022. The trend is consistent with slowly increasing waste and wastewater loads, although the BTR cautions that the waste inventory depends heavily on surrogate data and default factors (DECC, 2024).

The waste sector profile is structurally concentrated. Wastewater treatment and discharge accounted for 79.67 Gg $CO_2e$ in 2022, or about 80.5% of total waste sector emissions. Solid waste disposal accounted for 19.31 Gg $CO_2e$, or about 19.5%. Biological treatment of solid waste and incineration/open burning together represented less than 0.1 % of the reported total. The reported values reflect very limited published data on composting and incineration/open burning, and the BTR notes that estimates for these sub-categories rely on assumptions and expert judgement (DECC, 2024).

Wastewater is the largest source because domestic wastewater emissions are estimated using population as a surrogate, while industrial wastewater includes production data for breweries and distilleries. The BTR states that Bhutan has lagoon treatment systems in Phuentsholing and Gelephu, one large compact treatment system in Thimphu, and several compact treatment systems in urban areas. In the absence of measured wastewater flows, biochemical oxygen demand loads and treatment-system performance data, the inventory uses IPCC-consistent default approaches. This points to a clear improvement priority: build a wastewater data system that records influent and effluent characteristics, treatment type, sludge management and plant operating conditions (DECC, 2024).

Solid waste disposal emissions are smaller than wastewater emissions but strategically important because methane generation from disposal sites is driven by the accumulation of degradable organic carbon over time. The BTR reports that solid waste disposal estimates use population projection data, a per-capita waste generation rate of 0.23 kg per capita per day and an assumed 50% organic fraction based on the 2019 National Waste Inventory Survey. The 2022 solid-waste estimate corresponds to 0.69 Gg $CH_4$, reported in the BTR, and appears in the CRT table as 19.31 Gg $CO_2e$ when converted to carbon dioxide equivalent. This highlights the importance of organic-waste diversion and disposal-site management (DECC, 2024).

The BTR provides a forward-looking BAU projection for waste emissions from 2023 to 2030. This projection rises from 111.78 Gg $CO_2e$ in 2023 to approximately 124.26 Gg $CO_2e$ in 2030. The projection suggests an average increase of about 1.78 Gg $CO_2e$ per year over the period. Because the 2023 projected value is higher than the latest 2022 inventory value, it should be read as a modelling trajectory rather than a direct continuation of the 2019–2022 inventory series. For this report, the 2019–2022 CRT values are used as historical inventory data, and the BTR Table 34 values are used as the official BAU projection reference (DECC, 2024).

*Source note for Figures 5, 6 and 7 below: Historical values are extracted from CRT emission-trend table. Projection values are drawn from Bhutan's BTR Table 34. The BTR waste chapter reports 99.01 Gg $CO_2e$ for the waste category in 2022 and explains key assumptions for solid waste, composting, open burning and wastewater treatment. (DECC, 2024).*

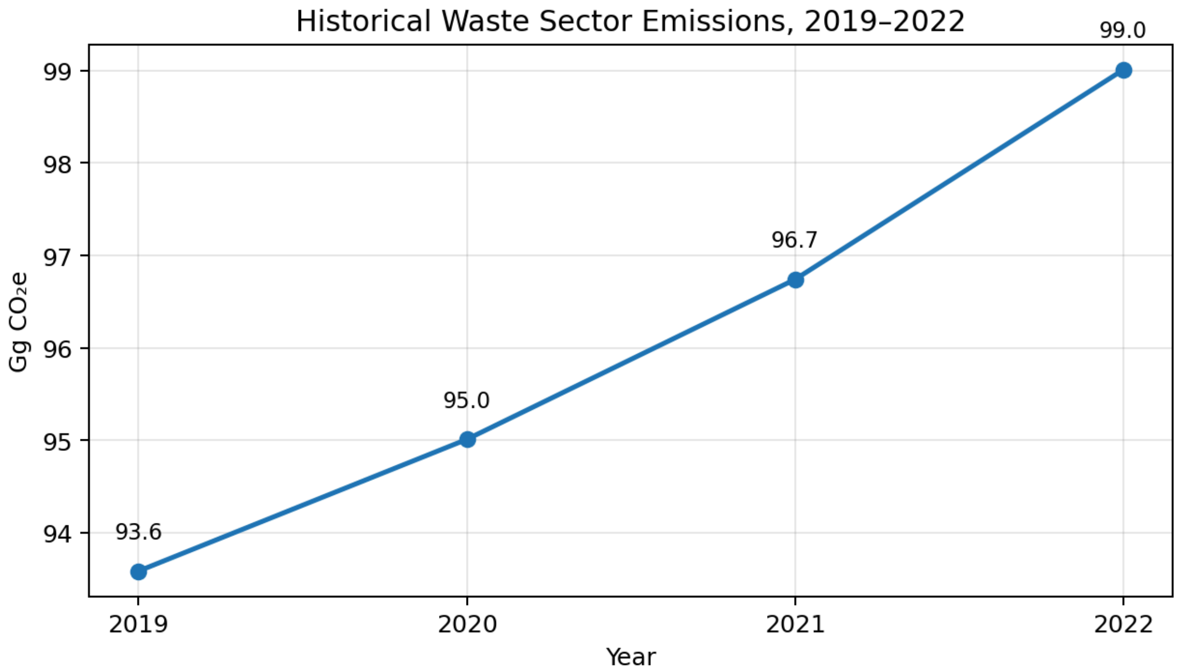


*Figure 5. Historical waste emissions, 2019–2022.*

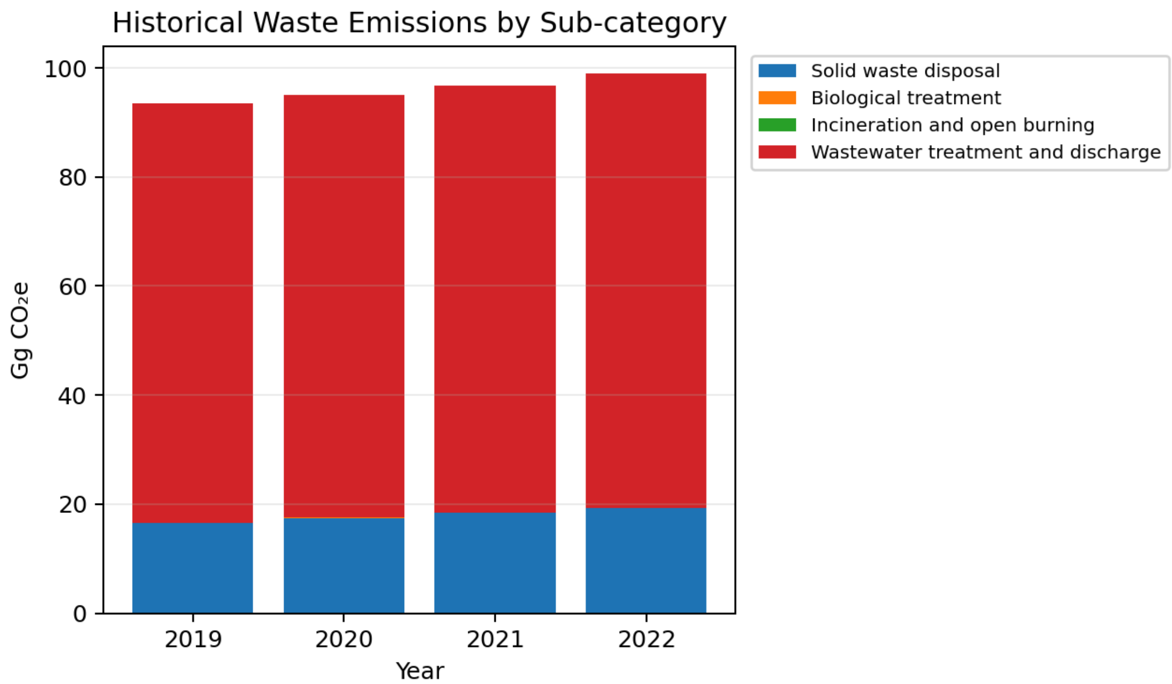


*Figure 6. Historical waste emissions by sub-category.*

*Table 3. Historical waste emissions by sub-category, 2019–2022*

| Year | Total waste (Gg $CO_2$e) | Solid waste disposal (Gg $CO_2$e) | Biological treatmen t (Gg $CO_2$e) | Incineration and open burning (Gg $CO_2$e) | Wastewater treatment and discharge (Gg $CO_2$e) | Waste emissions share from |
|---|---|---|---|---|---|---|

| | | | | | | wastewater (%) |
|---|---|---|---|---|---|---|
| 2019 | 93.58 | 16.47 | 0.04 | 0.00 | 77.08 | 82.36 |
| 2020 | 95.01 | 17.47 | 0.04 | 0.00 | 77.50 | 81.57 |
| 2021 | 96.74 | 18.40 | 0.04 | 0.00 | 78.30 | 80.94 |
| 2022 | 99.01 | 19.31 | 0.04 | 0.00 | 79.67 | 80.46 |

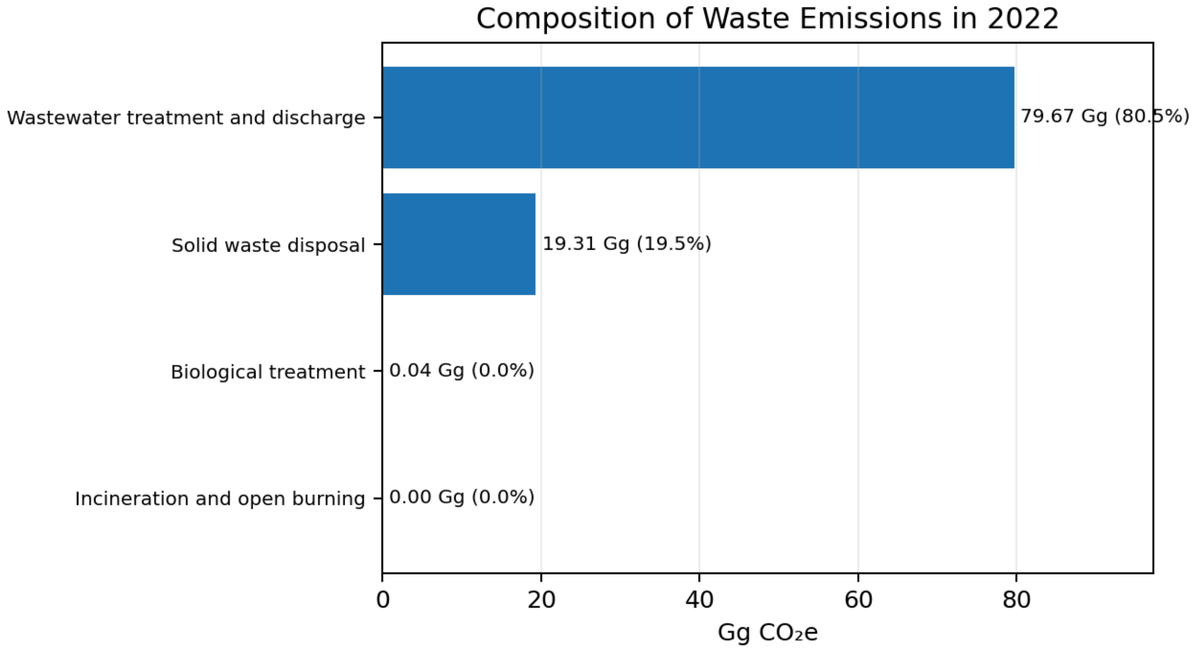


*Figure 7. Composition of waste emissions in 2022.*

### 5.2.1 Interpretation of historical trends

The total increase in waste sector emissions between 2019 and 2022 is mainly driven by both wastewater treatment and solid waste disposal. Wastewater emissions increased by 2.59 Gg $CO_2$e over the period, from 77.08 to 79.67 Gg $CO_2$e. Solid waste disposal increased by 2.84 Gg $CO_2$e, from 16.47 to 19.31 Gg $CO_2$e. The wastewater increase is slightly smaller in percentage terms because the base is much larger, while the solid waste disposal increase is more significant in relative terms at about 17.2%. This suggests that the strongest near-term mitigation opportunities are likely to come from organic waste diversion, landfill disposal reduction and wastewater treatment improvements (DECC, 2024).

The reported biological treatment value of 0.035 Gg $CO_2$e per year is effectively flat. This reflects the BTR's statement that there is no published data on the amount of waste composted and that the inventory team relied on expert judgement to allocate 5% of generated waste as composted. From a mitigation perspective, this is a major data gap. If composting, anaerobic digestion, community organic waste processing or institutional composting expand, Bhutan will need a monitoring system that records input quantities, technology type, compost use, rejected residuals and operational conditions (DECC, 2024).

Open burning and incineration are reported as 0.003 Gg $CO_2e$ annually in the CRT table. The BTR states that medical and infectious wastes are incinerated but that actual quantities were unavailable, while open burning of cardboard and packaging waste was estimated using an assumed 5% of relevant waste. The reported value is therefore more a placeholder based on assumptions than a comprehensive measurement of combustion-related waste emissions. Strengthening reporting from hospitals, municipalities and private waste handlers would improve both emissions estimates and environmental safeguards (DECC, 2024).

### 5.2.2 BAU projections

The BTR projection (Figure 8 and Table 4) provides a BAU waste emissions pathway for the period 2023–2030. The projection increases steadily from 111.78 Gg $CO_2e$ in 2023 to 120.69 Gg $CO_2e$ in 2028 and 124.26 Gg $CO_2e$ in 2030. This indicates that, without stronger mitigation, waste emissions could be about 25% higher in 2030 than the 2022 inventory value of 99.01 Gg $CO_2e$ (DECC, 2024).

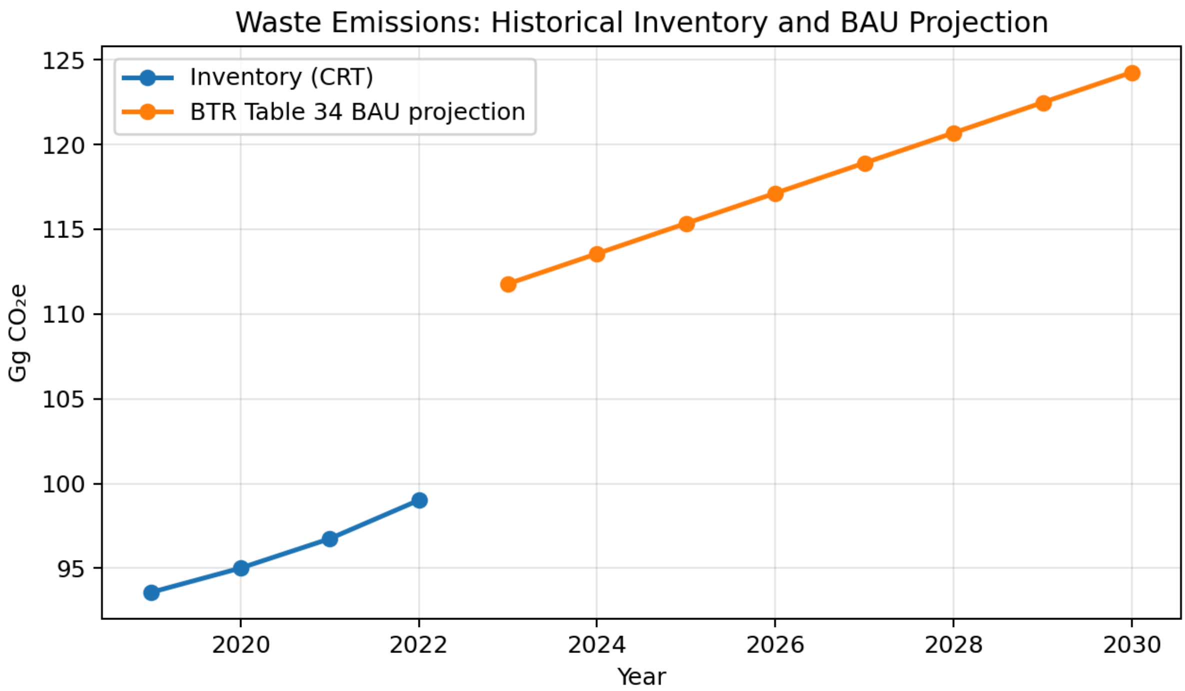


*Figure 8. Historical inventory and BAU projection for waste emissions.*

*Table 4. BAU waste emissions projection, 2023–2030*

| Year | Waste BAU (Gg $CO_2e$) |
|---|---|
| 2023 | 111.78 |
| 2024 | 113.56 |
| 2025 | 115.35 |
| 2026 | 117.13 |
| 2027 | 118.91 |
| 2028 | 120.69 |
| 2029 | 122.48 |
| 2030 | 124.26 |

### 5.3 Emissions mitigation scenarios and sustainability strategies

Three mitigation scenarios were developed to illustrate how different levels of policy ambition could affect waste emissions through 2030. These are analytical scenarios based on the BTR's BAU projection, the historical CRT emission data, and the mitigation directions described in the BTR. Each scenario is expressed as a reduction relative to BAU by 2030, with the reduction increasing gradually over the period to reflect implementation time (DECC, 2024).

Scenario 1 represents incremental reforms that strengthen existing systems without fundamentally changing the current waste management model. Scenario 2 represents accelerated circular economy implementation, in which source segregation, material recovery, composting and improved wastewater management become mainstreamed across major urban areas and institutions. Scenario 3 represents a transformation pathway aligned with the Zero Waste Bhutan ambition, the BTR's emphasis on reducing landfill disposal from more than 80% to less than 20% by 2030, and a more comprehensive wastewater upgrade programme (DECC, 2024).

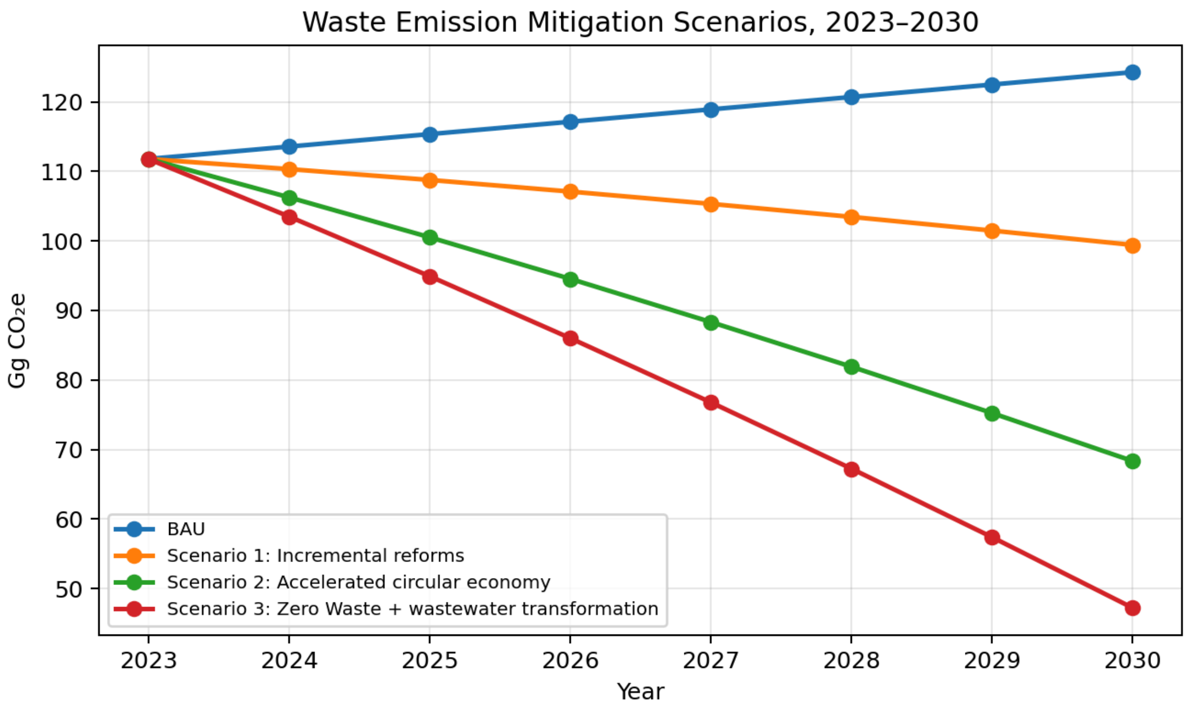


*Figure 9. Waste emissions mitigation scenarios, 2023–2030.*

*Table 5. Scenario emission pathways for the waste sector, 2023–2030*

| Year | Waste BAU ($Gg\ CO_2e$) | Scenario 1: Incremental reforms (20% below BAU by 2030) | Scenario 2: Accelerated circular economy (45% below BAU by 2030) | Scenario 3: Zero Waste and wastewater transformation (62% below BAU by 2030) |
|---|---|---|---|---|
| 2023 | 111.78 | 111.78 | 111.78 | 111.78 |
| 2024 | 113.56 | 110.32 | 106.26 | 103.50 |

| | | | | |
|---|---|---|---|---|
| 2025 | 115.35 | 108.76 | 100.52 | 94.92 |
| 2026 | 117.13 | 107.09 | 94.54 | 86.01 |
| 2027 | 118.91 | 105.32 | 88.33 | 76.78 |
| 2028 | 120.69 | 103.45 | 81.90 | 67.24 |
| 2029 | 122.48 | 101.48 | 75.24 | 57.39 |
| 2030 | 124.26 | 99.41 | 68.34 | 47.22 |

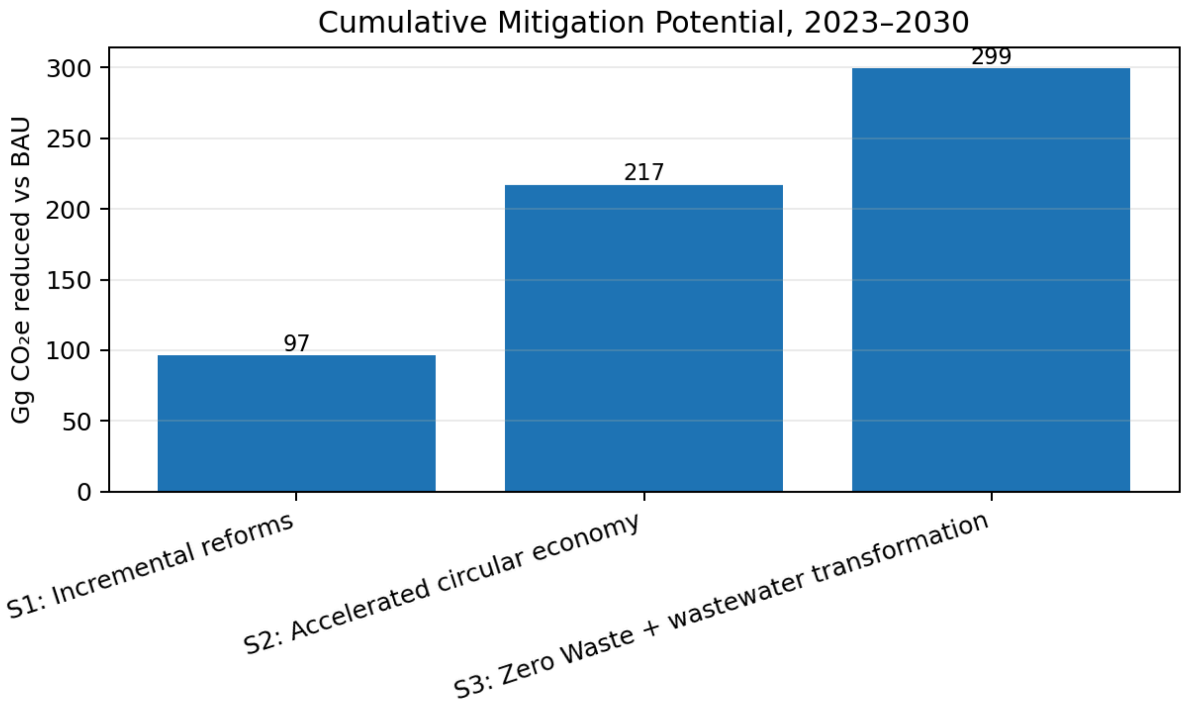


*Figure 10. Waste cumulative emission reductions compared with BAU, 2023–2030.*

*Table 6. Scenario summary and cumulative emission mitigation impact for waste sector*

| Scenario | 2030 emissions (Gg $CO_2e$) | Cumulative emissions 2023-2030 (Gg $CO_2e$) | Cumulative reduction vs BAU (Gg $CO_2e$) | Cumulative reduction vs BAU (%) |
|---|---|---|---|---|
| BAU | 124.26 | 944.16 | 0.00 | 0.00 |
| Scenario 1: Incremental reforms | 99.41 | 847.61 | 96.55 | 10.23 |
| Scenario 2: Accelerated circular economy | 68.34 | 726.91 | 217.25 | 23.01 |
| Scenario 3: Zero Waste and wastewater transformation | 47.22 | 644.84 | 299.32 | 31.70 |

### 5.3.1 Scenario 1: Incremental waste management reforms

This scenario assumes that Bhutan strengthens current waste management actions but does not fully transform the system. Key measures include improved source segregation in priority thromdes, gradual expansion of composting for markets and institutions, improved collection coverage, better recordkeeping by municipal and private waste handlers, and operational improvements in existing wastewater-treatment systems. The scenario reaches a 20% reduction below BAU by 2030. Under this pathway, 2030 waste emissions would be approximately 99.41 Gg $CO_2e$, close to the 2022 inventory level. Cumulative emissions from 2023 to 2030 would be about 847.61 Gg $CO_2e$, reducing emissions by 96.55 Gg $CO_2e$ compared with BAU over the period. This scenario is realistic and relatively low risk, but it mainly stabilizes emissions rather than placing the sector on a deeper decarbonization pathway (DECC, 2024).

### 5.3.2 Scenario 2: Accelerated circular economy and organic waste diversion

This scenario assumes that Bhutan rapidly scales source segregation, composting, recycling and material recovery. It prioritizes the diversion of food waste, green waste, paper and other recoverable materials away from disposal sites. It also assumes stronger participation by hotels, schools, monasteries, markets, public institutions, offices and tourism businesses, supported by procurement rules, service contracts and awareness campaigns. For wastewater, the scenario includes improved treatment performance and sludge management in larger urban areas. The scenario reaches a 45% reduction below BAU by 2030. Under this pathway, 2030 emissions fall to about 68.34 Gg $CO_2e$ and cumulative emissions from 2023 to 2030 fall to about 726.91 Gg $CO_2e$, reducing emissions by 217.25 Gg $CO_2e$ compared with BAU. This scenario delivers more substantial climate and environmental benefits while remaining technically achievable if supported by investment, enforcement and private sector participation (DECC, 2024).

### 5.3.3 Scenario 3: Zero Waste Bhutan and wastewater transformation

This scenario is the most ambitious and is designed to reflect the long-term direction described in the BTR. It assumes that Bhutan reverses the current pattern of disposing more than 80% of waste to landfills and moves toward less than 20% by 2030. It combines mandatory source segregation, decentralized and centralized composting, material recovery facilities, high recycling rates, landfill residual minimization, improved disposal-site management, methane avoidance or capture at priority sites where feasible, and upgraded wastewater treatment and sludge management. The scenario reaches a 62% reduction below BAU by 2030. Under this pathway, 2030 emissions decline to about 47.22 Gg $CO_2e$ and cumulative emissions from 2023 to 2030 fall to about 644.84 Gg $CO_2e$, reducing emissions by 299.32 Gg $CO_2e$ compared with BAU. This pathway is ambitious but consistent with the BTR's estimate that the waste sector has substantial cumulative mitigation potential through composting, recycling and wastewater-treatment improvements (DECC, 2024).

## 5.4 Strategies for emissions reductions and environmental sustainability

### 5.4.1 Strategy 1: Build a national waste and wastewater MRV system

The highest priority is to improve data. Bhutan should establish an integrated digital waste and wastewater MRV system covering waste generation, collection, source segregation, material recovery, composting, disposal, open burning, incineration, wastewater flows, treatment performance and sludge handling. Thromdes, dzongkhags and major waste generators should report standardized data at least annually. The system should distinguish household, commercial, institutional, health-care, tourism, construction and industrial streams. This will reduce uncertainty in the inventory and allow mitigation measures to be tracked credibly (DECC, 2024).

### 5.4.2 Strategy 2: Make organic-waste diversion the core mitigation action

Organic waste is the main driver of methane from solid waste disposal. Bhutan should prioritize food and green-waste separation, institutional composting, market-waste composting, community composting, and where technically viable, anaerobic digestion for larger concentrated organic streams. Compost quality standards and safe end-use guidelines are essential to ensure that organic waste processing supports soil health and does not create contamination risks (DECC, 2024).

### 5.4.3 Strategy 3: Scale recycling and material recovery through value chains

Recycling should be treated as an economic value chain rather than an awareness campaign alone. Material recovery facilities, aggregation points, standards for sorted materials, contracts with recyclers, reverse logistics, and private sector participation are needed. Priority streams include paper and cardboard, Polyethylene Terephthalate (PET) and High-Density Polyethylene (HDPE), metals, glass, e-waste, used oil and packaging waste from tourism and retail. Extended producer responsibility can help finance recovery of packaging and difficult-to-recycle materials.

### 5.4.4 Strategy 4: Upgrade wastewater treatment and sludge management

Because wastewater is the largest reported waste emission source, mitigation must include wastewater infrastructure and operations. Bhutan should prioritize measurement of flows and organic load, improved operation of lagoon and compact treatment systems, energy-efficient aeration where applicable, decentralized treatment for smaller settlements, fecal sludge management, and safe sludge treatment or co-composting. Climate benefits should be pursued together with water-quality, public-health and river-protection benefits (DECC, 2024).

### 5.4.5 Strategy 5: Reduce open burning and improve residual disposal

Open burning should be reduced through reliable collection, accessible disposal options, enforcement and alternatives for cardboard, packaging and agricultural or institutional waste. Residual waste that cannot be recovered should be disposed of in well-managed engineered facilities with leachate control, daily cover, drainage, safety measures and data recording. For larger sites, methane avoidance, flaring or recovery should be assessed, although feasibility will depend on waste quantities and landfill characteristics.

### 5.4.6 Strategy 6: Use policy instruments to support behavior and markets

Sustained mitigation will require regulations, incentives and institutional roles. Useful instruments include mandatory source segregation, landfill restrictions on organic waste, differentiated user fees, public procurement of recycled products and compost, green tourism standards, business reporting requirements, EPR for packaging, and performance-based grants to local governments. Measures should be phased to avoid burdening households and small businesses without providing practical alternatives.

### 5.4.7 Strategy 7: Link waste management to climate finance and green jobs

Waste sector mitigation can support green employment in collection, sorting, composting, recycling logistics, facility operation, data management and public outreach. Bhutan can package waste management investments as climate and sustainability projects, including for urban resilience, circular economy, methane reduction, wastewater treatment and river protection. Carbon finance may be more feasible for larger, measurable methane-reduction interventions, but most benefits will come from public investment, municipal service reform and private sector value chain development.

## 5.5 Conclusion

Bhutan's waste emissions are modest in national terms but are rising and are highly relevant to the country's environmental sustainability objectives. The CRT data shows an increase from 93.58 Gg $CO_2e$ in 2019 to 99.01 Gg $CO_2e$ in 2022. Wastewater treatment and discharge is the dominant source, followed by solid waste disposal. The BAU projection in the BTR indicates a rise to about 124.26 Gg $CO_2e$ by 2030, suggesting that additional measures are needed to avoid a gradual increase in emissions (DECC, 2024).

The scenario analysis shows that incremental reforms can stabilize emissions around current levels, but deeper reductions require accelerated circular economy implementation and transformation of wastewater management. The most ambitious scenario reduces 2030 emissions to about 47.22 Gg $CO_2e$ and produces cumulative reductions of about 299.4 Gg $CO_2e$ over 2023–2030 compared with BAU. This pathway requires coordinated national and local action, reliable data, capital investment, private sector participation and sustained public engagement (DECC, 2024).

The priority package for Bhutan is clear: strengthen MRV, divert organic waste, scale recycling and material recovery, improve wastewater and sludge management, eliminate open burning, and ensure that residual disposal is safe and well managed. These measures would reduce emissions while also supporting water quality, public health, landscape protection, green jobs, circular economy development and Bhutan's continued commitment to carbon-neutral and environmentally sustainable development.

# 6. Transport sector analysis

## 6.1 Introduction

Bhutan's national focus is on sustaining economic development and connectivity while maintaining its carbon-neutral status and reducing avoidable growth in emissions from sectors that depend on imported fossil fuels. Transport is central to this challenge. Because Bhutan is landlocked and mountainous, mobility of people and goods depends heavily on roads. The national road network performs a lifeline function by connecting Dzongkhags, Gewogs, urban centers, rural communities, border points, markets, health and education services, hydropower sites and tourism destinations. This makes transport essential for social inclusion, service delivery, trade, food supply, emergency response and balanced regional development. At the same time, the current transport system is highly dependent on petrol and diesel imports, which makes it one of the most important sources of energy-related greenhouse gas emissions. The BTR explicitly states that, as a landlocked country, Bhutan is heavily reliant on road transport.

The climate significance of the sector is heightened by Bhutan's clean electricity system. Since Bhutan's grid is dominated by hydropower, emissions from electricity generation are reported as negligible, and electrification of transport can shift useful energy demand away from imported petroleum products toward domestic renewable electricity. This makes electric mobility particularly attractive in Bhutan compared with countries where electricity generation is fossil-fuel intensive. The transition is therefore not only a climate mitigation measure; it is also an energy security, balance of payments, air quality and urban air quality strategy. Reduced petroleum demand can lower exposure to fuel price volatility, while cleaner public transport and improved pedestrian and cycling infrastructure can improve urban livability, road safety and public health.

The BTR identifies transport as the primary source of greenhouse gas emissions in the energy sector, responsible for more than 60% of energy-sector emissions, and reports that the Low-Emission Development Strategy (LEDS) for Surface Transport would require substantial investment in infrastructure and enabling measures from 2021 to 2030 (DECC, 2024). It further identifies short- and medium-term interventions that include promotion of electric vehicles and shared mobility, improved fuel-efficiency and emission standards, mass transit improvements, open bus rapid transit networks, light rail transit, public bicycle systems, improved pedestrian footpaths and rationalization of personal vehicle ownership through restrictions on imports of fossil-fuel vehicles. These policy directions provide the strategic basis for the scenarios developed in this report.

The CRT data is the foundation for the historical analysis of transport emissions. It records petrol and diesel import data used for estimating road-transport emissions, sourced from the Petroleum, Oil and Lubricants section of the Department of Trade and other energy-sector records. The workbook also notes an important inventory limitation: in the absence of a transport model and disaggregated data on kilometers travelled by vehicle category, national fuel-import data are used to estimate. This limitation is consistent with the BTR methodology, which reports that a Tier 1 approach was applied using fuel import data and IPCC default emission factors (DECC, 2024). The implication is that the available inventory is sufficient for national trend analysis and strategic planning, but future policy design would benefit from more detailed vehicle kilometer, occupancy, load-factor, route, fleet age and technology data.

This report analyses the historical transport fuel and emission trends reflected in the CRT, and develops projections for 2024–2030. Historical emissions are estimated from petrol and diesel volumes using standard fuel-density, net calorific value and carbon emission factor assumptions consistent with IPCC inventory practice (Intergovernmental Panel on Climate Change [IPCC], 2006). The estimates focus on road transport $CO_2$ emissions because the CRT data are primarily road-fuel data and because $CO_2$ accounts for the overwhelming share of transport sector greenhouse gas emissions. The BTR also reports non-$CO_2$ gases from transport – 0.05 Gg $CH_4$ and 0.02 Gg $N_2O$ in 2022 – as well as domestic aviation emissions of 1.16 Gg $CO_2e$, but these are small relative to road transport $CO_2$ and are treated qualitatively in this report where appropriate (DECC, 2024).

This report also recognizes that transport decarbonization is not simply a matter of replacing vehicles. In Bhutan, the sustainability of the transport transition depends on the integration of five mutually reinforcing measures: cleaner vehicle technologies, reliable and attractive public transport, safe non-motorized mobility, compact land-use and corridor planning, and stronger data systems for inventory improvement and policy monitoring. Electrification can reduce emissions per kilometer, but total emissions will continue to rise if vehicle ownership, congestion and freight demand grow without complementary demand management and modal shift measures. Conversely, public transport, walking and cycling can reduce vehicle kilometers travelled, but their mitigation potential will be limited unless service quality, infrastructure, safety and convenience are improved. The strongest scenario therefore combines technology transition with system-level mobility planning.

Lower transport emissions support Bhutan's carbon-neutral commitment, improve local air quality in urban corridors, reduce noise and congestion, and strengthen energy security by lowering dependence on imported petroleum. Better public transport and non-motorized infrastructure can also improve access for lower-income households, students, elderly people and residents who do not own private vehicles. The mitigation scenarios therefore consider both emissions reduction and sustainability co-benefits, consistent with the BTR's emphasis on sustainable and convenient transport modes, integration of land-use and transport planning, and transition of vehicle fleets to cleaner fuels (DECC, 2024).

## 6.2 Analysis of transport emissions: historical trends and projections

The BTR reports that Bhutan's transport inventory covers road and domestic air transportation and uses a Tier 1 methodology based on fuel import data and default IPCC emission factors (DECC, 2024). The CRT data follows the same broad logic, using petrol and diesel import data from the POL section of the Department of Trade and related energy records. Because a detailed transport model is not yet available, the historical estimates should be interpreted as national fuel-based inventory estimates rather than bottom-up estimates by vehicle type, route, occupancy, load or distance travelled.

The available fuel data show three distinct periods. The first is a growth period from 2006 to 2014, when petrol imports rose from 15,216 kL to 31,289 kL and diesel imports rose from 50,654 kL to 117,274 kL. The second is the high-demand pre-pandemic period of 2018–2019, when petrol imports reached 46,912–50,959 kL and diesel imports exceeded 154,000 kL. The third is the disruption and recovery period after 2020, when fuel imports fell sharply, especially diesel, before petrol recovered in 2023 while diesel remained lower than the 2018–2019 levels. This pattern reflects the sensitivity of transport emissions to mobility demand, economic activity, construction, trade and pandemic-related disruptions.

Diesel dominates the estimated road-transport emissions profile. This is consistent with Bhutan's reliance on freight, buses, heavy-duty vehicles and diesel light-duty trucks for inter-district mobility and supply chains. In 2022, calculated road-transport $CO_2$ emissions from the attached fuel-import data are approximately 362.9 Gg $CO_2e$, of which diesel accounts for roughly 279.6 Gg $CO_2e$ and petrol for 83.4 Gg $CO_2e$ (see Figures 11, 12, and 13 and Table 7). The BTR reports that the transport category produced 370 Gg $CO_2e$, 0.05 Gg $CH_4$ and 0.02 Gg $N_2O$ in 2022, and that domestic aviation contributed 1.16 Gg $CO_2e$ (DECC, 2024). The close relationship between the calculated road-fuel estimate and the BTR transport figure confirms that the CRT provides a useful basis for trend analysis.

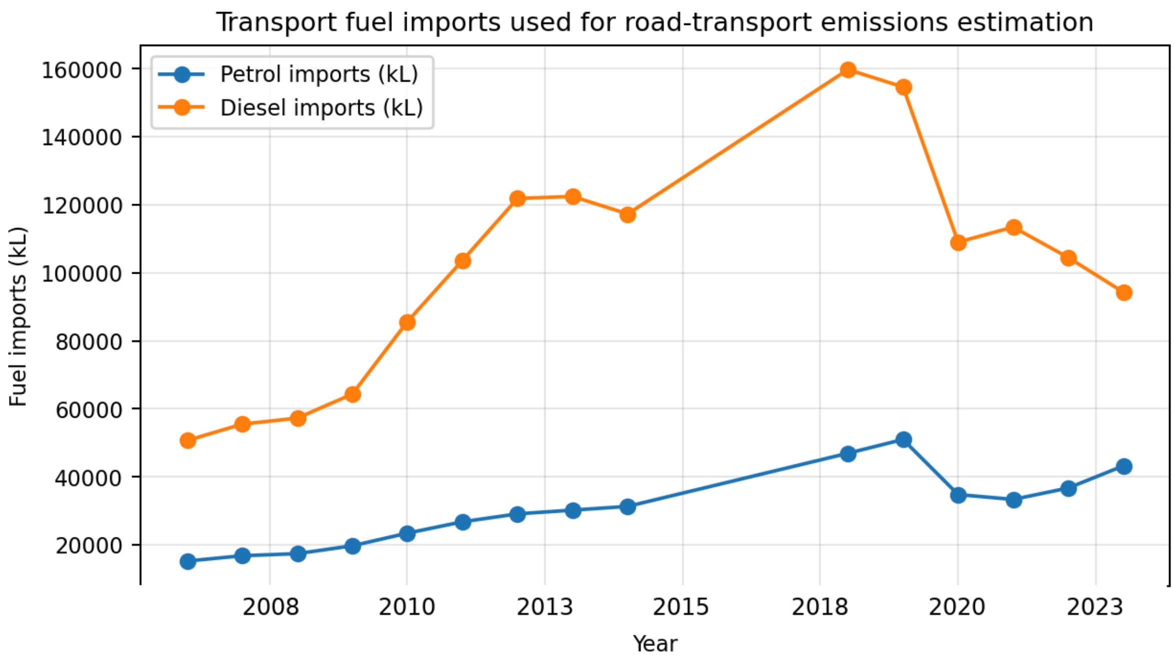


*Figure 11. Historical petrol and diesel imports used for transport emission estimation.*

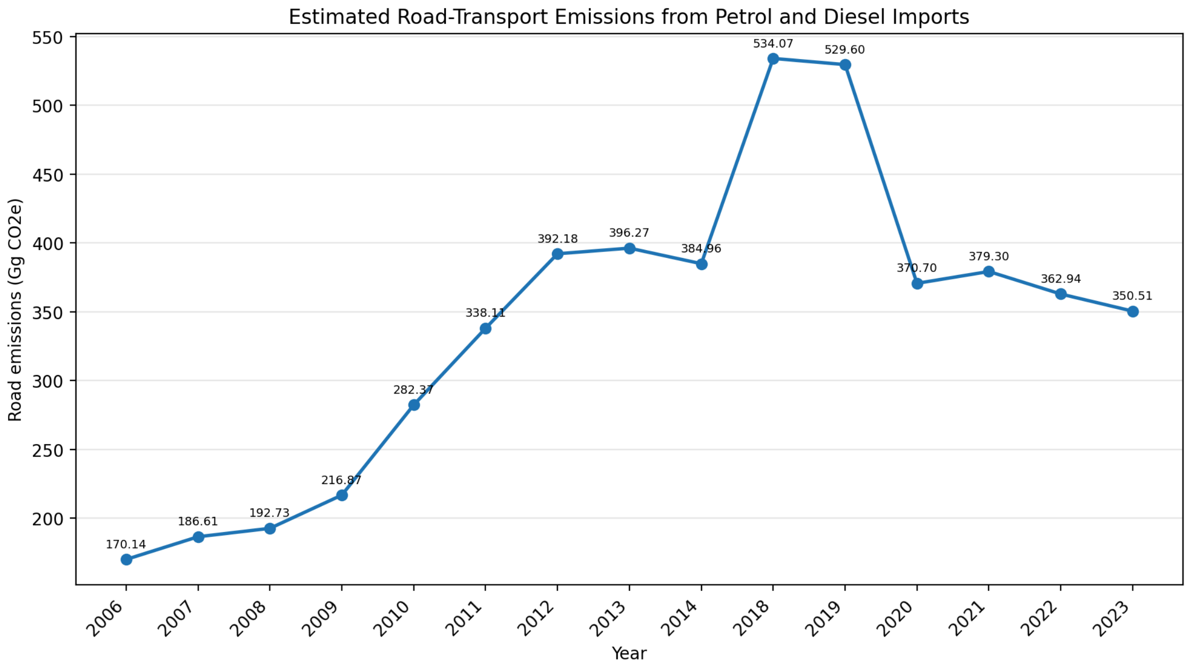


*Figure 12. Estimated road-transport $CO_2$ emissions from petrol and diesel imports.*

*Table 7. Historical fuel imports and calculated road-transport $CO_2$ emissions*

| Year | Petrol (kL) | Diesel (kL) | Road (Gg $CO_2$e) | Petrol share (%) | Diesel share (%) |
|---|---|---|---|---|---|
| 2006 | 15216 | 50654 | 170.14 | 20.32 | 79.68 |
| 2007 | 16781 | 55477 | 186.61 | 20.43 | 79.57 |
| 2008 | 17393 | 57245 | 192.73 | 20.50 | 79.50 |
| 2009 | 19709 | 64300 | 216.87 | 20.65 | 79.35 |
| 2010 | 23,422.50 | 85620 | 282.37 | 18.84 | 81.16 |
| 2011 | 26,761.10 | 103,610.90 | 338.11 | 17.98 | 82.02 |
| 2012 | 29094 | 121,832.00 | 392.18 | 16.85 | 83.15 |
| 2013 | 30,195.20 | 122,424.80 | 396.27 | 17.31 | 82.69 |
| 2014 | 31,289.20 | 117,273.80 | 384.96 | 18.46 | 81.54 |
| 2018 | 46,912.34 | 159,722.50 | 534.07 | 19.96 | 80.04 |
| 2019 | 50,958.51 | 154,616.59 | 529.60 | 21.86 | 78.14 |
| 2020 | 34,775.52 | 108,986.50 | 370.70 | 21.31 | 78.69 |
| 2021 | 33,330.51 | 113,423.52 | 379.30 | 19.96 | 80.04 |
| 2022 | 36,696.72 | 104,455.21 | 362.94 | 22.97 | 77.03 |
| 2023 | 43,197.18 | 94,293.10 | 350.51 | 28.00 | 72.00 |

*Note: Emission estimates are calculated from fuel-import data using standard fuel-density, net-calorific-value and $CO_2$ emission-factor assumptions. The CRT contains data gaps for some years; the table includes years with petrol and diesel import records.*

The historical pattern suggests that transport emissions in Bhutan are structurally linked to diesel demand. The calculated emissions increased from 170.14 Gg $CO_2$e in 2006 to 384.96 Gg $CO_2$e in 2014. They then reached 534.07 Gg $CO_2$e in 2018 and 529.60 Gg $CO_2$e in 2019 before declining to 370.70 Gg $CO_2$e in 2020. The 2020 decline is consistent with the period of COVID-19 disruption, but it should not be interpreted as a structural decarbonization trend. Petrol demand recovered strongly by 2023, while diesel demand remained below the pre-pandemic level. This combination lowered total calculated road emissions to 350.51 Gg $CO_2$e in 2023, but future demand growth could quickly reverse the decline unless mitigation measures are implemented.

The BTR's energy-sector projection is not disaggregated into transport-specific projections, but it shows that energy-sector emissions are expected to rise from 855.42 Gg $CO_2$e in 2022 to 1,166.19 Gg $CO_2$e by 2030 under the national projection table (DECC, 2024). Since transport accounts for more than 60% of energy-sector emissions, a large share of the future increase in energy-sector emissions may be linked to transport demand unless the surface transport strategy is implemented effectively (DECC, 2024). The updated projection developed in this report uses a 3.5% annual BAU growth rate from the 2023 calculated road-emissions baseline, and then compares this BAU pathway with the same three progressively stronger scenarios (see Table 8 and Figures 13 and 14).

*Table 8. Projected transport emissions under BAU and mitigation scenarios, 2024–2030*

| Year | BAU emissions (Gg $CO_2$e) | Scenario 1: EV and bus electrification | Scenario 2: Public transport, NMT and fuel standards | Scenario 3: Integrated low-carbon mobility transition |
|---|---|---|---|---|
| 2024 | 362.78 | 355.52 | 355.52 | 355.52 |
| 2025 | 375.48 | 359.83 | 353.57 | 347.31 |
| 2026 | 388.62 | 364.00 | 351.05 | 338.10 |
| 2027 | 402.22 | 368.03 | 347.92 | 327.81 |
| 2028 | 416.30 | 371.89 | 344.14 | 316.38 |
| 2029 | 430.87 | 375.57 | 339.67 | 303.76 |
| 2030 | 445.95 | 379.05 | 334.46 | 289.87 |

*Note: BAU is projected from the 2023 calculated road-emissions baseline using 3.5% annual growth. Mitigation scenarios apply progressively stronger reductions relative to BAU by 2030. These are analytical estimates prepared for this report and are not official Government of Bhutan projections.*

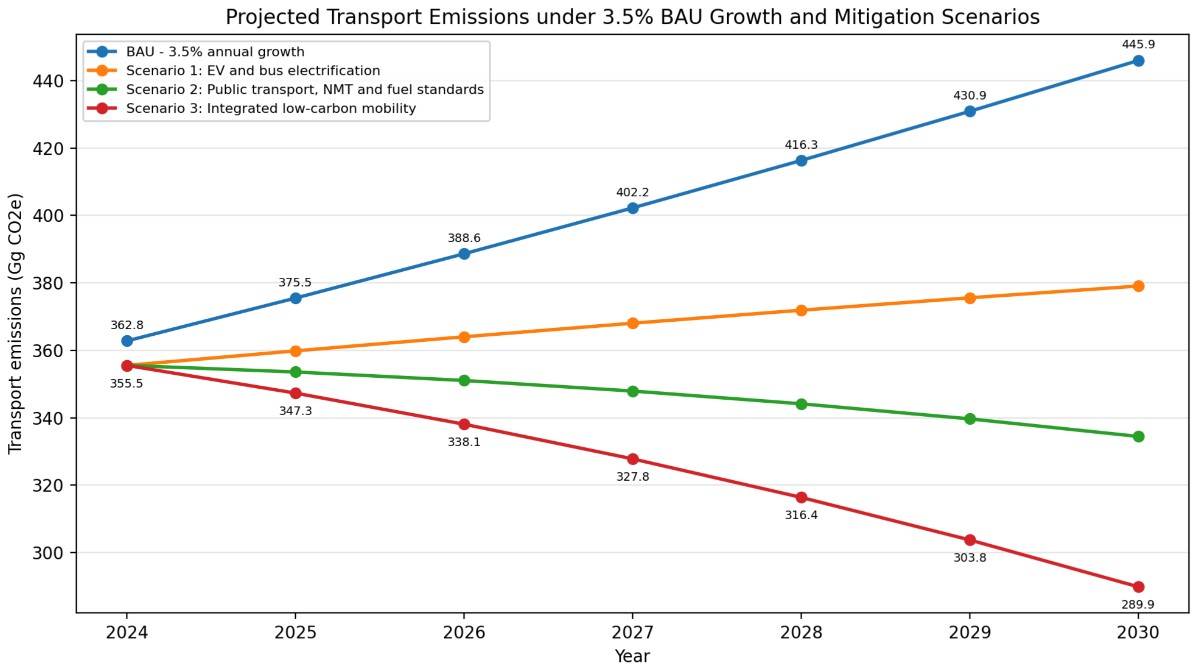


*Figure 13. Projected transport emissions under BAU and mitigation scenarios.*

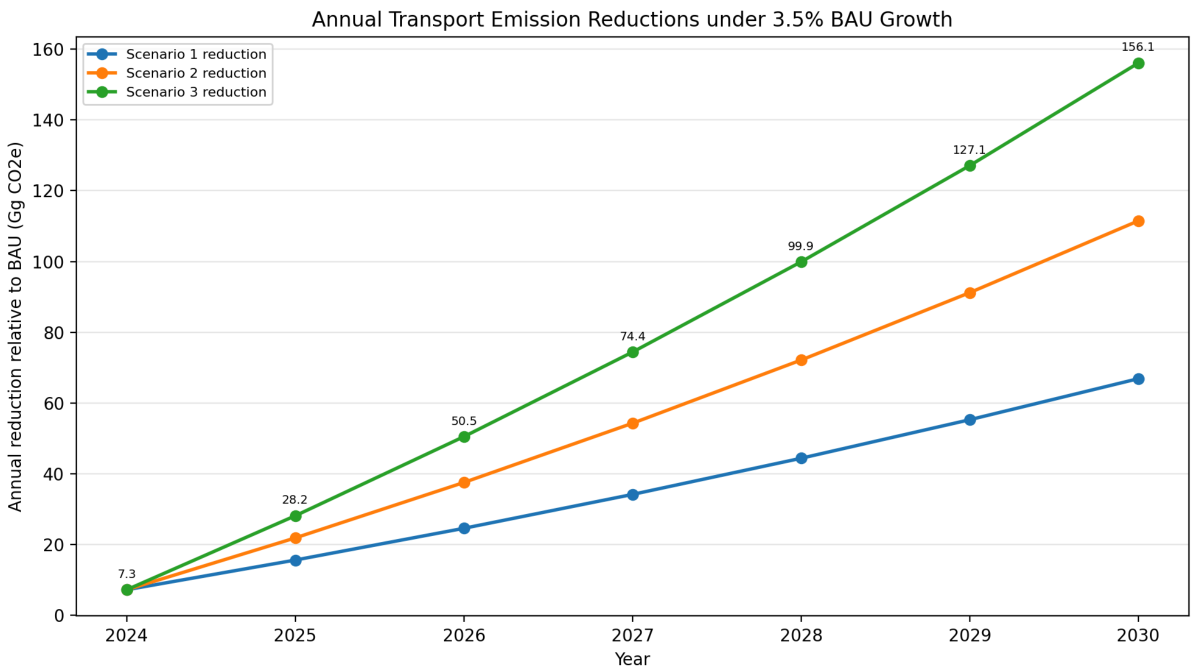


*Figure 14. Annual emission reductions relative to BAU.*

The analysis also covers the official vehicle registration statistics for December 2020, December 2021, December 2022, December 2023, December 2024, December 2025 and March 2026. Vehicle registrations are not the same as transport emissions because emissions depend on vehicle kilometers travelled, fuel type, fuel economy, route conditions, load factors, occupancy and vehicle age. However, registration stock is an important driver of future transport energy demand. It provides a complementary indicator to the fuel-import based emissions analysis and helps explain why electric mobility, public transport, non-motorized transport and demand management are central to Bhutan's low-carbon transport strategy. The registration tables below (see Tables 9, 10, and 11) report the number of motor vehicles by region, ownership class, vehicle type and EV category. For this report, the year-end December values are used for 2020-2025, while March 2026 is treated as the latest available in-year stock point.

*Table 9. Registered vehicles and EVs in Bhutan, 2020 to (March) 2026*

| Year / period | Total registered vehicles as of year end (except for 2026) | Total registered EVs as of year end (except for 2026) | EV share of stock (%) |
|---|---|---|---|
| 2020 | 112,058 | 133 | 0.12 |
| 2021 | 119,636 | 248 | 0.21 |
| 2022 | 125,534 | 471 | 0.38 |
| 2023 | 126,650 | 619 | 0.49 |
| 2024 | 129,303 | 714 | 0.55 |
| 2025 | 124,546 | 1,148 | 0.92 |
| Mar-2026 | 128,237 | 1,252 | 0.98 |

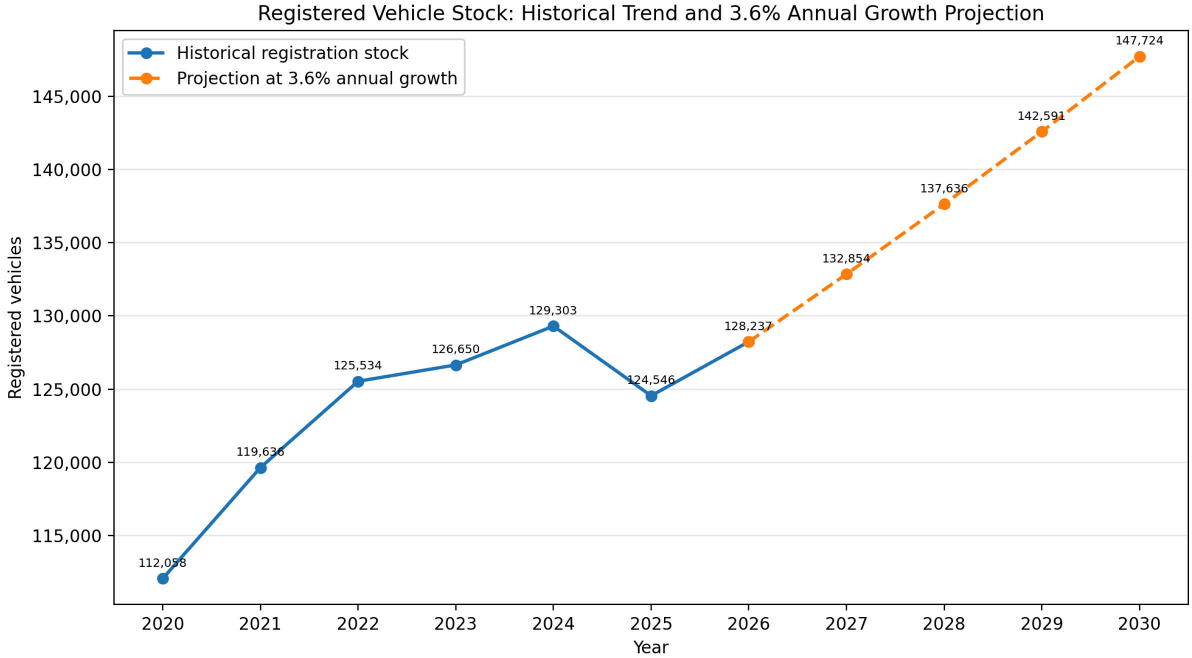


*Figure 15. Registered vehicle stock in Bhutan: historical trend and projection to 2030*

The number of registered motor vehicles increased from 112,058 in December 2020 to 129,303 in December 2024. This indicates a 15.4% increase over four years and a compound annual growth rate of about 3.6% during 2020-2024 (see Figure 15). The December 2025 data reports a lower total of 124,546, while the March 2026 data shows 128,237 total registered vehicles. Because the March 2026 value rebounds toward the 2024 level, the December 2025 decline is treated cautiously and may reflect data updating, fleet deregistration, reporting transition or other administrative adjustments rather than a structural fall in mobility demand. Overall, the stock evidence still points to steady growth in Bhutan's vehicle fleet, reinforcing the need to manage future transport energy demand.

The indicative projection uses the latest March 2026 registered stock of 128,237 vehicles as the baseline and applies a compound annual growth rate of 3.6% per year. Under this assumption, total registered vehicles would reach approximately 147,724 by 2030. This is seen as a significant growth rate relative to the small population and limited road infrastructure of Bhutan.

*Table 10. Indicative projection of registered vehicles and EV stock, 2026-2030*

| Year | Projected registered vehicles | Projected EV stock | Projected EV share (%) |
|---|---|---|---|
| 2026 | 128,237 | 1,252 | 0.98 |
| 2027 | 132,854 | 1,599 | 1.20 |
| 2028 | 137,636 | 2,041 | 1.48 |
| 2029 | 142,591 | 2,606 | 1.83 |
| 2030 | 147,724 | 3,328 | 2.25 |

*Note: Total vehicle stock is projected using the 2020-March 2026 compound annual growth rate; EV stock is projected using the 2022-March 2026 compound annual growth rate because the early 2020 EV base was very small.*

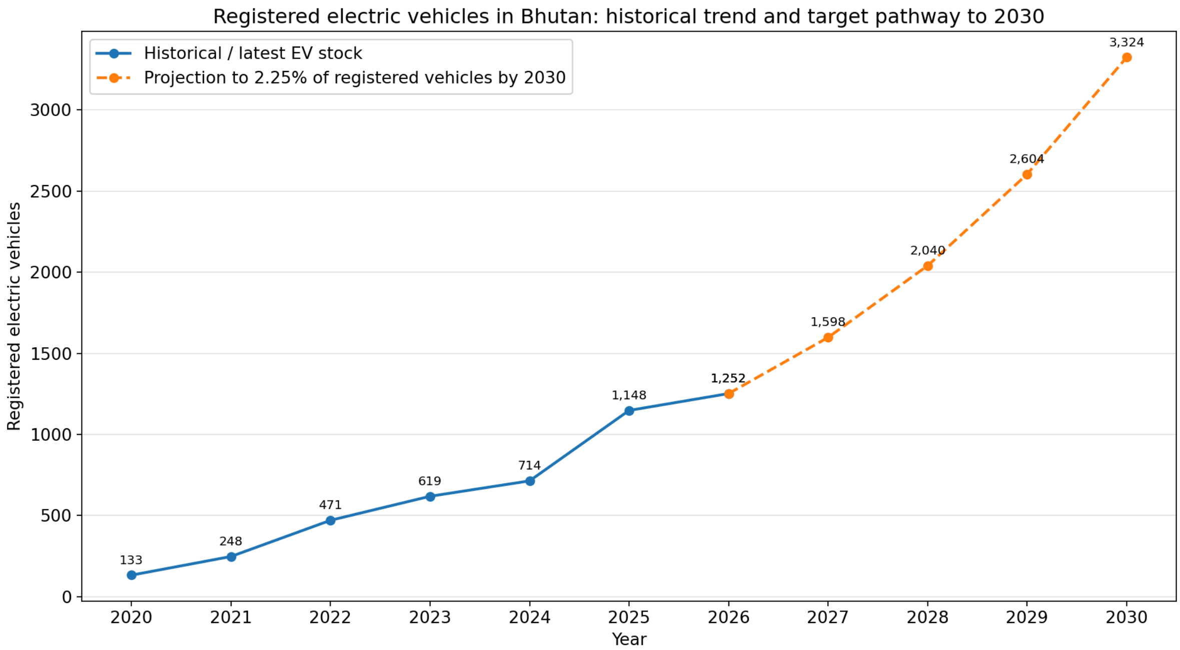


*Figure 16. Registered EVs in Bhutan: historical trend and projection to 2030*

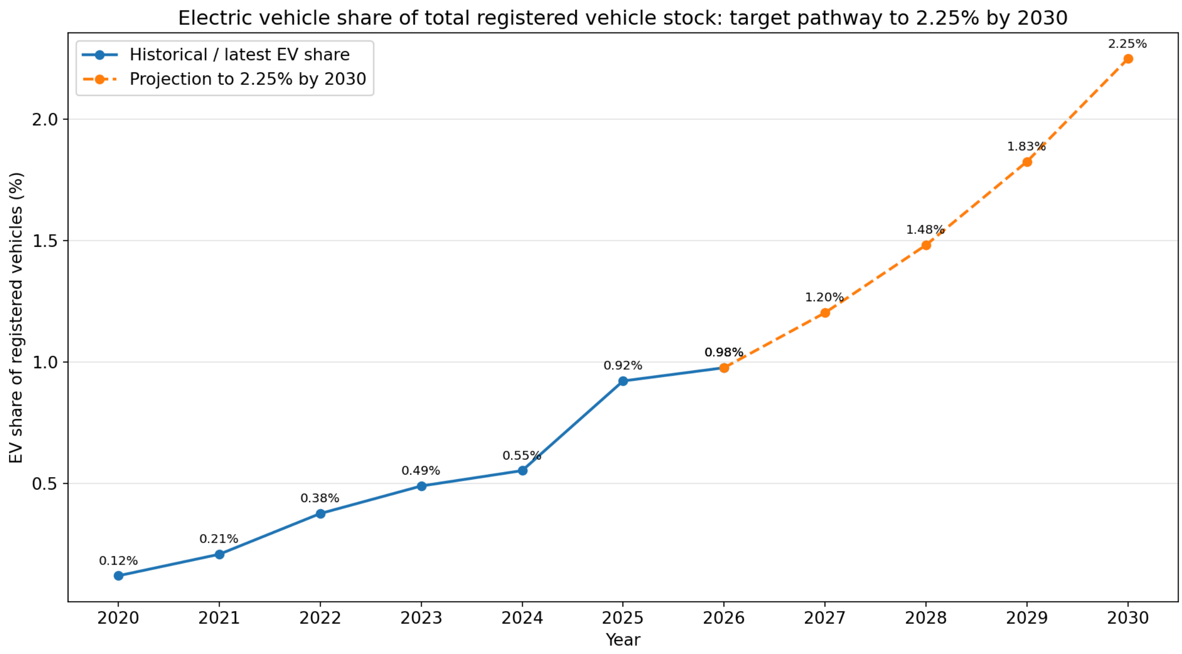


*Figure 17. Electric vehicle share of total registered vehicle stock*

Registered EVs increased from 133 in December 2020 to 714 in December 2024, 1,148 in December 2025 and 1,252 in March 2026. The EVs therefore increased more rapidly than the total vehicle stock, but from a very low base. The EV share rose from 0.12% of registered vehicles in 2020 to 0.55% in 2024, 0.92% in 2025 and 0.98% by March 2026. Under the indicative projection, EV stock could reach about 3,328 by 2030, equal to about 2.25% of the registered vehicle stock (see Figures 16 and 17). This shows that EV adoption is accelerating, but additional policy support would be needed if Bhutan aims for a more transformative EV share by 2030.

*Table 11. Registered vehicle stock by vehicle type, as of March 2026*

| Vehicle type | Registered vehicles | Share of total stock (%) |
|---|---|---|
| Heavy vehicle | 7,307 | 5.70 |
| Heavy bus | 650 | 0.51 |
| Medium vehicle | 1,830 | 1.43 |
| Medium bus | 687 | 0.54 |
| Light vehicle | 91,828 | 71.61 |
| Two-wheeler | 9,415 | 7.34 |
| Power tiller | 4,037 | 3.15 |
| Tractor | 894 | 0.70 |
| Equipment | 4,372 | 3.41 |
| Taxi | 7,217 | 5.63 |

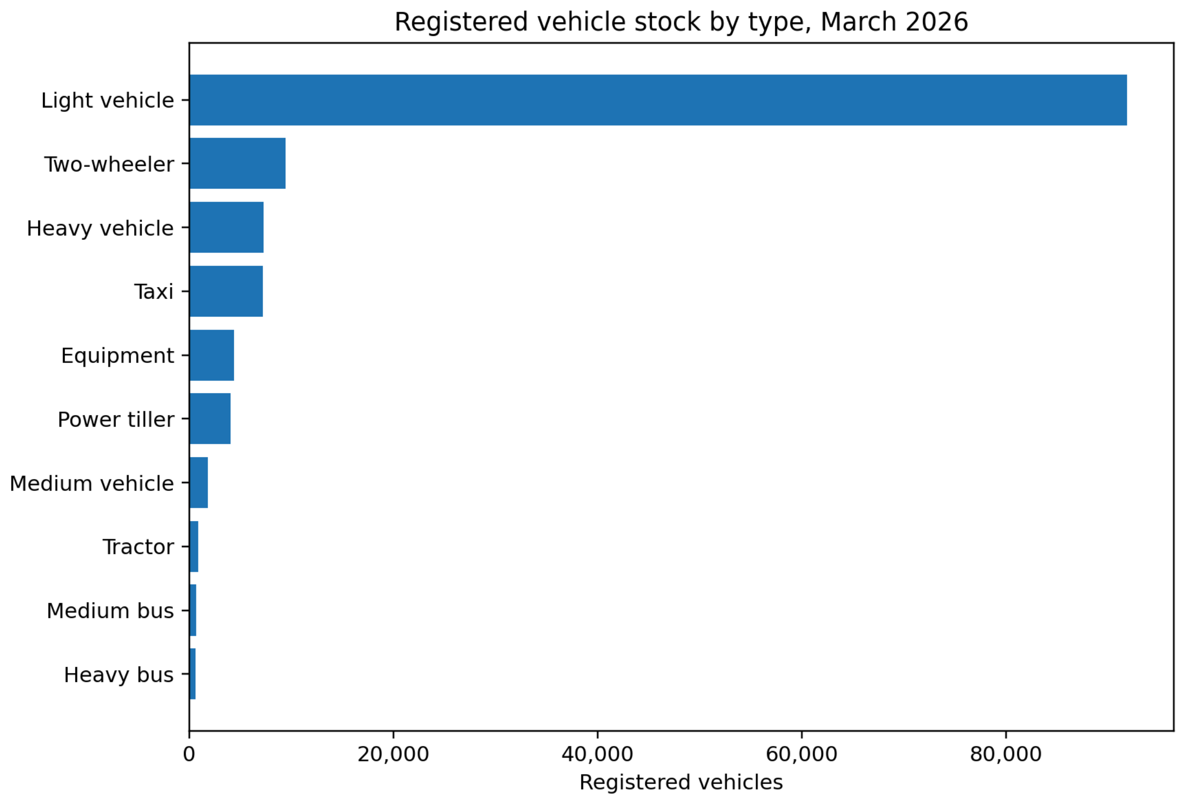


*Figure 18. Registered vehicle stock by type, March 2026*

The March 2026 registration data show that light vehicles dominate the vehicle stock, accounting for 91,828 vehicles or 71.61% of all registered vehicles. Two-wheelers account for 9,415 vehicles or 7.34%, taxis for 7,217 vehicles or 5.63%, heavy vehicles for 7,307 vehicles or 5.7%, and equipment for 4,372 vehicles or 3.41% (see Figure 18). This composition confirms that private and light vehicles are central to the fleet transition, while taxis, buses and other high-utilization fleets remain important early targets for electrification because they can deliver larger emission reductions per vehicle. Heavy vehicles, equipment and tractors also need efficiency, maintenance and future low-carbon fuel strategies because they are harder to electrify quickly.

The registration trend strengthens the rationale for the three transport mitigation scenarios. Scenario 1 should prioritize electric taxis, public buses, government fleets and light vehicles because these are visible and scalable segments. Scenario 2 should add public transport, walking, cycling and efficiency measures because vehicle stock growth can otherwise offset the benefits of electrification. Scenario 3 remains the preferred long-term pathway because the fleet projection shows continued growth to 2030; without avoid-shift-improve measures, the total number of vehicles will keep increasing even if the EV share rises. The vehicle-stock analysis also reinforces the need for a national transport MRV system that links vehicle registration, energy type, fuel use, EV charging, vehicle kilometers travelled and public transport ridership.

## 6.3 Emissions mitigation scenarios

Three mitigation scenarios were developed to illustrate how different levels of transport policy ambition could affect Bhutan's road transport emissions through 2030. These are analytical scenarios based on the attached transport sector data workbook, the historical emissions estimated from fuel-use data, and the mitigation priorities described in the BTR. Each scenario is expressed as a reduction relative to the BAU pathway, with Scenario 1 reaching 15% below BAU by 2030, Scenario 2 reaching 25% below BAU by 2030, and Scenario 3 reaching 35% below BAU by 2030. Tables 12 and 13 summarize the emissions reductions potentials and interventions relevant to each scenario.

*Table 12. Annual emissions reduction relative to BAU, 2024–2030*

| Year | Scenario 1 reduction | Scenario 2 reduction | Scenario 3 reduction |
|---|---|---|---|
| 2024 | 7.26 | 7.26 | 7.26 |
| 2025 | 15.64 | 21.90 | 28.16 |
| 2026 | 24.61 | 37.57 | 50.52 |
| 2027 | 34.19 | 54.30 | 74.41 |
| 2028 | 44.40 | 72.16 | 99.91 |
| 2029 | 55.29 | 91.20 | 127.11 |
| 2030 | 66.89 | 111.49 | 156.08 |

*Table 13. Mitigation scenario strategies and sustainability benefits*

| Scenario | 2030 mitigation level | Core interventions | Sustainability benefits |
|---|---|---|---|
| Scenario 1: EV and bus electrification | 15% below BAU by 2030 | EV purchase incentives; electric public bus procurement; charging infrastructure; electrification of taxis and government fleets; battery standards and maintenance capacity. | Direct fuel substitution from petrol/diesel to renewable electricity; lower urban air pollutants; reduced petroleum imports. |
| Scenario 2: Public transport, NMT and fuel standards | 25% below BAU by 2030 | Bus priority lanes; improved route planning; integrated ticketing; non-motorized transport networks; pedestrianization; vehicle fuel-efficiency and emission standards. | Lower private vehicle kilometers; higher public transport share; improved access and road safety; lower congestion. |
| Scenario 3: Integrated low-carbon mobility transition | 35% below BAU by 2030 | All Scenario 1 and 2 measures plus compact land-use planning, parking management, freight logistics optimization, digital monitoring and fossil-fuel vehicle import rationalization. | System-wide reduction in transport energy demand; faster decarbonization; stronger climate, health, equity and urban sustainability benefits. |

### 6.3.1 Scenario 1: EV and electric bus acceleration

This scenario assumes a moderate but steady acceleration of electric mobility, focused first on high-utilization vehicle segments where the emissions reduction return per vehicle is high. The priority measures include electric public buses, electric taxis, electric government and municipal fleets, electric two-wheelers in urban areas, targeted purchase incentives, concessional finance, reduced import duties for priority vehicle classes, depot and corridor charging infrastructure, and basic battery safety and end-of-life management systems. It is an appropriate near-term pathway for Bhutan because electricity is overwhelmingly supplied by renewable hydropower, allowing direct substitution of petrol and diesel consumption without creating significant domestic power sector emissions. Under the revised 3.5% BAU growth pathway, Scenario 1 reaches 15% below BAU by 2030, reducing projected road transport emissions from 445.95 Gg $CO_2$e under BAU to 379.05 Gg $CO_2$e. Cumulative mitigation over 2024-2030 is estimated at 248.29 Gg $CO_2$e.

### 6.3.2 Scenario 2: Public transport, non-motorized transport and fuel efficiency transition

This scenario assumes that Bhutan combines vehicle electrification with stronger demand-side and efficiency measures. It includes the Scenario 1 electric mobility actions, but adds better public transport service quality, route integration, fare and ticketing improvements, bus priority measures, safer walking routes, pedestrian improvements around schools and town centers, cycling and micromobility pilots, parking management, and stronger fuel-efficiency or import standards for vehicles that remain dependent on internal-combustion engines. The central logic is that transport mitigation should reduce both the carbon intensity of vehicles and the amount of avoidable private vehicle travel. Under the revised 3.5% BAU growth pathway, Scenario 2 reaches 25% below BAU by 2030, reducing projected road transport emissions to 334.46 Gg $CO_2$e and producing cumulative mitigation of 395.87 Gg $CO_2$e over 2024-2030.

### 6.3.3 Scenario 3: Integrated low-carbon mobility transformation

This scenario represents the most ambitious and system-wide transport transition. It combines the electric-mobility measures in Scenario 1 and the public transport, non-motorized transport and efficiency measures in Scenario 2 with compact land use planning, transit oriented development, freight consolidation, logistics optimization, parking and vehicle demand management, urban pedestrianization, digital monitoring of vehicle activity, and stronger institutional coordination across transport, urban planning, energy and climate agencies. It recognizes that electrification alone may not be sufficient if vehicle-kilometers continue to grow rapidly; therefore, the scenario combines technology change with avoid-shift-improve measures. Under the revised 3.5% BAU growth pathway, Scenario 3 reaches 35% below BAU by 2030, reducing projected road transport emissions to 289.87 Gg $CO_2e$ and generating cumulative mitigation of 543.44 Gg $CO_2e$ over 2024-2030.

## 6.4 Strategic recommendations for emissions reduction and environmental sustainability

### 6.4.1 Strategy 1: Prioritize electric public transport and high-utilization fleets

Bhutan should prioritize electric public transport before relying exclusively on private electric cars. Electric buses have high utilization, visible public benefits and strong emissions-reduction potential per vehicle. The proposed procurement of electric buses under the Bhutan Green Transport Project should therefore be linked to bus-priority infrastructure, depot charging, route redesign and reliable operations, rather than treated only as a vehicle-purchase programme (DECC, 2024).

### 6.4.2 Strategy 2: Combine electrification with demand management and compact urban planning

Bhutan should combine electrification with demand management. If the number of vehicles and vehicle kilometers continues to grow, electrification alone may reduce direct emissions but will not solve congestion, parking pressure, road safety and urban livability challenges. Parking management, transit-oriented development, pedestrianization of city centers and safer walking routes can help moderate demand for short private motorized trips. These measures are especially relevant in Thimphu and other urban areas where traffic concentration is increasing.

### 6.4.3 Strategy 3: Strengthen efficiency standards for vehicles that cannot electrify immediately

Fuel-efficiency and import standards should be strengthened for vehicle categories that are difficult to electrify rapidly. Diesel trucks and inter-district freight vehicles dominate emissions and may require a longer transition pathway. In the short term, standards for imported vehicles, inspection and maintenance, driver training, route optimization and freight consolidation can reduce emissions while electric or alternative-fuel freight options mature.

### 6.4.4 Strategy 4: Develop a reliable national charging and battery management network

Charging infrastructure should be planned as a national network rather than a set of isolated urban chargers. Reliable inter-district charging will be essential if electric vehicles are to support tourism, taxis, government fleets and inter-urban mobility. Charging infrastructure should be integrated with hydropower based electricity planning, distribution-grid upgrades, battery safety standards and maintenance training.

### 6.4.5 Strategy 5: Build a higher tier transport emissions data and MRV system

Bhutan should improve transport data systems for a higher tier inventory. The current fuel-import method is appropriate for Tier 1 national reporting, but it does not show which vehicle types, corridors, user groups or trip purposes drive emissions. A digital transport emissions data system should collect annual data on vehicle registrations by fuel and age, vehicle kilometers travelled, public transport ridership, freight volumes, EV charging electricity, route level bus performance and fuel sales by use category. This would improve the evidence base for future BTRs, NDC tracking and investment planning.

### 6.4.6 Strategy 6: Track mitigation co-benefits for sustainability, equity and resilience

Mitigation planning should explicitly track co-benefits. A low-carbon transport transition can reduce air pollution, noise, fuel imports, household transport costs, congestion and road safety risks. It can also improve access for people who cannot drive or cannot afford private vehicles. Monitoring indicators should therefore include not only Gg $CO_2e$ reduced, but also ridership, walking and cycling mode share, average bus speed, EV charging reliability, fuel import savings, local air quality improvements and access for vulnerable groups.

## 6.5 Conclusion

Bhutan's transport sector is a central mitigation priority because it links national connectivity, economic development, fuel-import dependence, urban air quality and the country's long-term carbon-neutrality commitment. The analysis shows that road transport emissions are structurally driven by petrol and diesel use, with diesel remaining the dominant contributor because of freight, buses, heavy vehicles and other high-use vehicle categories. Historical fuel-import data indicate a strong increase in road-transport emissions from 2006 to the pre-pandemic period, followed by a temporary decline during COVID-19 and partial recovery thereafter. This pattern confirms that observed reductions during disruption years should not be interpreted as structural decarbonization; without deliberate policy and investment, growth in vehicle ownership and mobility demand is likely to continue increasing transport-sector emissions.

Registered vehicles increased from about 112,058 in December 2020 to 124,546 in December 2025 and 128,237 by March 2026, while registered EVs increased from 133 in December 2020 to 1,148 in December 2025 and 1,252 by March 2026. The EV projection assumes that EVs reach 2.25% of total registered vehicles by 2030. This indicates that EV adoption is accelerating, but EVs still represent a small share of the total vehicle stock. The fleet remains dominated by light vehicles, taxis, two-wheelers, heavy vehicles and other internal-combustion categories. Therefore, electrification must be accelerated, but it must also be accompanied by public transport reform, non-motorized transport, fleet-efficiency standards, freight-efficiency measures and demand management.

The BAU projection indicates that transport emissions could rise to about 445.95 Gg $CO_2e$ by 2030 if road transport demand grows at 3.5% per year without stronger mitigation. The three mitigation scenarios show that progressively stronger policy packages can materially reduce this trajectory. Scenario 1, focused on EV and bus electrification, reduces 2030 emissions to about 379.05 Gg $CO_2e$. Scenario 2, which adds public transport, non-motorized transport and fuel-efficiency measures, reduces 2030 emissions to about 334.46 Gg $CO_2e$. Scenario 3, the integrated low-carbon mobility transformation pathway, reduces 2030 emissions to about 289.87 Gg $CO_2e$. The scenario results demonstrate that electrification alone is important but insufficient; the most robust pathway combines technology transition with avoid-shift-improve measures across the whole mobility system.

The priority recommendation is to implement an integrated national low-carbon mobility programme. Such a programme should prioritize electric public buses, taxis, government and municipal fleets, and high-utilization vehicles; establish a reliable charging network; strengthen standards for imported vehicles; improve public transport route planning and service quality; expand walking and cycling infrastructure; and develop parking, congestion and land-use measures that reduce avoidable private-vehicle growth. Diesel-dependent freight and heavy-duty vehicles should be addressed through efficiency standards, inspection and maintenance, logistics optimization, driver training and a phased transition toward cleaner technologies as they become technically and commercially feasible.

MRV systems are essential for effective transport mitigation. The current inventory approach, based mainly on fuel-import data, is appropriate for national Tier 1 reporting, but it does not provide enough detail to identify which vehicle categories, corridors, user groups or trip purposes are driving emissions growth. Bhutan should therefore build a higher-tier transport emissions data system that links fuel sales, vehicle registrations by type and energy source, vehicle kilometers travelled, public transport ridership, EV charging data, freight activity, and inspection and maintenance records. This would improve future BTR reporting, support NDC tracking and strengthen the design of bankable climate-finance investments.

A successful low-carbon mobility pathway would reduce Gg $CO_2e$ emissions, lower petroleum imports, improve air quality, reduce congestion, enhance access for people without private vehicles, and support cleaner and more livable urban centers. The evidence from the emissions trend, vehicle-registration data and scenario analysis points to a clear conclusion: Bhutan can significantly bend the transport emissions trajectory by 2030 if electrification, public transport, non-motorized transport, vehicle efficiency standards and integrated urban planning are implemented together as one coherent mobility transformation package.

# 7. Industrial Processes and Product Use sector analysis

## 7.1 Introduction

Bhutan's industrial processes and product use (IPPU) sector is central to the country's climate-policy agenda because it is closely linked to the productive base of the economy while also representing one of the largest sources of reported anthropogenic greenhouse gas emissions. The sector covers non-energy process emissions from mineral products, metal production, and non-energy product use. In Bhutan's case, the most material IPPU sources are cement clinker production, ferroalloy production, and the use of lubricants. The BTR identifies cement production and ferroalloys as the dominant IPPU activities and reports that IPPU accounted for about 673.93 Gg $CO_2$e in 2022, making it the largest emitting inventory sector when land-use removals are excluded (DECC, 2024). This means that low-carbon industrial development is not only a mitigation issue, but also a core question of how Bhutan can continue to diversify its economy while maintaining its constitutional and international commitment to remain carbon-neutral.

The IPPU sector is structurally different from the energy, transport, agriculture, and waste sectors. In the energy sector, emissions are driven mainly by fuel combustion and can often be reduced through electrification, renewable energy, efficiency, or fuel switching. In the IPPU sector, emissions can arise directly from chemical and physical transformation processes. In cement production, the calcination of limestone during clinker production releases $CO_2$ as a process emission. Even when a cement plant uses clean electricity, process $CO_2$ is still emitted unless clinker production is reduced, alternative materials are used, or carbon capture and utilization/storage is introduced. In ferroalloy production, emissions arise from the use of fossil-based reductants, such as non-coking coal, semi-coke and coal, which reduce silica in quartz or quartzite and metal-containing ores to produce ferroalloys such as ferrosilicon and ferromanganese. The BTR notes that Bhutan's metal industry is one of the fastest growing industrial activities, and that the use of imported reductants creates both a mitigation priority and a data quality challenge (DECC, 2024).

The CRT emission trend data provides the historical basis for the analysis in this report. It shows that total IPPU emissions increased from 612.84 Gg $CO_2$e in 2019 to 693.82 Gg $CO_2$e in 2020 and 698.35 Gg $CO_2$e in 2021, before declining to 673.93 Gg $CO_2$e in 2022. This aggregate movement masks a major structural shift inside the sector. Emissions from the mineral industry, effectively cement-related process emissions, fell from 490.05 Gg $CO_2$e in 2019 and 2020 to 335.54 Gg $CO_2$e in 2022. Over the same period, emissions from the metal industry rose sharply from 121.68 Gg $CO_2$e in 2019 to 337.53 Gg $CO_2$e in 2022. Lubricant-use emissions remained very small, declining from 1.11 Gg $CO_2$e in 2019 to 0.86 Gg $CO_2$e in 2022. The trend therefore shows an IPPU sector whose total emissions were relatively stable between 2020 and 2022, but whose internal emissions profile shifted from cement dominance to a near-even balance between cement and ferroalloys.

This changing sector profile has important policy implications. In 2019, approximately four-fifths of IPPU emissions in the CRT data came from mineral industry emissions, while metal industry emissions accounted for less than one-fifth. By 2022, cement and ferroalloys contributed almost equal shares of total IPPU emissions. The BTR confirms this profile by reporting 335.54 Gg $CO_2e$ from clinker production, 337.5 Gg $CO_2e$ from ferroalloy production, and 0.86 Gg $CO_2e$ from lubricant use in 2022 (DECC, 2024). Therefore, a mitigation strategy that focuses only on cement would be incomplete. Conversely, a strategy that focuses only on ferroalloys would miss the persistent and hard-to-abate process emissions from clinker production. An effective IPPU mitigation pathway must combine clinker substitution, cement blending, process efficiency, alternative low-carbon binders, reductant substitution, improved material and energy efficiency in ferroalloy production, and stronger industrial MRV.

Inventory methodology and data quality are also central to interpreting the IPPU trend. The BTR states that Bhutan's national inventory follows the 2006 IPCC Guidelines and that the IPPU activity data were obtained from annual trade statistics and the national industrial license database, while efforts were made to obtain plant-specific data (DECC, 2024; IPCC, 2006). For cement, the BTR explains that clinker-production data were used rather than cement-production data, making the estimate more accurate than earlier submissions because clinker production is the direct driver of process $CO_2$ emissions. For ferroalloys, however, the BTR notes discrepancies in plant-specific activity data and reliance on national-level data, including trade statistics on imported reductants. This means that the apparent growth of the metal-industry emissions category is policy-relevant but should be interpreted with continued attention to activity-data improvement, cross-checking of imported reductants, and plant-level reporting.

The climate significance of the IPPU sector is amplified by Bhutan's wider carbon-neutral development pathway. The BTR states that Bhutan's NDC is an economy-wide, multi-year target for 2020-2030 based on net GHG emissions and removals and that Bhutan remains on track to maintain carbon-neutrality due to the large sink capacity of forests and land-use systems (DECC, 2024). This national carbon-neutral status should not be interpreted as a reason to delay industrial mitigation. Rather, it creates a strong policy rationale for reducing gross emissions in sectors where growth could otherwise narrow the margin between national emissions and national removals. The industrial sector is particularly important because cement, minerals, metals and manufacturing can expand with infrastructure development, urbanization, export growth, and public investment. Without targeted action, IPPU emissions could rise even while Bhutan remains net carbon-neutral in aggregate.

Bhutan's IPPU sector requires an integrated industrial decarbonization strategy. In this analysis, Scenario 1 represents incremental industrial efficiency and clinker optimization. Scenario 2 assumes accelerated low-carbon cement and ferroalloy transformation, including greater clinker substitution and reductant change. Scenario 3 reflects full LEDS implementation for industries, including deeper process transformation, energy-efficiency measures, waste heat recovery, refuse-derived fuels where environmentally appropriate, electric boilers, direct hot charging, efficient motor systems, and stronger plant-level MRV. The strategic objective is not only to reduce $CO_2$ emissions but also to support resource efficiency, cleaner production, reduced local pollution, improved competitiveness, and stronger industrial governance.

## 7.2 Analysis of IPPU emissions: historical trends and projections

The CRT data show that Bhutan's IPPU emissions were 612.84 Gg $CO_2$e in 2019, increased to 693.82 Gg $CO_2$e in 2020, reached 698.35 Gg $CO_2$e in 2021, and declined modestly to 673.93 Gg $CO_2$e in 2022. Over the full 2019-2022 period, total IPPU emissions increased by 61.09 Gg $CO_2$e, or about 10%. The sector therefore shows a rising medium-term trend despite the decline between 2021 and 2022. In national terms, the sector is significant because the BTR identifies IPPU as the largest emitting anthropogenic sector in 2022 when removals are excluded and reports that the sector is dominated by cement, ferroalloy production and lubricant use (DECC, 2024).

The most important analytical finding is that total IPPU emissions are no longer driven by cement alone. Mineral industry emissions declined by 154.51 Gg $CO_2$e from 2019 to 2022, while metal industry emissions increased by 215.85 Gg $CO_2$e over the same period. The mineral industry decline reflects lower reported clinker-related process emissions in the CRT series, while the metal industry increase reflects the rapid expansion of ferroalloys and the accounting of fossil-based reductants. Lubricant-use emissions are immaterial in aggregate terms but remain part of the inventory boundary because non-energy products from fuels and solvent use are included under IPPU (DECC, 2024).

The BTR provides an official sectoral projection pathway to 2030. It states that the emission projection was developed through linear trend analysis of Energy, IPPU, Agriculture, Waste and FOLU, using historical emissions from earlier reporting and the latest inventory data (DECC, 2024). For IPPU, the BTR projection increases from 1,053.77 Gg $CO_2$e in 2023 to about 1,303.78 Gg $CO_2$e in 2030. Because this projection is higher than the recent CRT historical values, it should be treated as a policy baseline that reflects broader long-term industrial growth expectations rather than a direct short-term extrapolation of 2019-2022 emissions alone. The projection is nevertheless useful for mitigation planning because it highlights the risk that industrial process emissions could increase substantially if industrial output expands under business-as-usual conditions.

*Source note for figures: Historical values in the following tables and graphs are extracted from the attached Bhutan CRT emission-trend table (see Table 14). BAU projection values are drawn from the BTR's Table 34. Scenario estimates are analytical calculations prepared for this report using the BTR BAU projection and mitigation potential as anchors.*

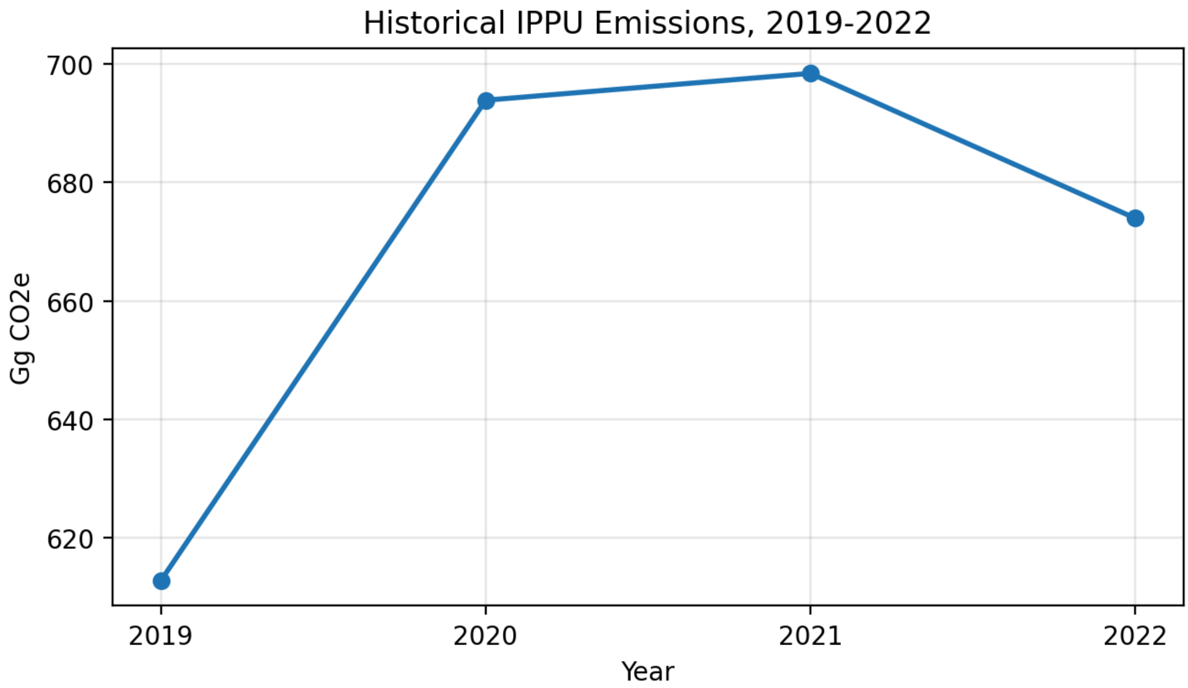


*Figure 19. Historical IPPU-sector emissions, 2019-2022.*

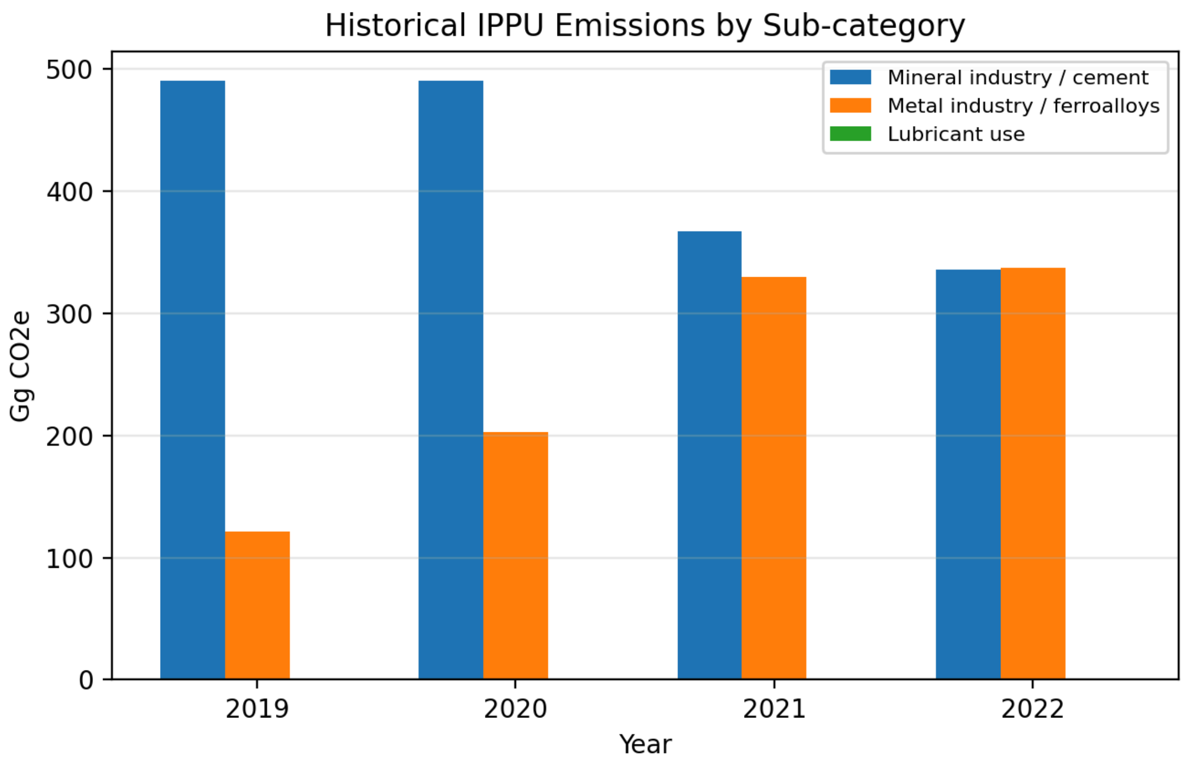


*Figure 20. Historical IPPU emissions by sub-category, 2019-2022.*

*Table 14. Historical IPPU emissions by sub-category, 2019-2022*

| Year | IPPU total (Gg $CO_2e$) | Mineral industry / cement (Gg $CO_2e$) | Metal industry / ferroalloys (Gg $CO_2e$) | Non-energy products / lubricant |
|---|---|---|---|---|

| | | | | use (Gg $CO_2e$) |
|---|---|---|---|---|
| 2019 | 612.84 | 490.05 | 121.68 | 1.11 |
| 2020 | 693.82 | 490.05 | 202.66 | 1.11 |
| 2021 | 698.35 | 367.50 | 329.90 | 0.96 |
| 2022 | 673.93 | 335.54 | 337.53 | 0.86 |

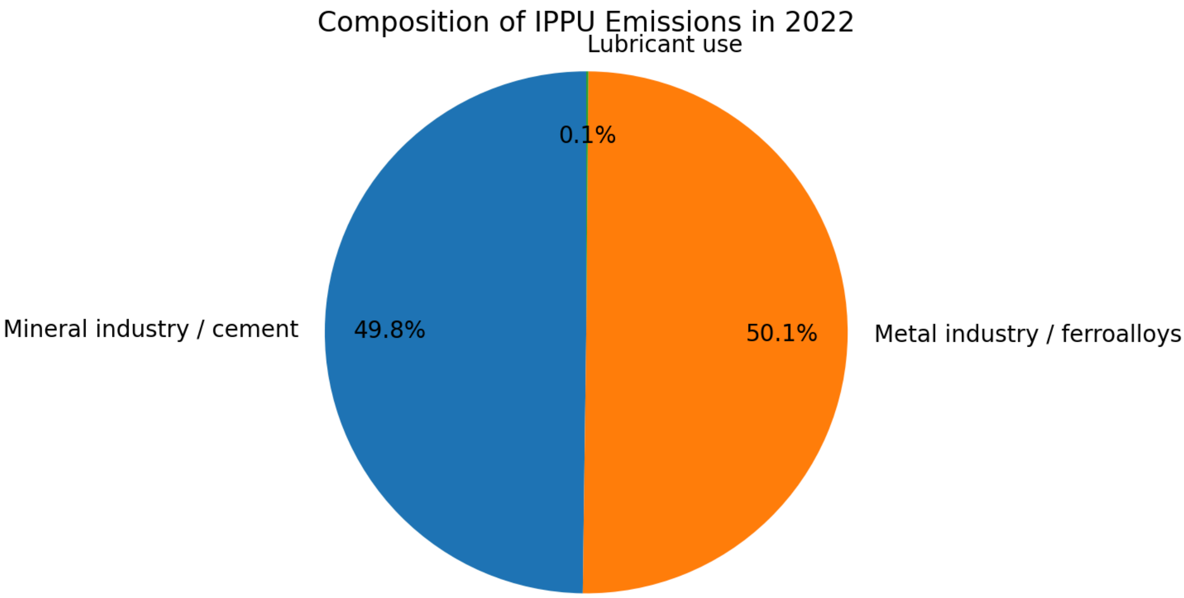


*Figure 21. Composition of IPPU emissions in 2022.*

### 7.2.1 Interpretation of historical trends

The historical trend shows both structural concentration and sectoral transition. Mineral industry emissions accounted for 79.96% of total IPPU emissions in 2019 but only 49.79% in 2022. The decline does not mean that cement is no longer important: it remains a large and hard-to-abate source because clinker production creates process $CO_2$. However, the trend indicates that cement mitigation alone will not be enough to manage total IPPU emissions.

Metal industry emissions increased from 121.68 Gg $CO_2e$ in 2019 to 337.53 Gg $CO_2e$ in 2022, rising from 19.85% to 50.08% of total IPPU emissions. This is consistent with the BTR's statement that ferroalloys are one of the fastest-growing industrial sources in Bhutan. It also indicates a need for better tracking of reductant imports, plant-level material balances, and low-carbon production options. The BTR notes that national-level data were used where plant-level data were not reliable, reinforcing the importance of MRV improvements for future inventories (DECC, 2024).

Lubricant-use emissions are very small and declined from 1.11 Gg $CO_2e$ in 2019 to 0.86 Gg $CO_2e$ in 2022. The BTR notes, however, that lubricant import data may underestimate actual use because the recorded quantities reflect imported lubricants through import licenses while open borders exist between India and Bhutan (DECC, 2024). Although lubricant use is not a major mitigation priority, improving its data coverage would strengthen completeness and transparency.

### 7.2.2 BAU projection

For the minimum five-year projection requested in this assignment, the BTR BAU pathway provides an eight-year projection from 2023 to 2030. Under this pathway, IPPU emissions rise from 1,053.77 Gg $CO_2$e in 2023 to 1,196.63 Gg $CO_2$e in 2027, and then to approximately 1,303.78 Gg $CO_2$e by 2030 (see Figure 22 and Table 15). This implies an increase of about 250.01 Gg $CO_2$e between 2023 and 2030, or 23.7 % over the period. The pathway indicates that if Bhutan's industrial sector expands without deeper mitigation, IPPU emissions could become an increasingly important pressure on national carbon-neutrality.

The projection should be read alongside the BTR's mitigation-potential estimate. The BTR estimates that implementing LEDS for industries could reduce IPPU emissions cumulatively by 7,140 Gg $CO_2$e from 2021 to 2030, compared with a projected BAU emissions total of 11,395.70 Gg $CO_2$e for IPPU over the same period (DECC, 2024). This suggests that IPPU offers one of Bhutan's largest single-sector mitigation opportunities.

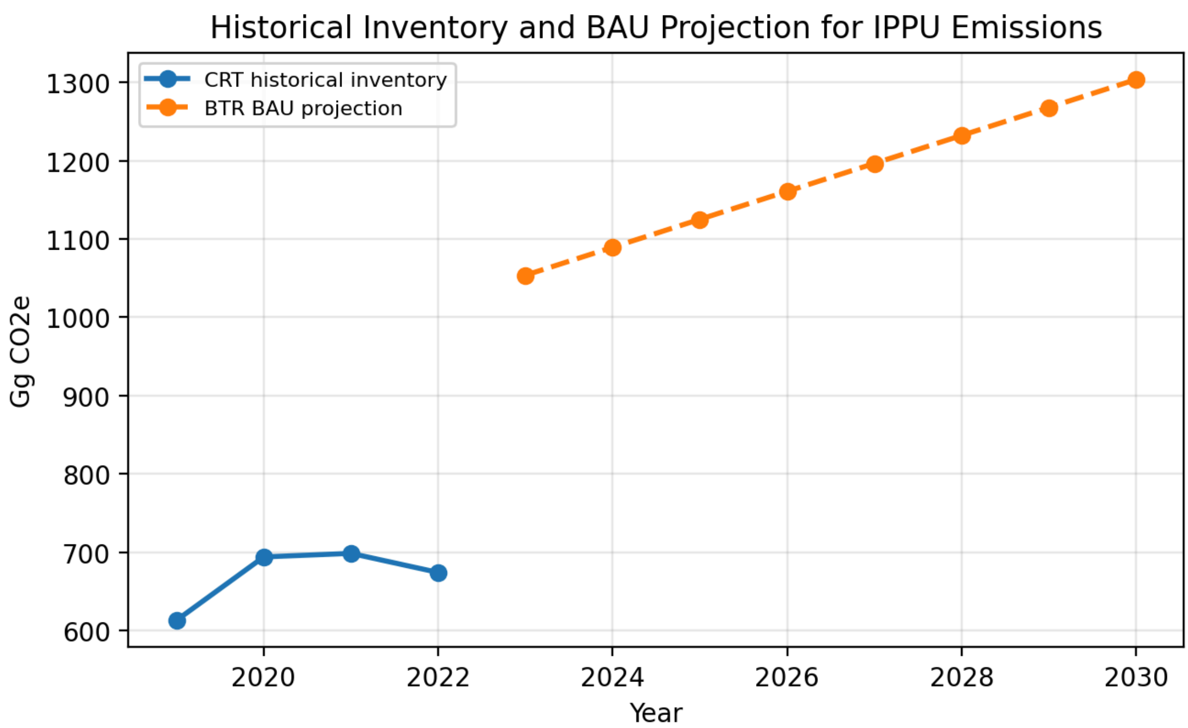


*Figure 22. Historical inventory and BAU projection for IPPU-sector emissions.*

*Table 15. BAU IPPU-emission projection, 2023-2030*

| Year | BAU IPPU projection (Gg $CO_2$e) |
|---|---|
| 2023 | 1,053.77 |
| 2024 | 1,089.48 |

| | |
|---|---|
| 2025 | 1,125.20 |
| 2026 | 1,160.92 |
| 2027 | 1,196.63 |
| 2028 | 1,232.35 |
| 2029 | 1,268.07 |
| 2030 | 1,303.78 |

### 7.3 Emissions mitigation scenarios and sustainability strategies

Three mitigation scenarios were developed to show how different levels of implementation ambition could affect IPPU emissions. Each scenario is compared with the BTR BAU projection.

The scenarios shown in Figure 23 and 24, and Tables 16 and 17, are anchored in the mitigation options listed in the BTR for industries. The BTR identifies process-related measures such as reducing fossil-origin reductants with renewable charcoal and cement blending, and energy-efficiency measures such as waste heat recovery, refuse-derived fuels in cement plants, energy efficiency in production processes, direct hot charging for integrated production, efficient electric motor systems, and conversion of diesel boilers to electric boilers (DECC, 2024). These measures provide the basis for the scenario narratives and the strategic recommendations below.

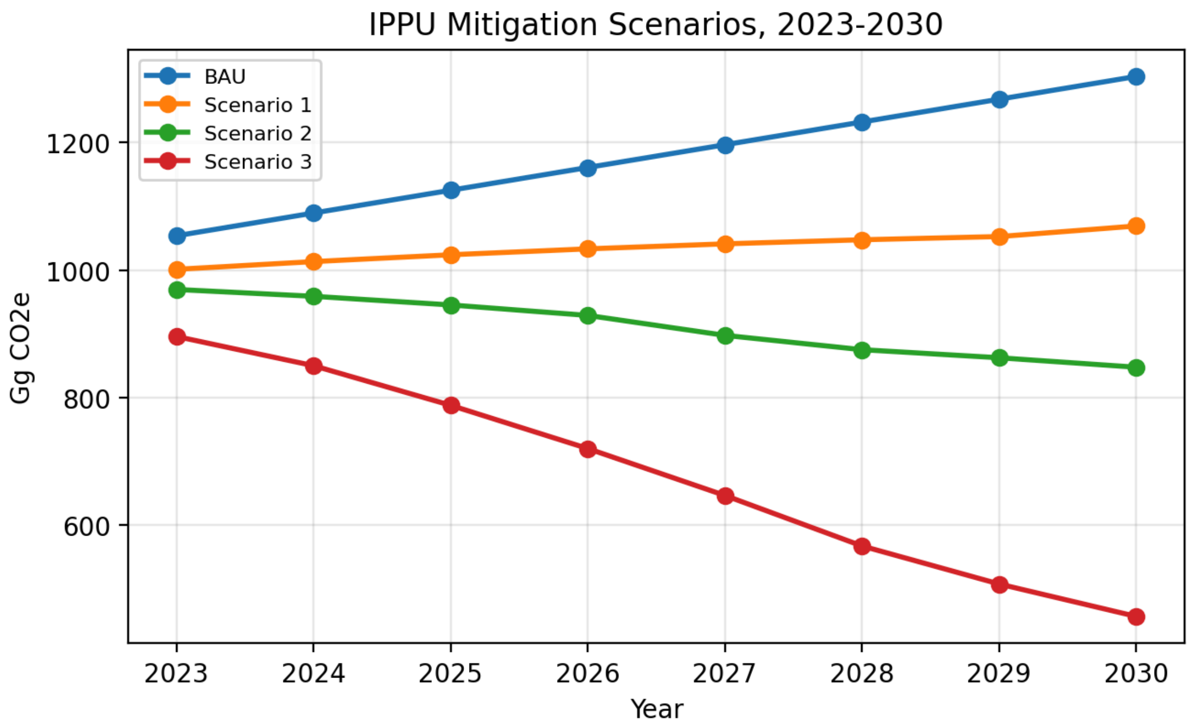


*Figure 23. IPPU-emission mitigation scenarios, 2023-2030.*

*Table 16. Scenario emission reduction pathways, 2023-2030*

| Year | BAU ($Gg\ CO_2e$) | Scenario 1 ($Gg\ CO_2e$) | Scenario 2 ($Gg\ CO_2e$) | Scenario 3 ($Gg\ CO_2e$) |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| 2023 | 1,053.77 | 1,001.08 | 969.47 | 895.70 |
| 2024 | 1,089.48 | 1,013.22 | 958.74 | 849.79 |
| 2025 | 1,125.20 | 1,023.93 | 945.17 | 787.64 |
| 2026 | 1,160.92 | 1,033.22 | 928.74 | 719.77 |
| 2027 | 1,196.63 | 1,041.07 | 897.47 | 646.18 |
| 2028 | 1,232.35 | 1,047.50 | 874.97 | 566.88 |
| 2029 | 1,268.07 | 1,052.50 | 862.29 | 507.23 |
| 2030 | 1,303.78 | 1,069.10 | 847.46 | 456.32 |

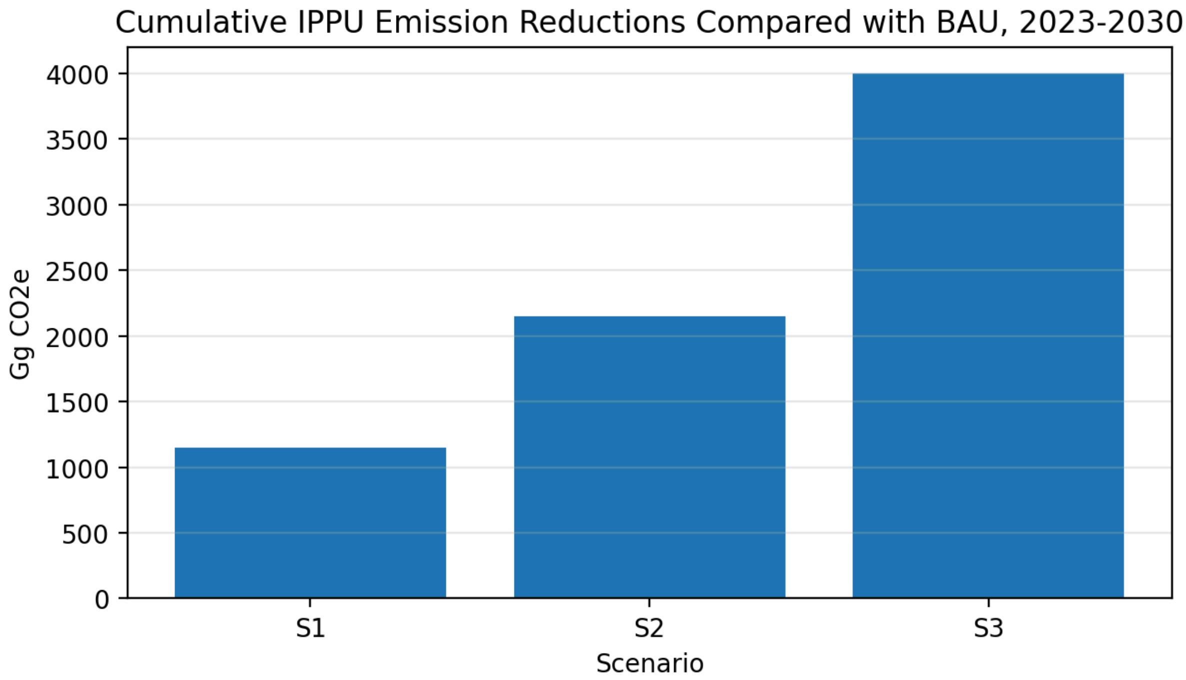


*Figure 24. Cumulative emission reductions compared with BAU, 2023-2030.*

*Table 17. Scenario summary and cumulative mitigation impact*

| Scenario | Cumulative 2023-2030 emissions (Gg $CO_2$e) | Cumulative reduction vs BAU (Gg $CO_2$e) | 2030 emissions (Gg $CO_2$e) | 2030 reduction vs BAU (%) |
|---|---|---|---|---|
| Scenario 1: Industrial efficiency and clinker optimization | 8,281.62 | 1,148.58 | 1,069.10 | 18.00 |
| Scenario 2: Low-carbon cement and ferroalloy transformation | 7,284.31 | 2,145.89 | 847.46 | 35.00 |
| Scenario 3: Full LEDS industries transformation | 5,429.51 | 4,000.69 | 456.32 | 65.00 |

### 7.3.1 Scenario 1: Industrial efficiency and clinker optimization

Scenario 1 represents a moderate mitigation pathway based on incremental improvements in existing industrial systems. It assumes that Bhutan strengthens industrial energy-efficiency practices, improves process control, expands energy audits, and begins to reduce clinker intensity through cement blending. The scenario also assumes early-stage improvements in ferroalloy material efficiency and better tracking of reductant use, but does not assume full-scale transformation of production technologies. Relative to BAU, the scenario reduces emissions by 5 % in 2023, rising gradually to 18 % by 2030.

Under Scenario 1, 2030 IPPU emissions are estimated at 1,069.10 Gg $CO_2$e, compared with the BAU value of 1,303.78 Gg $CO_2$e. Cumulative reductions from 2023 to 2030 are estimated at 1,148.59 Gg $CO_2$e. This pathway would slow emissions growth but would not fundamentally change the emissions trajectory. It is therefore best understood as a minimum policy package that buys time, improves data, and prepares industries for more transformative measures.

### 7.3.2 Scenario 2: Low-carbon cement and ferroalloy transformation

Scenario 2 represents an accelerated industrial decarbonization pathway. It assumes stronger cement-sector measures, including a sustained reduction in clinker-to-cement ratios, wider use of blended cements where technically appropriate, improved kiln performance, waste heat recovery, and substitution of suitable alternative fuels or refuse-derived fuels under strict environmental controls. It also assumes more substantial ferroalloy measures, including partial substitution of fossil-origin reductants with sustainably sourced renewable charcoal, improved furnace efficiency, direct hot charging where feasible, and stronger material-yield optimization. Relative to BAU, the scenario reduces emissions by 8% in 2023, increasing to 35% by 2030.

Under Scenario 2, 2030 IPPU emissions are estimated at 847.46 Gg $CO_2$e. Cumulative reductions from 2023 to 2030 are estimated at 2,145.90 Gg $CO_2$e. This pathway would bend the emissions trajectory downward compared with BAU while maintaining industrial production. It would require coordinated action among industry, energy institutions, environmental regulators, trade-data authorities, and finance providers. The scenario also requires safeguards to ensure that renewable charcoal does not create land-use, biodiversity or community impacts.

### 7.3.3 Scenario 3: Full LEDS Industries Transformation

Scenario 3 is the high-ambition pathway and is designed to reflect full implementation of the BTR's LEDS strategy direction for industries. It assumes integrated industrial transformation across cement, ferroalloys and industrial energy systems. In cement, the pathway combines clinker substitution, alternative binders, efficiency, waste heat recovery, low-carbon fuels, and progressive preparation for advanced technologies such as carbon capture where future feasibility is established. In ferroalloys, it assumes deep reductant substitution, stronger plant-level material balances, improved furnace operation, and systematic deployment of low-carbon process improvements. It also assumes comprehensive industrial MRV, digital reporting, and investment planning. Relative to BAU, the scenario reduces emissions by 15% in 2023 and 65% by 2030.

Under Scenario 3, 2030 IPPU emissions are estimated at 456.32 Gg $CO_2$e, with cumulative reductions of 4,000.68 Gg $CO_2$e from 2023 to 2030. This is the only scenario that moves the sector toward a transformative low-carbon industrial pathway. It is broadly consistent with the scale of ambition implied by the BTR's statement that full implementation of industrial LEDS strategies could yield 7,140 Gg $CO_2$e in cumulative mitigation from 2021 to 2030 (DECC, 2024). Achieving this scenario would require finance, technology cooperation, private sector participation, clear regulatory signals, and rigorous sustainability safeguards.

## 7.4 Strategies for emissions reductions and environmental sustainability

### 7.4.1 Strategy 1: Establish a plant-level IPPU MRV and material-balance system

Bhutan should prioritize a plant-level IPPU MRV system that records clinker production, cement composition, limestone use, reductant imports and consumption, ferroalloy production, lubricant imports, and process parameters. The BTR notes discrepancies in reductant data and limitations in plant-specific activity data, especially for ferroalloys. A strengthened MRV system would improve inventory accuracy, support emissions benchmarking, and enable industries to document mitigation actions credibly (DECC, 2024).

### 7.4.2 Strategy 2: Reduce clinker intensity in cement production

Cement mitigation should focus first on reducing the clinker-to-cement ratio through blended cement, supplementary cementitious materials, improved quality standards, and demand-side acceptance of low-clinker cement. Because clinker calcination is the direct source of process $CO_2$, reducing clinker intensity is among the most immediate and cost-effective mitigation options for mineral-industry emissions.

### 7.4.3 Strategy 3: Improve cement plant energy efficiency and recover waste heat

Even though the IPPU category focuses on process emissions, cement plants also have major energy-efficiency opportunities that reduce fuel and electricity demand. Waste heat recovery, efficient grinding, optimized kiln operation, improved insulation, and preventive maintenance can reduce both direct and indirect environmental impacts. These actions are consistent with the BTR's industrial mitigation measures, including waste heat recovery and efficiency in production processes (DECC, 2024).

### 7.4.4 Strategy 4: Transform ferroalloy reductant use with sustainability safeguards

The rapid rise of metal-industry emissions makes ferroalloy production a priority. Bhutan should assess the technical and sustainability feasibility of replacing a share of fossil-origin reductants with renewable charcoal or other lower-carbon alternatives. Any biomass-based reductant strategy must include strict safeguards to prevent forest degradation, land-use conflicts, biodiversity impacts, and unsustainable harvesting.

### 7.4.5 Strategy 5: Increase resource efficiency and circular material use

Industrial sustainability should include circular-economy measures such as recovery and reuse of by-products, improved material yields, reduction of off-spec production, and industrial symbiosis between cement, construction and metal industries. These measures can reduce both emissions and waste while improving competitiveness.

### 7.4.6 Strategy 6: Mobilize finance for low-carbon industrial technology

Scenario 2 and Scenario 3 require capital investment in plant upgrades, process control, waste heat recovery, alternative materials, testing laboratories, and low-carbon reductant supply chains. Bhutan can combine domestic policy incentives with climate finance, concessional loans, green credit lines, and targeted technical assistance to support private industries in implementing low-carbon technologies.

### 7.4.7 Strategy 7: Align industrial mitigation with environmental regulation and green procurement

Industrial mitigation should be reinforced by environmental permitting, product standards, green public procurement, and emissions reporting requirements. Public infrastructure projects can create demand for low-clinker and lower-carbon cement, while industrial licensing and environmental clearances can encourage best available practices.

## 7.5 Conclusion

Bhutan's IPPU sector is both an economic opportunity and a climate-management priority. The attached CRT data shows that IPPU emissions increased by about 10% from 2019 to 2022, with a major internal shift from cement dominance toward a near-equal contribution from cement and ferroalloy production. The BTR confirms that cement clinker production and ferroalloy production are the dominant IPPU sources, reporting 335.54 Gg $CO_2e$ from clinker production and 337.5 Gg $CO_2e$ from ferroalloys in 2022 (DECC, 2024).

The BTR's BAU projection indicates that IPPU emissions could increase to around 1,303.78 Gg $CO_2e$ by 2030 if industrial growth continues without deeper mitigation. The scenario analysis shows that incremental efficiency and clinker optimization could reduce cumulative emissions by about 1,148.59 Gg $CO_2e$ from 2023 to 2030; accelerated low-carbon cement and ferroalloy transformation could reduce emissions by about 2,145.90 Gg $CO_2e$; and full industrial LEDS implementation could reduce emissions by about 4,000.68 Gg $CO_2e$ during the same period.

The priority package for Bhutan is clear: strengthen plant-level MRV, reduce clinker intensity, improve cement and ferroalloy efficiency, transform reductant use with safeguards, mobilize low-carbon industrial finance, and align industrial policy with green procurement and environmental regulation. These actions would support Bhutan's carbon-neutral development pathway while improving industrial competitiveness, resource efficiency and environmental sustainability.

# 8. Agriculture sector analysis

## 8.1 Introduction

Agriculture is the foundation of food security, rural livelihoods, landscape management and cultural continuity in Bhutan. In this analysis, the agriculture sector has been narrowed to focus on non-livestock crop and soil emissions because the livestock sector is analyzed separately in Section 10. The agriculture section therefore focuses on rice cultivation, agricultural soils, urea application, nutrient management, soil health, perennial crops and agroforestry. Livestock-specific sources, assumptions, projections and mitigation measures are excluded from this agriculture section and retained only in the separate livestock analysis in section 10.

The BTR identifies agriculture and livestock as part of Bhutan's Renewable Natural Resource sector and frames food-system emissions as survival emissions because they arise from activities that sustain rural households and national food security. This framing remains relevant for crop-based agriculture. Mitigation measures must therefore be designed so that they do not undermine food production, farmer income, nutritional security or climate resilience. For Bhutan, a successful low-emission agriculture pathway should reduce methane and nitrous oxide emissions while supporting water efficiency, soil fertility, resilient crop production, biodiversity, and adaptation to climate variability (DECC, 2024).

The main greenhouse gases associated with the revised agriculture scope are methane from rice cultivation, nitrous oxide from agricultural soils and nitrogen inputs, and carbon dioxide from urea application. Methane from flooded paddy fields depends on water regime, organic matter, soil condition, residue management and cultivation practices. Nitrous oxide depends on the quantity, timing and efficiency of nitrogen inputs, including synthetic fertilizer, organic manure and crop residues. Carbon dioxide from urea application is relatively small but should be retained for completeness. The analysis follows the BTR's use of IPCC inventory approaches, while recognizing that the current report is a decision-support analysis rather than an official recalculation of the national inventory (DECC, 2024; IPCC, 2006).

The analysis uses the CRT data for 2019-2022 to examine rice cultivation, agricultural soils and urea application. For forward-looking analysis, the section uses an agriculture baseline anchored in the BTR's reported agriculture estimate of 45.18 Gg $CO_2$e in 2022. A conservative 0.5% annual BAU growth assumption is then applied to develop a 2023-2030 planning projection. Three mitigation scenarios are developed around rice-water management, nutrient efficiency and integrated climate-smart crop systems.

The mitigation strategies proposed in this section combine climate and environmental sustainability objectives. Improved rice-water management can reduce methane while improving water productivity. Better nutrient management can reduce nitrous oxide and protect water quality. Organic and biofertilizer systems, when properly managed, can improve soil organic matter and nutrient cycling. Perennial crops, agroforestry and climate-smart restoration can strengthen resilience and increase biomass in agricultural landscapes. These measures complement, but do not duplicate, the livestock-specific strategies in Section 10.

## 8.2 Analysis of agriculture sector emissions: historical trends and projections

The historical agriculture analysis includes only rice cultivation, agricultural soils and urea application. On this basis, agriculture emissions declined from 50.10 Gg $CO_2$e in 2019 to 38.94 Gg $CO_2$e in 2022 (see Figure 25 and Table 18), equivalent to a reduction of about 22.3% over the four-year period. This decline is mainly explained by a reduction in rice-cultivation emissions, which fell from 37.57 Gg $CO_2$e in 2019 to 28.15 Gg $CO_2$e in 2022. Agricultural soils declined from 11.60 Gg $CO_2$e to 10.06 Gg $CO_2$e, while urea application remained small, declining from 0.93 Gg $CO_2$e to 0.73 Gg $CO_2$e.

Rice cultivation is the dominant source within the revised agriculture profile. In 2022, rice cultivation accounted for about 72.3% of the revised agriculture total, agricultural soils accounted for about 25.8%, and urea application accounted for about 1.9%. This confirms that the most important crop-sector mitigation opportunity is methane reduction from paddy systems, complemented by improved nutrient management and soil practices. The BTR also identifies rice cultivation as the dominant source within agriculture emissions in 2022 (DECC, 2024).

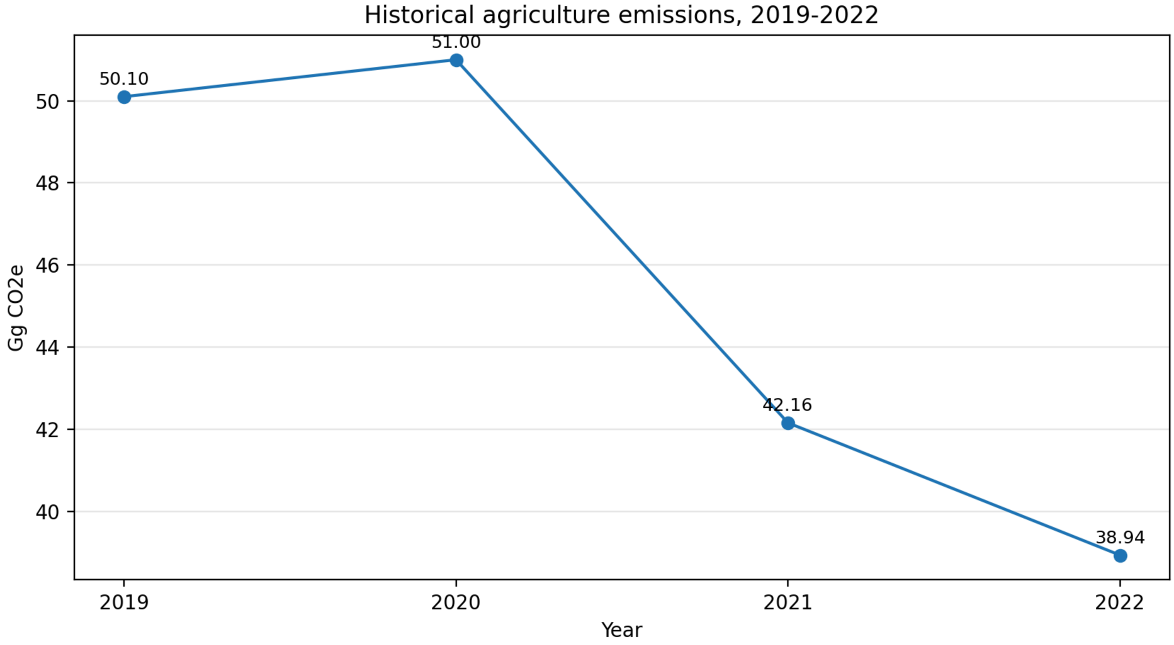


*Figure 25. Historical agriculture emissions, 2019–2022.*

*Table 18. Historical agriculture emissions by source category, 2019–2022.*

| Year | Agriculture total (Gg $CO_2$e) | Rice cultivation (Gg $CO_2$e) | Agricultural soils (Gg $CO_2$e) | Urea application (Gg $CO_2$e) |
|---|---|---|---|---|
| 2019 | 50.10 | 37.57 | 11.60 | 0.93 |
| 2020 | 50.99 | 38.65 | 11.29 | 1.06 |
| 2021 | 42.16 | 29.60 | 11.68 | 0.88 |
| 2022 | 38.94 | 28.15 | 10.06 | 0.73 |

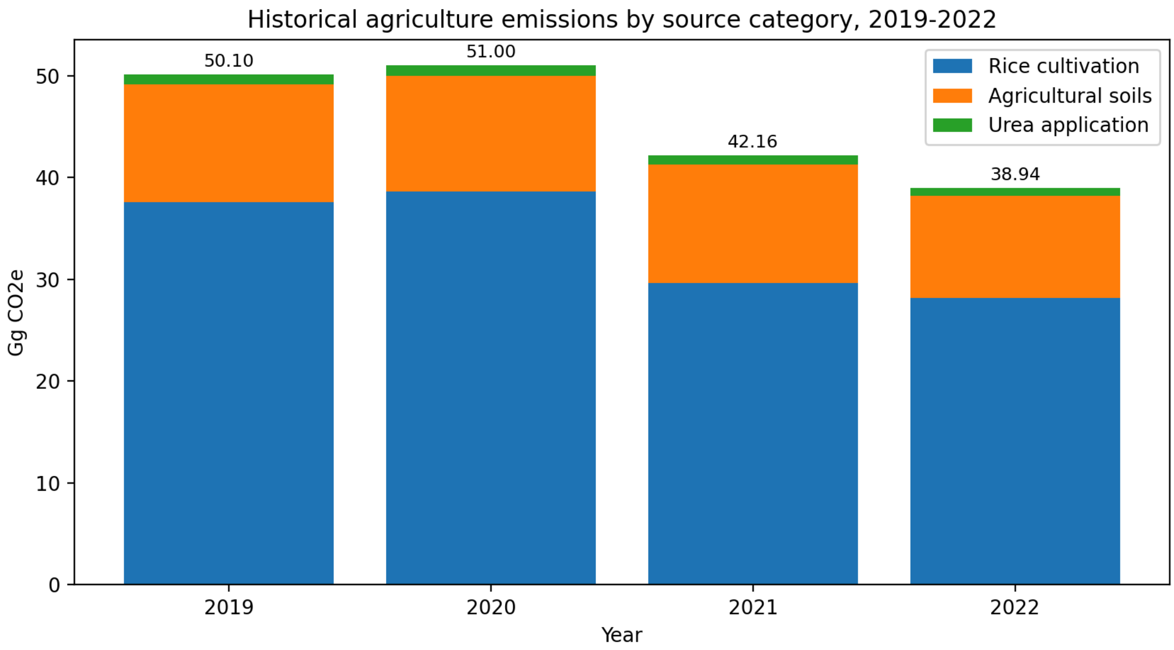


*Figure 26. Historical agriculture emissions by source category.*

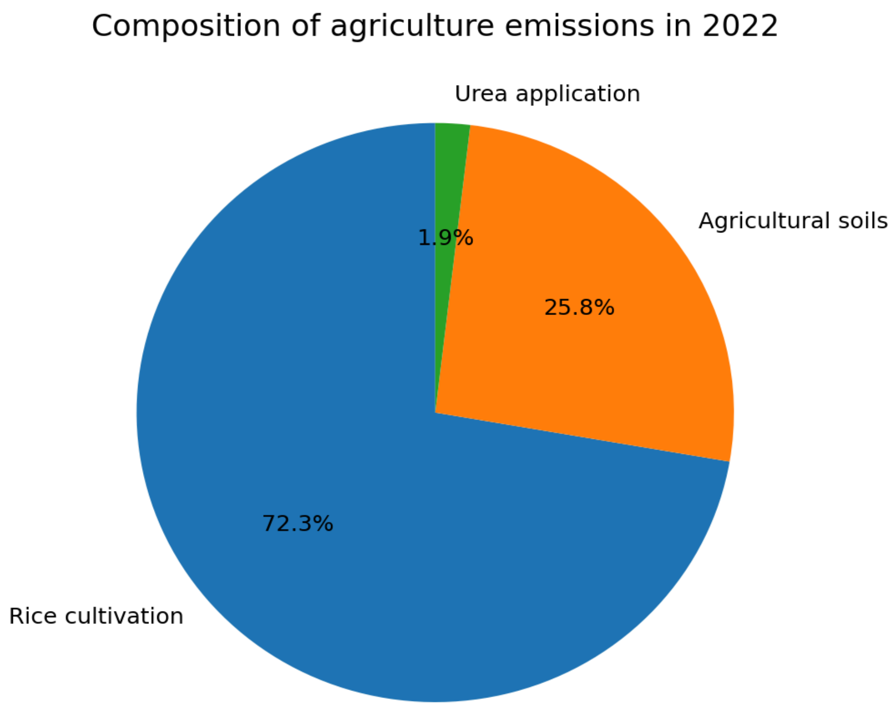


*Figure 27. Composition of agriculture emissions in 2022.*

### 8.2.1 Interpretation of historical trends

The data show that crop- and soil-related agriculture emissions have declined over the recent inventory period. The most significant driver is rice cultivation, where emissions declined by 9.42 Gg $CO_2$e from 2019 to 2022. This decline should be interpreted with caution because agriculture activity data can be affected by cultivated area, water regime, assumptions in inventory calculations and changes in reporting. Nevertheless, the source profile clearly identifies paddy systems as the central mitigation entry point for crop-based agriculture.

Rice methane mitigation should focus on water management and agronomic practices rather than reductions in production. Potential measures include alternate wetting and drying where irrigation control is feasible, improved water scheduling, residue management, soil amendment practices, improved varieties and farmer training. Bhutan's mountainous terrain and diverse agroecological zones mean that rice mitigation measures should be piloted and adapted locally rather than applied uniformly.

Agricultural soils and urea application form the second mitigation cluster. Although these sources are smaller than rice methane, they are important for environmental sustainability because inefficient nitrogen use can contribute to nitrous oxide emissions, nutrient losses and water-quality impacts. Improved soil testing, nutrient budgeting, compost and organic-input quality standards, and site-specific fertilizer application can reduce emissions while supporting soil fertility and crop productivity.

### 8.2.2 BAU projection

Because the BTR agriculture projection includes both crop and livestock dynamics, this agriculture sector analysis uses a separate analytical BAU projection for non-livestock agriculture. The projection is anchored in the BTR's reported agriculture estimate of 45.18 Gg $CO_2$e in 2022 and applies a conservative 0.5% annual growth assumption through 2030. This generates a BAU pathway rising from 45.41 Gg $CO_2$e in 2023 to 47.02 Gg $CO_2$e in 2030. The projection is a planning baseline used to compare crop- and soil-focused mitigation scenarios (DECC, 2024).

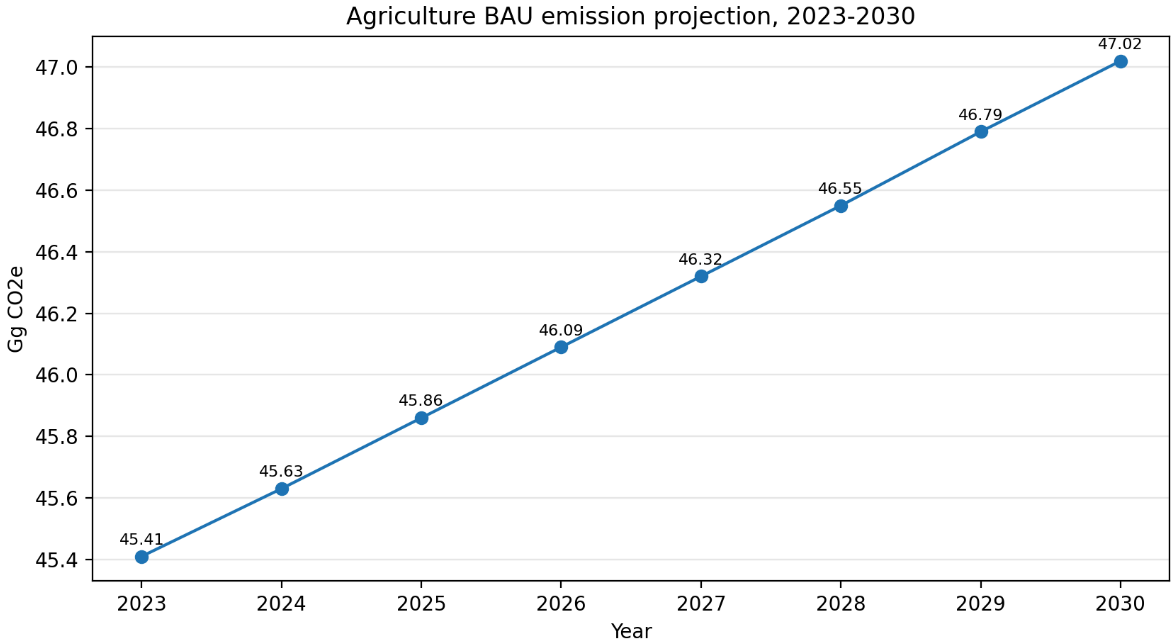


*Figure 28. Agriculture BAU emission projection, 2023–2030.*

*Table 19. Agriculture BAU projection, 2023–2030.*

| Year | BAU agriculture projection (Gg $CO_2$e) |
|---|---|
| 2023 | 45.41 |
| 2024 | 45.63 |
| 2025 | 45.86 |
| 2026 | 46.09 |
| 2027 | 46.32 |
| 2028 | 46.55 |
| 2029 | 46.79 |
| 2030 | 47.02 |

## 8.3 Emissions mitigation scenarios and sustainability strategies

Three mitigation scenarios were developed for the agriculture sector. The scenarios use the crop-only BAU projection as the baseline and apply progressively stronger reductions by 2030. Scenario 1 focuses on rice-water management and improved residue practices and reaches 10% below BAU by 2030. Scenario 2 combines rice-water management with nutrient efficiency, soil testing and organic nutrient transition and reaches 18% below BAU by 2030. Scenario 3 represents an integrated climate-smart crop and soil transformation pathway, including rice methane reduction, nutrient efficiency, soil health, perennial crops, agroforestry and climate-smart restoration, reaching 30% below BAU by 2030 (see Figures 29 and 30 and Tables 20 and 21).

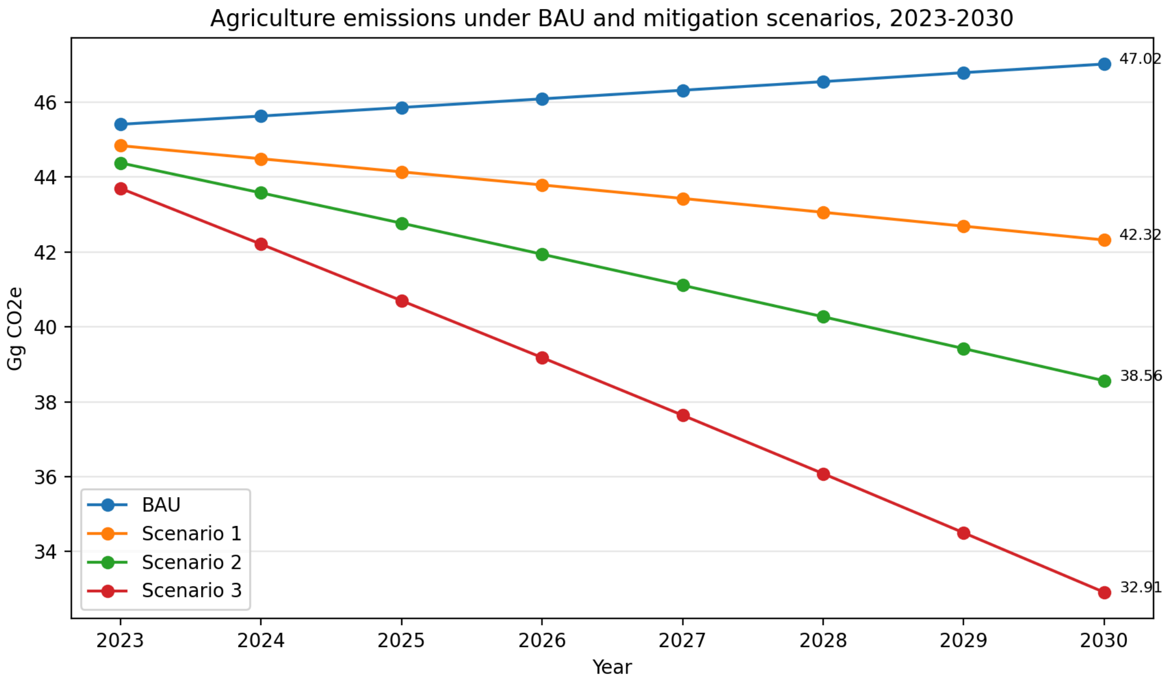


*Figure 29. Agriculture mitigation scenarios compared with BAU, 2023–2030.*

*Table 20. Mitigation scenario emission pathways, 2023–2030.*

| Year | BAU agriculture ($Gg\ CO_2e$) | Scenario 1: Rice-water management ($Gg\ CO_2e$) | Scenario 2: Nutrient and soil transition ($Gg\ CO_2e$) | Scenario 3: Climate-smart crop systems ($Gg\ CO_2e$) |
|---|---|---|---|---|
| 2023 | 45.41 | 44.84 | 44.38 | 43.70 |
| 2024 | 45.63 | 44.49 | 43.58 | 42.21 |
| 2025 | 45.86 | 44.14 | 42.77 | 40.70 |
| 2026 | 46.09 | 43.79 | 41.94 | 39.18 |
| 2027 | 46.32 | 43.43 | 41.11 | 37.64 |
| 2028 | 46.55 | 43.06 | 40.27 | 36.08 |
| 2029 | 46.79 | 42.69 | 39.42 | 34.50 |
| 2030 | 47.02 | 42.32 | 38.56 | 32.91 |

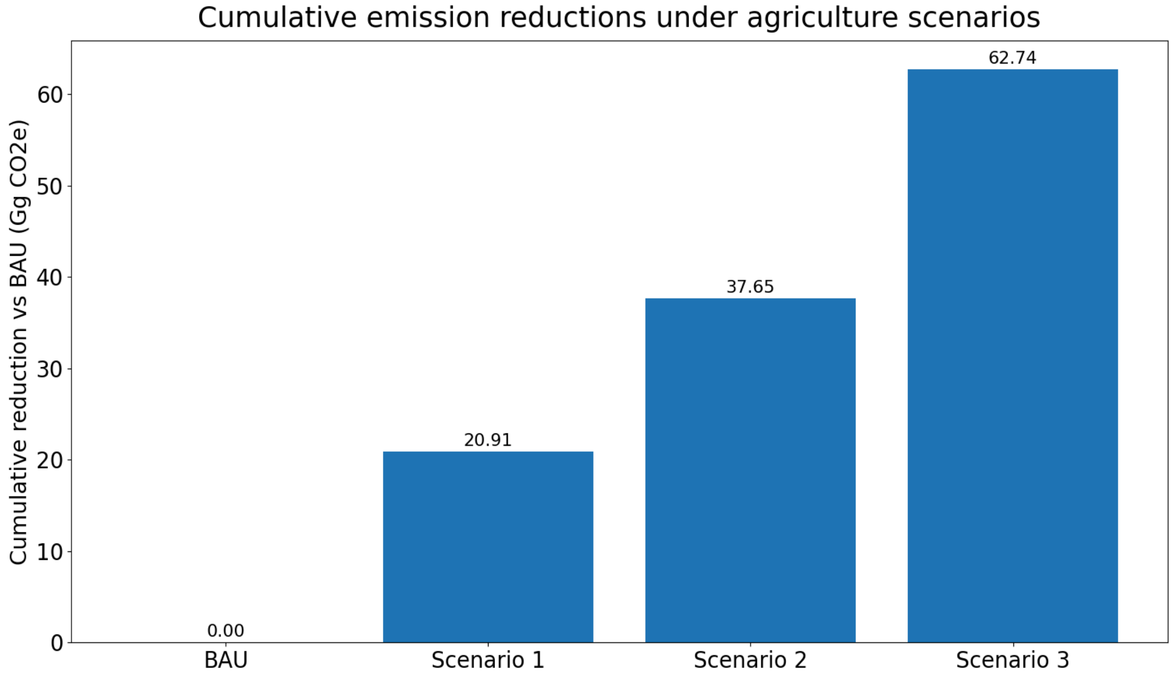


*Figure 30. Cumulative emission reductions under the three scenarios compared with BAU.*

*Table 21. Summary of scenario outcomes, 2023–2030.*

| Scenario | Cumulative 2023-2030 emissions (Gg CO2e) | Cumulative reduction vs BAU (Gg CO2e) | 2030 emissions (Gg CO2e) | 2030 reduction vs BAU (%) |
|---|---|---|---|---|
| BAU | 369.67 | 0.00 | 47.02 | 0.00 |
| Scenario 1: Rice-water management | 348.75 | 20.91 | 42.32 | 10.00 |
| Scenario 2: Nutrient and soil transition | 332.02 | 37.65 | 38.56 | 18.00 |
| Scenario 3: Integrated climate-smart crop systems | 306.92 | 62.74 | 32.91 | 30.00 |

### 8.3.1 Scenario 1: Rice-water management and residue practices

Scenario 1 represents a practical near-term mitigation pathway focused on rice-water management and improved paddy agronomy. It assumes that emissions reductions are achieved through improved irrigation scheduling, alternate wetting and drying where technically feasible, residue management, farmer training and better field-level monitoring of paddy practices. The scenario reaches 10% below BAU by 2030, reducing projected agriculture emissions from 47.02 Gg $CO_2e$ under BAU to 42.32 Gg $CO_2e$. Cumulative mitigation over 2023-2030 is estimated at 20.91 Gg $CO_2e$.

This scenario is relatively feasible because it focuses on the dominant source in the revised agriculture profile: rice cultivation. The approach should be implemented through demonstration plots, farmer field schools, irrigation-user coordination and monitoring of yield and water-use effects. The sustainability benefits include methane reduction, improved water productivity, more resilient rice systems and better understanding of site-specific paddy management.

### 8.3.2 Scenario 2: Nutrient efficiency, soil health and organic nutrient transition

Scenario 2 adds a broader nutrient and soil-management package to the rice-water measures in Scenario 1. It assumes expanded soil testing, site-specific nutrient management, improved timing and placement of nitrogen inputs, gradual substitution of synthetic fertilizer with properly processed organic inputs, compost quality control, and stronger monitoring of urea application. The scenario reaches 18% below BAU by 2030, reducing projected 2030 emissions to 38.56 Gg $CO_2$e. Cumulative mitigation over 2023-2030 is estimated at 37.65 Gg $CO_2$e.

This scenario has strong environmental sustainability benefits because nutrient efficiency can reduce nitrous oxide emissions, improve soil fertility and lower nutrient losses to water bodies. However, organic nutrient transition must be managed carefully. Poor-quality compost or unbalanced nutrient substitution can create yield risks or unintended emissions. Soil testing, nutrient budgets, compost standards and farmer advisory support are therefore essential.

### 8.3.3 Scenario 3: Integrated climate-smart crop systems transformation

Scenario 3 is the highest ambition crop- and soil-focused pathway. It combines rice methane reduction, nutrient efficiency, soil health improvement, crop diversification, perennial crop expansion, agroforestry, climate-smart restoration and stronger agriculture MRV. The scenario reaches 30% below BAU by 2030, reducing projected 2030 emissions to 32.91 Gg $CO_2$e. Cumulative mitigation over 2023-2030 is estimated at 62.74 Gg $CO_2$e.

This pathway treats crop-based agriculture as a climate-smart landscape system rather than a set of isolated practices. It would require stronger extension capacity, local pilots, irrigation planning, soil testing infrastructure, organic-input value chains, support for perennial crops and agroforestry, and mechanisms to track yield, income, water, soil and emissions outcomes. The benefits extend beyond mitigation to soil health, watershed protection, biodiversity, climate resilience and farm livelihood diversification.

## 8.4 Strategies for emissions reduction and environmental sustainability

### 8.4.1 Strategy 1: Strengthen agriculture MRV and improve activity data

Bhutan should strengthen activity data for rice area, water regime, fertilizer application, urea use, crop residues, organic manure and compost use, soil-management practices and perennial crop expansion. The revised agriculture analysis shows that crop and soil data should be tracked separately from livestock data to avoid double counting and improve the usefulness of future BTR reporting.

### 8.4.2 Strategy 2: Prioritize low-methane rice cultivation practices

Because rice cultivation is the dominant detailed source in the CRT agriculture data, rice methane mitigation should be a priority. Bhutan should pilot alternate wetting and drying, improved water scheduling, residue management, and climate-resilient varieties in areas where irrigation control is possible. Measures should be designed with farmers to protect yields and labor feasibility. Rice mitigation should be linked to water efficiency, climate adaptation, and farmer training rather than framed only as an emissions-reduction intervention.

### 8.4.3 Strategy 3: Improve nutrient efficiency and soil health

Nutrient efficiency should be improved through soil testing, balanced fertilizer recommendations, integrated nutrient management, better timing and placement of nitrogen inputs, and careful use of organic fertilizers. The objective is to reduce nitrous oxide emissions while improving soil fertility, crop productivity and water quality.

### 8.4.4 Strategy 4: Promote organic and biofertilizer systems with safeguards

Switching from synthetic to organic fertilizers is identified in the BTR as part of the LEDS for Food Security. This transition should be managed carefully through compost quality standards, pathogen control, nutrient budgeting and farmer training to avoid yield losses or unintended nitrous oxide emissions (DECC, 2024).

### 8.4.5 Strategy 5: Expand perennial crops, agroforestry and climate-smart restoration

Perennial crop production and agroforestry can increase biomass, support carbon sequestration, improve soil stability and diversify farmer income. These measures should be linked with watershed management, biodiversity protection, erosion control and climate adaptation.

### 8.4.6 Strategy 6: Mobilize finance for crop-based climate-smart agriculture

Higher-ambition crop-sector mitigation requires investment in irrigation management, soil testing, extension systems, organic-input supply chains, perennial crop establishment, agroforestry and MRV platforms. Bhutan should package these actions as a crop-based climate-smart agriculture programme that complements, but remains separate from, the livestock mitigation programme.

### 8.4.7 Strategy 7: Ensure agriculture and livestock are reconciled but not double counted

For programme design, agriculture and livestock should be managed as linked food-system pillars. For accounting and reporting, however, crop-based agriculture measures and livestock measures should be tracked separately and then reconciled within the national AFOLU inventory framework to avoid double counting. This is especially important when aggregating mitigation potentials across the report.

### 8.5 Conclusion

The revised agriculture sector analysis removes livestock components from the agriculture section because livestock is presented separately in Section 10. The updated agriculture analysis therefore focuses on rice cultivation, agricultural soils and urea application. On this revised basis, agriculture emissions declined from 50.10 Gg $CO_2$e in 2019 to 38.94 Gg $CO_2$e in 2022. Rice cultivation remains the dominant source, accounting for about 72.3% of the revised 2022 agriculture total.

The updated BAU projection is anchored in the BTR's agriculture estimate of 45.18 Gg $CO_2$e in 2022 and applies a conservative 0.5% annual growth assumption. Under this pathway, agriculture emissions rise modestly to about 47.02 Gg $CO_2$e by 2030. The three mitigation scenarios show that crop- and soil-focused interventions can bend this trajectory. Scenario 1, focused on rice-water management, provides about 20.91 Gg $CO_2$e cumulative mitigation over 2023-2030. Scenario 2, focused on nutrient efficiency and soil health, provides about 37.65 Gg $CO_2$e. Scenario 3, an integrated climate-smart crop systems pathway, provides about 62.74 Gg $CO_2$e.

The priority package for agriculture is: strengthen crop and soil MRV, reduce rice methane through better water and residue management, improve nutrient efficiency, promote organic and biofertilizer systems with safeguards, expand perennial crops and agroforestry, and mobilize finance for crop-based climate-smart agriculture. Livestock-related sources and mitigation measures should remain in the separate livestock section. This separation improves analytical clarity, avoids double counting and supports more targeted programme design for Bhutan's low-emission food-system transition.

## 9. Forestry and LULUCF sector analysis

### 9.1 Introduction

Bhutan’s forestry sector is central to the country’s climate strategy because the national greenhouse gas balance is defined not only by the level of emissions from energy, industry, agriculture and waste, but also by the ability of forests and other land-use systems to remove carbon dioxide from the atmosphere. In Bhutan’s reporting framework, the relevant sector is generally presented as land use, land-use change and forestry (LULUCF) or forest and other land use (FOLU). This terminology reflects the fact that the forestry sector includes both direct forest-land removals and emissions from land conversion, forest disturbance, wood removals, fuelwood use and other land categories. In the BTR, it is explained that the inventory is prepared under the 2006 IPCC Guidelines and that removals by sinks occur in the AFOLU sector as a result of improved forest management and reforestation (DECC, 2024).

Bhutan's climate policy context makes the forestry sector different from the other emitting sectors. The national objective is to remain carbon-neutral, meaning that total greenhouse gas emissions should not exceed total removals by sinks, particularly forests. This is anchored in the country's constitutional mandate to maintain at least 60% of the land area under forest cover and in national policies that emphasize forest conservation, sustainable forest management, protected areas, ecological corridors, watershed protection and community-based natural resource management. In the BTR, Bhutan identifies forest conservation and management under the National REDD+ Strategy as a core mitigation measure, with the objective of maintaining forest carbon stock and sink capacity while increasing adaptive capacity to climate-change impacts (DECC, 2024).

The forestry sector therefore performs three connected functions. First, it offsets emissions from other sectors by maintaining a large national carbon sink. Second, it reduces direct land-use emissions by preventing deforestation, degradation and conversion of forest land to other land uses. Third, it contributes to environmental sustainability through biodiversity conservation, watershed regulation, slope stabilization, disaster risk reduction, rural livelihoods and cultural values. The sector's mitigation contribution cannot be assessed only through gross emissions; it must be evaluated through net emissions and removals. Negative values in the historical data represent net removals, whereas positive values in subcategories such as grassland, settlements and other land represent emissions or reduced sequestration associated with land-use dynamics.

The CRT data provide annual historical estimates for the LULUCF category from 2019 to 2022. These data show that Bhutan's LULUCF sector remained a very large net sink throughout the period, with total net removals of about -12,010.66 Gg $CO_2e$ in 2019, -11,422.90 Gg $CO_2e$ in 2020, -11,711.10 Gg $CO_2e$ in 2021 and -11,330.52 Gg $CO_2e$ in 2022. Forest land accounts for nearly all of this sink, demonstrating that forest conservation and biomass growth dominate the national land-use balance. At the same time, the trend indicates some weakening of the sink from 2019 to 2022, requiring continued policy attention to forest disturbance, conversion pressure, harvesting, fuelwood demand and land-use planning.

The BTR provides a complementary national projection to 2030. It presents FOLU gross emissions and sink capacity separately, showing that the sector will remain strongly net-negative but that the future balance depends on the relationship between increasing FOLU emissions and the forest sink. In the projection, FOLU gross emissions rise from 1,279.00 Gg $CO_2e$ in 2023 to approximately 1,465.88 Gg $CO_2e$ in 2030, while sink capacity improves from -10,514.32 Gg $CO_2e$ in 2023 to about -10,972.10 Gg $CO_2e$ in 2030. The resulting net forestry/LULUCF balance remains a large net removal, but the projection also highlights that continued investment is needed to maintain sink capacity and reduce gross land-use emissions (DECC, 2024).

The National Forest Inventory (NFI) Volume II: State of Forest Carbon Report adds the most detailed national evidence on forest carbon stocks and sequestration. The report estimates that Bhutan's forests contain 521.16 million tonnes of carbon, equal to 86% of total national carbon stock, with a forest carbon density of 194.72 tonnes C per hectare (FMID, 2023). It also estimates total national carbon stock, including non-forest areas, at 606.31 million tonnes C. The NFI further reports that total forest sequestration potential is about 11 million tonnes of $CO_2$ per year, with an average forest sequestration rate of 4.18 tonnes $CO_2$ per hectare per year (FMID, 2023).

These figures confirm that Bhutan's forest sink is an asset of national and global significance. However, the same NFI also documents vulnerabilities. It reports that the forest area decreased from 2.73 million hectares, or 71.13% of national land area, in the first NFI to 2.67 million hectares, or 69.71%, in the second NFI, and that forest carbon density decreased from the first inventory to the second inventory. It identifies possible drivers such as removal of bigger trees, replacement by younger stands, allocation of State Reserve Forest land for development, pests and diseases and other disturbances (FMID, 2023). This means that Bhutan's forests remain a strong carbon sink, but the quality, maturity and resilience of that sink require sustained management.

## 9.2 Analysis of forestry sector emissions

The historical analysis uses the CRT data for LULUCF. The CRT data classify the forestry sector within the broader land-use category and report negative values for removals. The 2019–2022 historical series shows that Bhutan remained a large net sink in every year. The total LULUCF net balance weakened from -12,010.66 Gg $CO_2$e in 2019 to -11,330.52 Gg $CO_2$e in 2022, equivalent to a decline of about 5.7% in the magnitude of net removals (See Table 22). The forest land subcategory is the dominant source of removals and accounts for almost all of the sectoral sink. Non-forest land categories, including grassland, settlements and other land, are positive in the CRT table, indicating emissions or lower sequestration relative to forest land.

*Table 22. Historical forestry/LULUCF emissions and removals from the CRT data, 2019–2022.*

| Year | LULUCF total net removals (Gg $CO_2$e) | Forest land (Gg $CO_2$e) | Cropland (Gg $CO_2$e) | Grassland (Gg $CO_2$e) | Settlements (Gg $CO_2$e) | Other land (Gg $CO_2$e) |
|---|---|---|---|---|---|---|
| 2019 | -12,010.66 | -12,003.57 | -91.78 | 8.21 | 18.15 | 58.34 |
| 2020 | -11,422.90 | -11,425.44 | -89.90 | 9.76 | 21.08 | 61.60 |
| 2021 | -11,711.10 | -11,816.58 | 5.30 | 11.31 | 24.01 | 64.87 |
| 2022 | -11,330.52 | -11,373.94 | -64.50 | 12.86 | 26.94 | 68.13 |

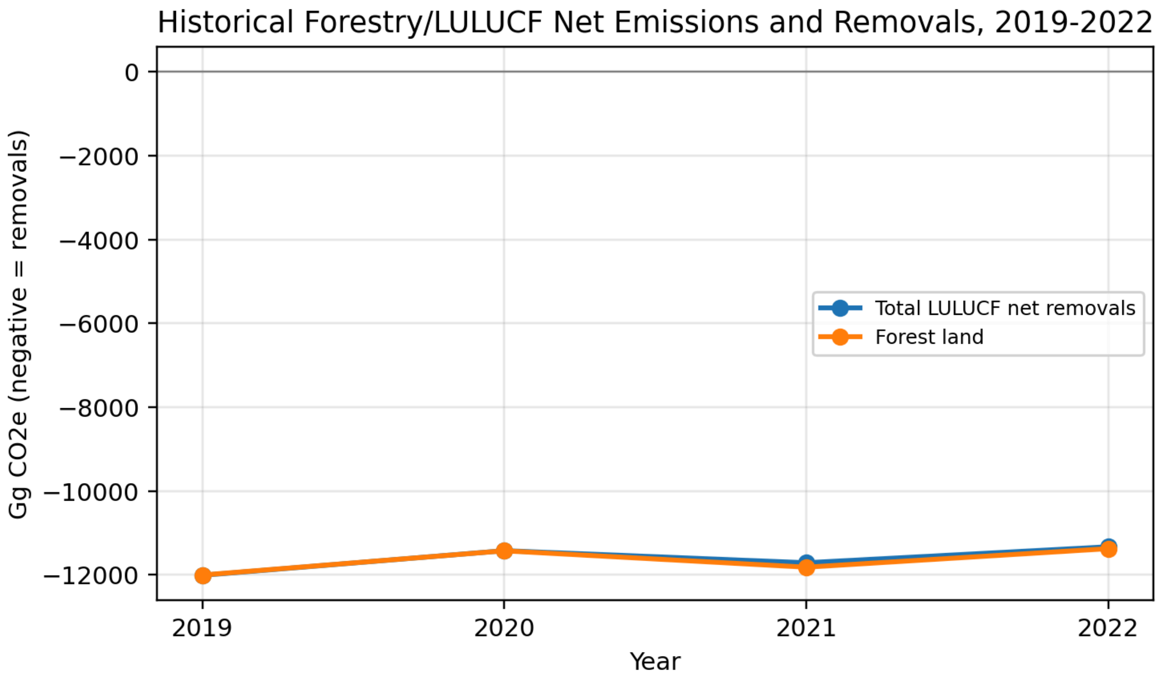


*Figure 31. Historical total LULUCF and forest-land net emissions/removals, 2019–2022.*

Figure 31 shows that forest land and total LULUCF move together. This indicates that the overall sectoral balance is primarily determined by forest-land removals rather than by smaller categories such as cropland, grassland, settlements and other land. The highest removal magnitude in the series is 2019, while 2022 shows the lowest magnitude. The trend should not be interpreted as a structural collapse of the forest sink, but it does point to the need for closer monitoring of gross land-use emissions and the quality of forest growth.

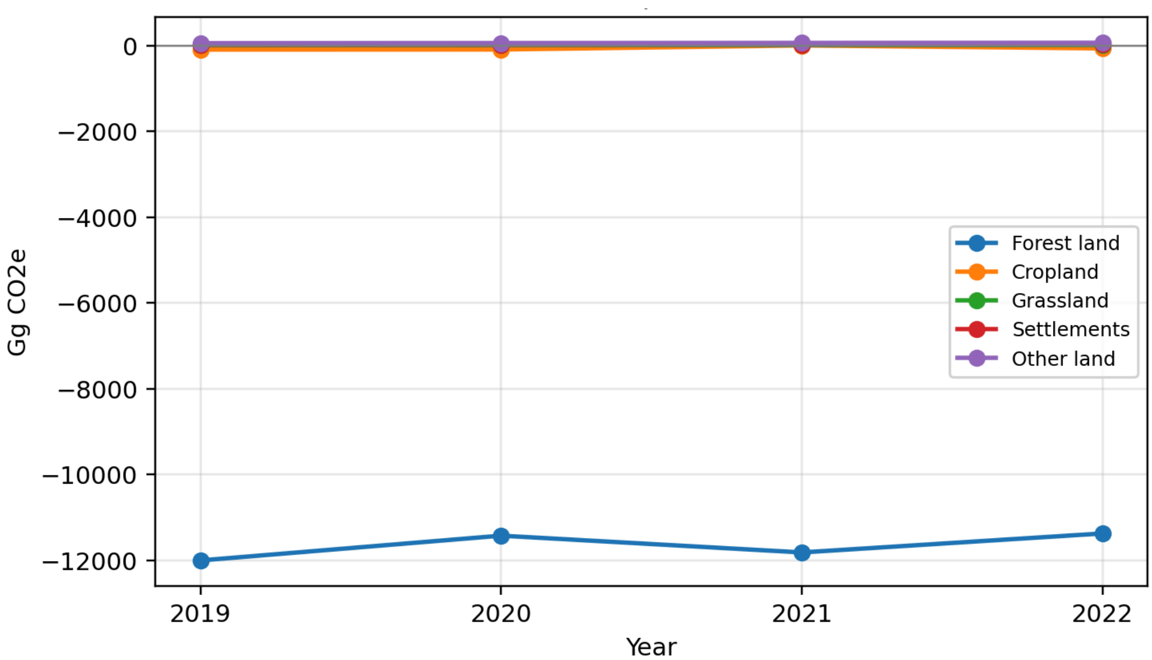


*Figure 32. Historical LULUCF components in the CRT data.*

Figure 32 separates the main land-use categories. Forest land remains strongly negative across the period, while grassland, settlements and other land are consistently positive. Cropland switches from negative removals in 2019 and 2020 to a small positive-emission in 2021 and returns to net removal in 2022. This pattern is consistent with a landscape where forest land performs the main sink function, while non-forest land categories create smaller but important pressures on the overall land-use balance. The BTR explains that forestry inventory activity data are derived from land-use and land-cover maps and Forest Reference Emission Level/Forest Reference Level sources, while gains and losses are estimated using IPCC methods, country-specific forest data and assumptions on biomass growth, harvest and disturbance (DECC, 2024).

### 9.2.1 Forest carbon stock and sequestration basis

The NFI provides the biophysical basis for interpreting the historical and projected emissions data. It reports that forests contain 521.16 million tonnes of carbon, with a density of 194.72 tonnes C per hectare. It also reports that national carbon stock including non-forest areas is 606.31 million tonnes C. Forest carbon is stored across above-ground biomass, below-ground biomass, coarse woody debris, litter and soil organic carbon (see Table 23 and Figure 33). The dominance of above-ground biomass and soil organic carbon highlights that forest protection must address both standing forest biomass and soil stability (FMID, 2023).

*Table 23. Forest carbon stock by carbon pool from the NFI Volume II.*

| Carbon pool | Carbon stock (million tonnes C) | Share of forest carbon stock (%) |
|---|---|---|
| Above-ground biomass | 246.00 | 47.20 |
| Below-ground biomass | 64.66 | 12.40 |
| Coarse woody debris | 8.46 | 1.60 |
| Litter | 19.71 | 3.80 |
| Soil organic carbon | 182.33 | 35.00 |

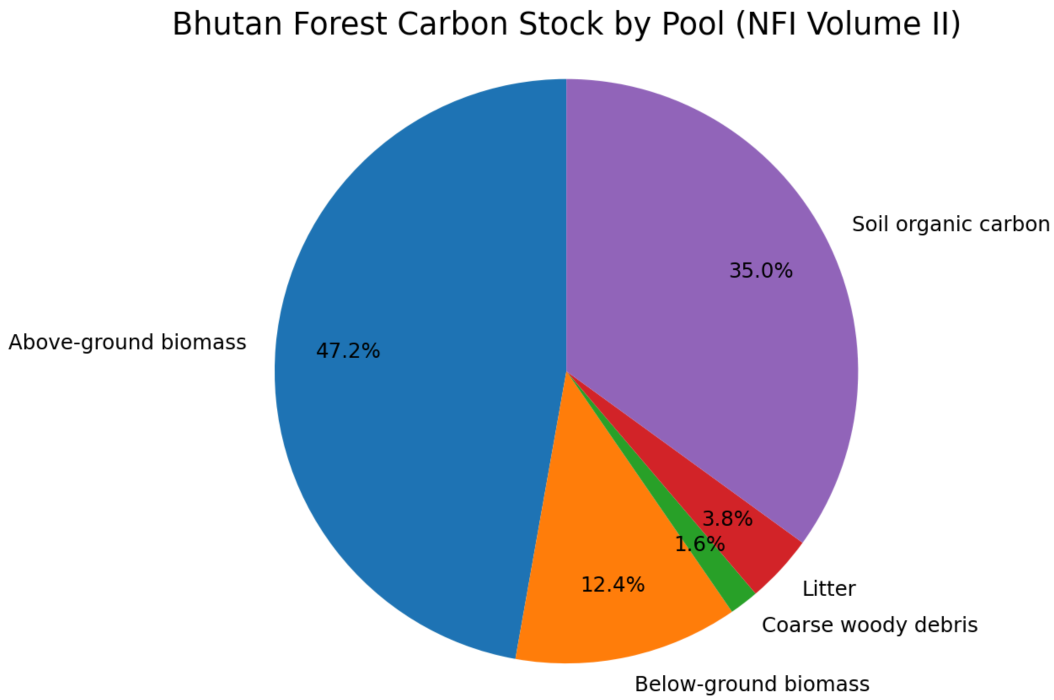


*Figure 33. Forest carbon stock by pool based on the NFI Volume II.*

The carbon-pool composition has important mitigation implications. Above-ground biomass accounts for 47.2% of the total forest carbon stock, meaning that the removal of large trees, degradation of mature forest stands and forest fires can quickly reduce sequestration potential. Soil organic carbon accounts for 35.0%, making soil conservation, slope protection and avoidance of forest conversion essential. The NFI notes that biomass growth in forests is 2.43 tonnes dry matter per hectare per year, equivalent to 1.14 tonnes C per hectare per year, and that total forest sequestration potential is 11 million tonnes $CO_2$ per year (FMID, 2023) (see Table 24 and Figure 34).

*Table 24. Key NFI indicators relevant to forestry mitigation.*

| Indicator | Value | Source |
|---|---|---|
| Forest carbon stock | 521.16 million tonnes C | FMID (2023) |
| Forest carbon density | 194.72 t C / ha | FMID (2023) |
| Total carbon stock including non-forest areas | 606.31 million tonnes C | FMID (2023) |
| National carbon density including non-forest areas | 267.94 t C / ha | FMID (2023) |
| Forest sequestration potential | 11.0 million tonnes $CO_2$ / yr | FMID (2023) |
| Forest sequestration rate | 4.18 t $CO_2$ / ha / yr | FMID (2023) |
| Forest area (2nd NFI) | 2.67 million ha | FMID (2023) |
| Forest cover share (2nd NFI) | 69.71% | FMID (2023) |
| Forest area (1st NFI) | 2.73 million ha | FMID (2023) |
| Forest cover share (1st NFI) | 71.13% | FMID (2023) |

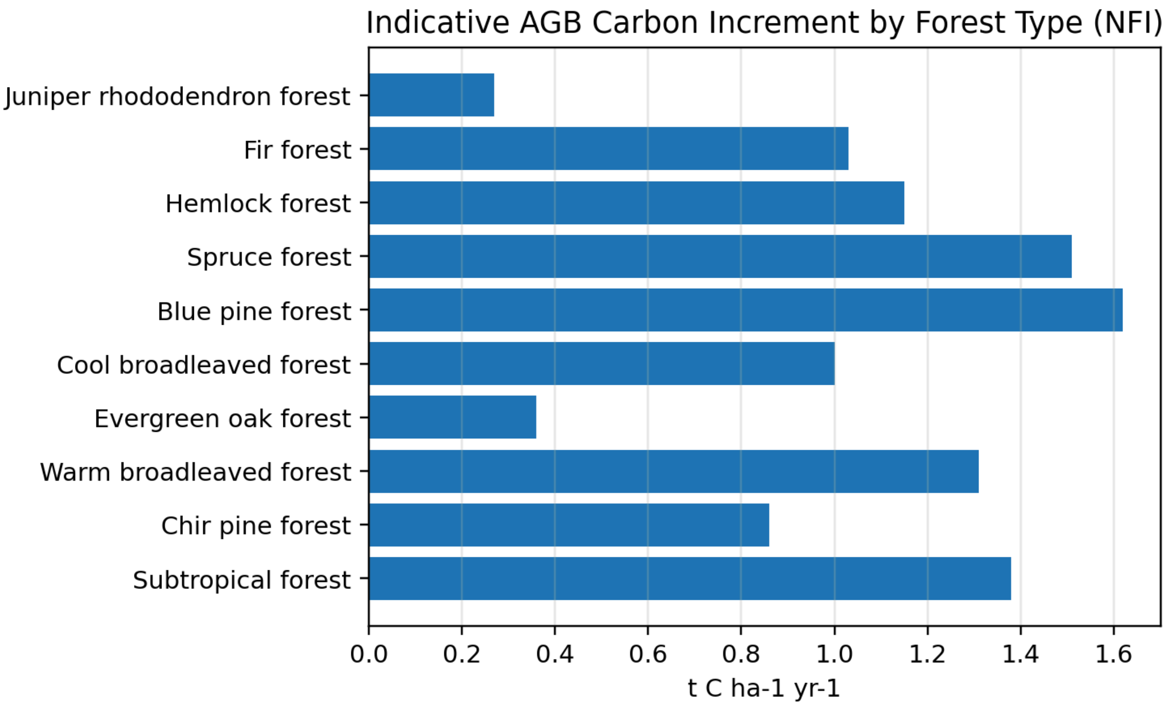


*Figure 34. Indicative above-ground carbon increment by forest type from NFI results.*

### 9.2.2 Projection of forestry emissions and removals

The projection uses the BTR pathway for FOLU gross emissions and sink capacity from 2020 to 2030. The projection was prepared by the Government of Bhutan using linear trend analysis across the five sectors and the sink capacity, drawing on historical inventories and the latest inventory years (DECC, 2024). For this report, the FOLU gross emissions and sink capacity columns are combined to show a net forestry/LULUCF balance. The net balance remains strongly negative throughout 2023–2030, which means the sector remains a net sink.

*Table 25. BTR forestry/LULUCF projection, 2020–2030.*

| Year | FOLU gross emissions (Gg $CO_2$e) | Sink capacity (Gg $CO_2$e) | Net forestry/LULUCF balance (Gg $CO_2$e) |
|---|---|---|---|
| 2020 | 2,103.76 | -12,781.30 | -10,677.54 |
| 2021 | 2,110.37 | -11,790.67 | -9,680.30 |
| 2022 | 2,114.35 | -11,344.93 | -9,230.58 |
| 2023 | 1,279.00 | -10,514.32 | -9,235.32 |
| 2024 | 1,305.70 | -10,579.71 | -9,274.01 |
| 2025 | 1,332.39 | -10,645.11 | -9,312.72 |
| 2026 | 1,359.09 | -10,710.51 | -9,351.42 |
| 2027 | 1,385.79 | -10,775.91 | -9,390.12 |
| 2028 | 1,412.49 | -10,841.30 | -9,428.81 |
| 2029 | 1,439.19 | -10,906.70 | -9,467.51 |
| 2030 | 1,465.88 | -10,972.10 | -9,506.22 |

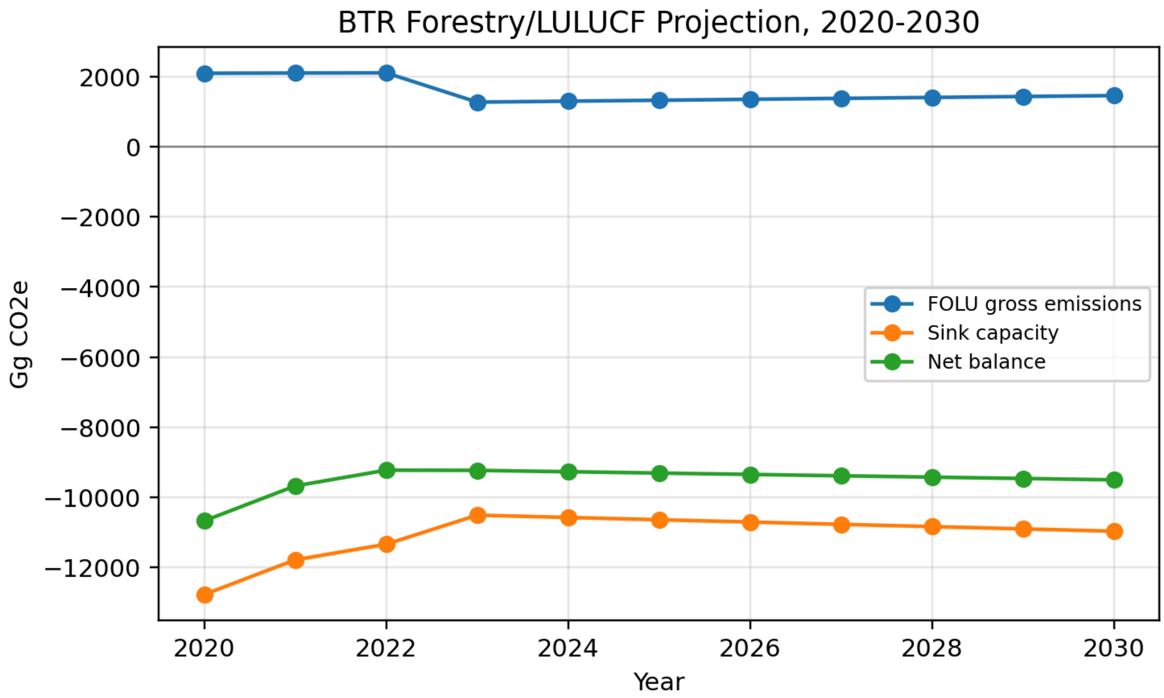


*Figure 35. BTR forestry/LULUCF projection showing gross FOLU emissions, sink capacity and net balance.*

The projection shows two simultaneous trends. FOLU gross emissions increase gradually, implying continued land-use pressure, while the sink capacity also strengthens gradually after 2023. The net balance remains between approximately -9,235 Gg $CO_2$e and -9,506 Gg $CO_2$e during 2023–2030 (See Table 25 and Figure 35). This is sufficient to keep the forestry sector a large sink, but the margin depends on maintaining forest cover, forest quality and biomass growth. In other words, the projected sink should not be treated as guaranteed; it depends on the continuation and strengthening of REDD+, sustainable forest management, restoration, fire management, pest management and improved land-use governance.

## 9.3 Emissions mitigation scenarios

The scenarios below are analytical planning scenarios prepared for this report. They are anchored to the BTR projection and to the NFI evidence on forest carbon stock and sequestration. Each scenario modifies the BTR baseline by reducing FOLU gross emissions and enhancing sink capacity. The scenarios are summarized in Table 26 and shown in Figures 36 and 37.

*Table 26. Summary of forestry mitigation scenario outcomes.*

| Scenario | Cumulative 2023-2030 additional net removals vs BAU (Gg $CO_2$e) | 2030 FOLU gross emissions (Gg $CO_2$e) | 2030 sink capacity (Gg $CO_2$e) | 2030 net balance (Gg $CO_2$e) | 2030 additional net removal vs BAU (%) |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| Scenario 1: Forest conservation and sustainable forest management | 1,093.88 | 1,392.59 | -11,147.65 | -9,755.06 | 2.60 |
| Scenario 2: Climate-smart restoration, plantation and agroforestry expansion | 2,518.21 | 1,341.28 | -11,410.98 | -10,069.70 | 5.90 |
| Scenario 3: Integrated REDD+ and resilient landscape transformation | 5,200.68 | 1,216.68 | -11,959.59 | -10,742.91 | 13.00 |

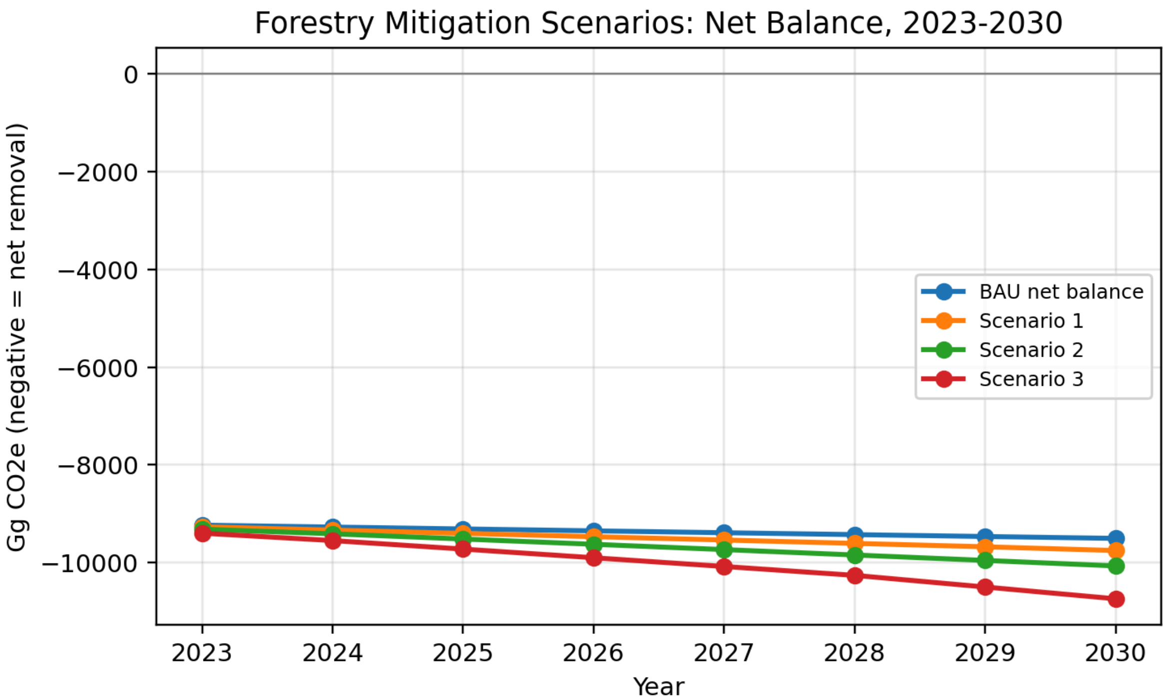


*Figure 36. Forestry mitigation scenarios compared with the BAU net forestry balance.*

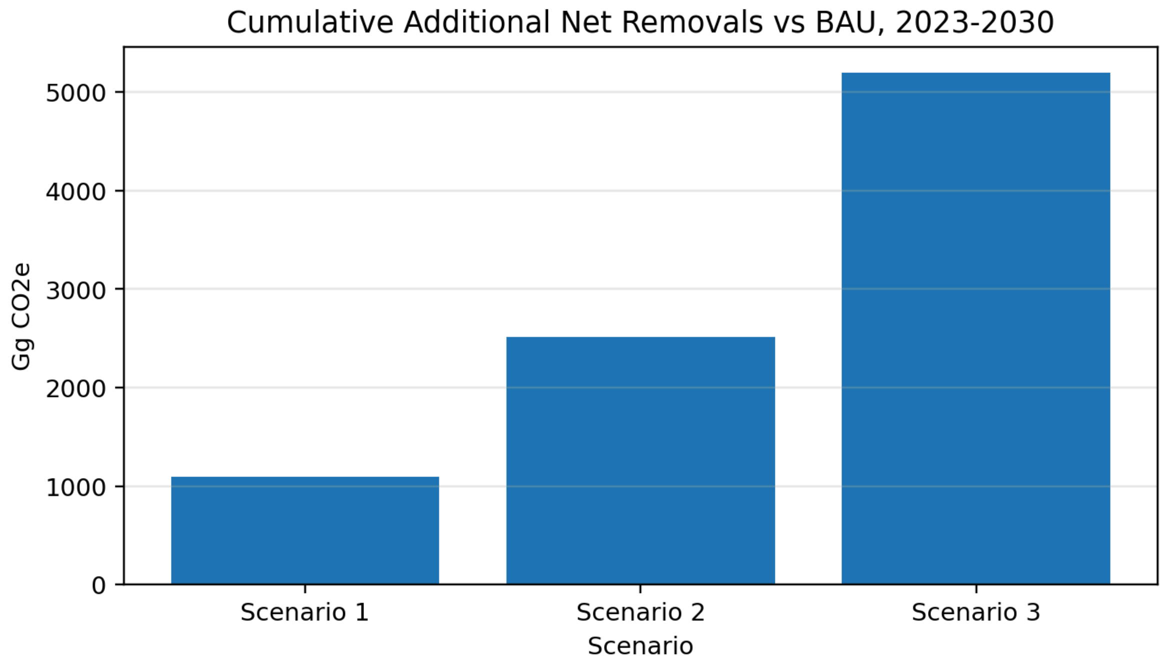


*Figure 37. Cumulative additional net removals compared with BAU, 2023–2030.*

### 9.3.1 Scenario 1: Forest conservation and sustainable forest management

Scenario 1 is a conservation-first pathway. It assumes that Bhutan strengthens existing forest conservation, protected area management, community forestry, sustainable harvesting and disturbance control. The scenario reflects the BTR mitigation measure on forest conservation and management under the National REDD+ Strategy, which aims to maintain forest carbon stock and sink capacity, preserve at least half of land area under protected areas and implement climate-smart restoration through plantation and restoration works (DECC, 2024).

In quantitative terms, Scenario 1 assumes that FOLU gross emissions fall gradually relative to BAU, reaching a 5% reduction by 2030, while sink capacity is enhanced by 1.6% by 2030. This produces cumulative additional net removals of about 1093.88 Gg $CO_2e$ from 2023 to 2030 compared with BAU. By 2030, the net forestry balance reaches -9755.06 Gg $CO_2e$ compared with a BAU balance of -9506.22 Gg $CO_2e$.

The strategy package includes stricter land-conversion screening for State Reserve Forest land, stronger use of environmental assessment for infrastructure crossing forest areas, fire-prevention and rapid-response systems, pest and disease monitoring, sustainable timber harvesting limits, and reinforcement of community forest management plans. This scenario is relatively modest and feasible because it builds on existing institutions and policy commitments, but it requires consistent finance for monitoring, enforcement and community-level implementation.

### 9.3.2 Scenario 2: Climate-smart restoration, plantation and agroforestry expansion

Scenario 2 adds an active restoration pathway to the conservation foundation. It assumes accelerated restoration of degraded forest areas, enrichment planting, riparian buffer restoration, assisted natural regeneration, urban greening and expansion of agroforestry and perennial tree systems in suitable areas. This aligns with the BTR's emphasis on enhancement of forest carbon stock through climate-smart restoration, and with the NFI finding that forest sequestration capacity has increased to over 11 million tonnes of $CO_2$ per year (DECC, 2024; FMID, 2023).

In quantitative terms, Scenario 2 assumes an 8.5% reduction in FOLU gross emissions and a 4% enhancement in sink capacity by 2030. This generates cumulative additional net removals of about 2518.21 Gg $CO_2$e during 2023–2030 compared with BAU. By 2030, the net forestry balance improves to -10069.70 Gg $CO_2$e.

The implementation package includes restoration of degraded watersheds, plantation of native or climate-resilient species, enrichment planting in degraded broadleaved and coniferous forests, restoration of riparian corridors, integration of fruit trees and perennial crops in climate-smart agricultural landscapes, and long-term maintenance of restored sites. This scenario has stronger co-benefits than Scenario 1 because it supports watershed protection, biodiversity connectivity, slope stabilization and rural income, but it also requires more capital investment and stronger nursery, extension and monitoring systems.

### 9.3.3 Scenario 3: Integrated REDD+ and resilient landscape transformation

Scenario 3 is the most ambitious pathway. It combines avoided deforestation, sustainable forest management, restoration, agroforestry, community-based incentives, improved monitoring, reduced fuelwood pressure and climate-resilient landscape planning. It treats the forestry sector not only as a carbon sink, but as a national resilience infrastructure system. This scenario is consistent with the BTR's framing of forestry as the cornerstone of Bhutan's carbon-neutral status and with the NFI's emphasis on forest carbon monitoring as a basis for policy, planning and decision-making (DECC, 2024; FMID, 2023).

In quantitative terms, Scenario 3 assumes that FOLU gross emissions are 17% below BAU by 2030 and that sink capacity is 9% higher than BAU by 2030. This produces cumulative additional net removals of about 5200.68 Gg $CO_2$e from 2023 to 2030. By 2030, the net forestry balance improves to -10742.91 Gg $CO_2$e, representing the strongest mitigation pathway among the three scenarios (see Table 27).

This scenario would require a programmatic REDD+ financing platform, stronger geospatial monitoring, annual or biennial land-use and land-cover mapping, fire and pest early warning, community benefit-sharing, restoration finance, private sector wood-efficiency measures and integration of forest carbon objectives into infrastructure, hydropower, tourism and urban planning. The BTR improvement plan specifically identifies the need to develop annual or biennial land-use and land-cover maps, stratify forest land by subcategory where possible, study carbon stock transfer between pools, improve data on biomass loss due to fire disturbance and improve the accuracy of gains and losses in forest land (DECC, 2024).

*Table 27. Net forestry/LULUCF balance under BAU and mitigation scenarios, 2023–2030.*

| Year | BAU net forestry balance (Gg $CO_2$e) | Scenario 1: Forest conservation and sustainable forest management net balance (Gg $CO_2$e) | Scenario 2: Climate-smart restoration, plantation and agroforestry expansion net balance (Gg $CO_2$e) | Scenario 3: Integrated REDD+ and resilient landscape transformation net balance (Gg $CO_2$e) |
|---|---|---|---|---|
| 2023 | -9,235.32 | -9,269.14 | -9,317.59 | -9,399.86 |
| 2024 | -9,274.01 | -9,335.92 | -9,412.45 | -9,550.88 |
| 2025 | -9,312.72 | -9,403.24 | -9,519.03 | -9,725.34 |
| 2026 | -9,351.42 | -9,471.08 | -9,626.79 | -9,902.16 |
| 2027 | -9,390.12 | -9,539.45 | -9,735.74 | -10,081.36 |
| 2028 | -9,428.81 | -9,608.35 | -9,845.86 | -10,262.91 |
| 2029 | -9,467.51 | -9,677.77 | -9,957.18 | -10,501.39 |
| 2030 | -9,506.22 | -9,755.06 | -10,069.70 | -10,742.91 |

## 9.4 Strategies for emissions reduction and environmental sustainability

### 9.4.1 Strategy 1: Protect existing high-carbon forests and prevent avoidable conversion

The greatest immediate mitigation benefit comes from maintaining existing forest carbon stocks. The NFI shows that above-ground biomass and soil organic carbon together dominate Bhutan's forest carbon stock; therefore, loss of mature stands and disturbance of forest soils can have long-term consequences. Land-use decisions should apply strict safeguards to State Reserve Forest land, infrastructure routing and settlement expansion, and should prioritize avoidance before compensatory planting.

### 9.4.2 Strategy 2: Strengthen sustainable forest management and disturbance control

The historical CRT trend suggests that the sink remains very strong but has weakened compared with 2019. Sustainable harvesting, timber traceability, reduced-impact logging, fuelwood substitution, fire prevention, pest and disease surveillance, and community-based forest management can reduce gross land-use emissions without undermining rural livelihoods.

### 9.4.3 Strategy 3: Expand climate-smart restoration and enrichment planting

Restoration should target degraded watersheds, eroded slopes, riparian zones, wildlife corridors and degraded community forests. Restoration should be designed for survival and long-term carbon accumulation, not only planted area. Species selection should use native and climate-resilient species and should reflect local hydrology, slope stability, biodiversity and livelihood needs.

### 9.4.4 Strategy 4: Integrate agroforestry and perennial trees into rural landscapes

Agroforestry can increase biomass carbon outside formal forests while supporting food security and rural incomes. It can also reduce pressure on natural forests by supplying fuelwood, fodder, fruit, timber and soil-conservation benefits. Agroforestry should be integrated with climate-smart agriculture, watershed management and community forestry extension.

### 9.4.5 Strategy 5: Improve MRV and inventory quality

The BTR identifies the need for annual or biennial land-use and land-cover maps, improved forest stratification, better estimates of biomass gains and losses, fire disturbance factors and carbon transfers among pools. These improvements should be prioritized because forestry is a key category for Bhutan's net national emissions balance.

### 9.4.6 Strategy 6: Mobilize REDD+ and ecosystem-service finance

Bhutan can use its strong forest-carbon evidence base to mobilize REDD+, Article 6, voluntary carbon market, biodiversity finance and watershed-service finance. Financing should prioritize long-term maintenance, community benefit-sharing, transparent MRV, safeguards, and ecological outcomes rather than short-term planting targets.

## 9.5 Conclusion

Bhutan's forestry and LULUCF sector is the foundation of the country's carbon-negative development pathway. Unlike the emitting sectors, forestry is primarily a net removal sector: the CRT data show that Bhutan remained a very large net sink between 2019 and 2022, with the LULUCF balance ranging from about -12,010.66 Gg $CO_2$e in 2019 to -11,330.52 Gg $CO_2$e in 2022. Forest land accounts for almost all of this sink, confirming that the protection and sustainable management of forests are central to maintaining Bhutan's national greenhouse gas balance (DECC, 2024).

The historical trend also shows that the magnitude of net removals weakened over the 2019-2022 period. This does not indicate a loss of Bhutan's forest-sink function, but it does signal that continued policy attention is required. Land conversion, forest disturbance, harvesting pressure, fuelwood use, infrastructure development, pest and disease risks, forest fires and climate-related stress could all affect the long-term stability of the sink. For this reason, the forestry strategy should not be limited to maintaining legal forest cover. It should also protect forest quality, carbon density, biomass growth, soil carbon, ecological connectivity and resilience to climate-related disturbance.

The National Forest Inventory provides strong evidence of the scale and importance of Bhutan's forest-carbon asset. It reports forest carbon stock of 521.16 million tonnes of carbon, forest carbon density of 194.72 tonnes C per hectare, and a forest sequestration potential of about 11 million tonnes $CO_2$ per year. It also shows that above-ground biomass and soil organic carbon are the two largest carbon pools, meaning that both standing forest biomass and forest soils require strong protection. These findings reinforce the conclusion that Bhutan's forests are not only a mitigation resource, but also a national resilience asset supporting biodiversity, watershed protection, slope stability, rural livelihoods and ecosystem services (FMID, 2023).

The scenario analysis demonstrates that the forestry sector can continue to provide substantial additional mitigation if conservation, restoration and REDD+ readiness are strengthened. Scenario 1, focused on forest conservation and sustainable forest management, generates about 1,093.88 Gg $CO_2$e of additional net removals over 2023-2030 compared with BAU. Scenario 2, which adds climate-smart restoration, plantation and agroforestry expansion, increases additional removals to about 2,518.21 Gg $CO_2$e. Scenario 3, the integrated REDD+ and resilient landscape transformation pathway, provides the strongest outcome, with about 5,200.68 Gg $CO_2$e of additional net removals by 2030. This confirms that a high-ambition forestry strategy can make a major contribution to Bhutan's continued carbon-negative status while also delivering environmental sustainability benefits.

The priority policy package should therefore combine four mutually reinforcing actions. First, Bhutan should protect existing high-carbon forests and avoid preventable conversion of State Reserve Forest land. Second, sustainable forest management, community forestry, disturbance control, fire prevention and pest monitoring should be strengthened to reduce gross land-use emissions and protect forest quality. Third, climate-smart restoration, assisted natural regeneration, enrichment planting, riparian restoration, agroforestry and perennial tree systems should be expanded in landscapes where they can increase carbon, biodiversity and livelihood benefits. Fourth, Bhutan should strengthen forestry MRV through repeated National Forest Inventory cycles, annual or biennial land-use and land-cover mapping, remote sensing, fire and disturbance monitoring, improved estimates of biomass gains and losses, and stronger integration between forest monitoring and national GHG inventory systems (DECC, 2024; FMID, 2023).

In conclusion, forestry should remain the cornerstone of Bhutan's long-term low-emission and climate-resilient development strategy. The sector's contribution goes beyond offsetting emissions from other sectors; it supports water security, biodiversity conservation, disaster-risk reduction, rural livelihoods, cultural values and national environmental integrity. However, the forest sink should not be taken for granted. Maintaining and enhancing it will require sustained investment, strong institutions, community participation, safeguards, REDD+ and ecosystem-service finance, and robust monitoring. If Bhutan combines forest conservation with climate-smart restoration and integrated landscape management, the forestry sector can continue to anchor national carbon-neutrality while strengthening the country's broader environmental sustainability and resilience objectives.

## 10. Livestock sector analysis

### 10.1 Introduction

In the national inventory, livestock emissions are primarily associated with methane from enteric fermentation and methane and nitrous oxide from manure management. Enteric fermentation occurs when ruminant animals digest feed and release methane as part of normal digestive processes. Manure management emissions arise from the handling, storage, treatment and deposition of animal manure. In Bhutan, the BTR reports that livestock production systems remain mixed: traditional systems such as migratory livestock farming and open grazing continue to be important, while stall feeding is increasingly adopted by progressive dairy farmers, especially in peri-urban areas. This transition matters because improved feeding can reduce methane emission intensity, while improved manure collection and treatment can create opportunities for biogas production and organic manure use (DECC, 2024).

The BTR's methodological discussion indicates that Bhutan uses IPCC-based inventory approaches and adopts manure management assumptions that reflect national expert judgement. For dairy and other cattle, 80% of manure is assumed to be managed under pasture/range/paddock and 20% under liquid or slurry systems. Buffalo, sheep, goats, horses, and mules/asses are assumed to be fully under pasture/range/paddock. Swine manure is assumed to be mainly managed as liquid or slurry, while poultry manure is primarily managed with litter. These assumptions are highly relevant for mitigation because the largest near-term opportunities are linked to improved feeding, improved animal productivity, manure capture where stall-feeding or confined systems are feasible, and a stronger evidence base for future Tier 2 inventory methods (DECC, 2024).

The livestock sector also illustrates the difference between absolute emissions and emission intensity. If animal numbers are reduced without attention to rural livelihoods, food security can be weakened. Conversely, if milk yield, animal health, feed quality and breeding efficiency improve, production can rise while emissions per liter of milk or unit of livestock product fall. Bhutan's BTR explicitly refers to the use of sex-sorted semen to increase improved milch cattle, stall-feeding practices to ensure proper nutrition and manure management, and the installation of 8,687 small and medium biogas units. These measures indicate that Bhutan is already pursuing a pathway where livestock mitigation is tied to productivity improvement, household energy substitution, organic manure generation and reduced environmental pressure (DECC, 2024).

The BTR reports the 2022 livestock total at 365 Gg $CO_2e$. For analytical trend purposes, this report uses a reconstructed split of 247.18 Gg $CO_2e$ for enteric fermentation and 117.82 Gg $CO_2e$ for manure management, scaled to the BTR total. This distribution has direct implications for mitigation strategy. Measures that target enteric methane, such as improved feeding, breed improvement, herd productivity and animal health, will have the greatest impact on the sector's emissions profile. Manure management remains smaller in absolute terms but can generate important co-benefits by producing biogas, reducing household dependence on firewood or fossil fuels, improving sanitation around farm systems and increasing organic fertilizer availability (DECC, 2024).

The CRT data is used in this report to examine the recent trend in reported livestock subcategories from 2019 to 2022. The CRT data provide a structured time-series for agriculture subcategories including enteric fermentation and manure management. However, the extracted CRT table marks cattle rows as "NA" in the detailed agriculture table, while the BTR narrative provides the full livestock estimate for 2022. To maintain consistency with the BTR while preserving the direction of change in the CRT, this analysis uses the BTR's 2022 livestock total as the official sector-level anchor and scales the CRT-reported 2019–2022 livestock subtotal to that anchor.

## 10.2 Analysis of livestock sector emissions

The historical trend analysis distinguishes between two datasets. First, the BTR provides the official 2022 livestock total of 365 Gg $CO_2e$, with 247.18 Gg $CO_2e$ from enteric fermentation and 117.82 Gg $CO_2e$ from manure management. Second, the CRT workbook provides a recent time series for reported agriculture subcategories. Because the CRT extraction reports cattle rows as "NA" in the detailed agriculture table but the BTR gives the full livestock total, the historical series shown in Table 28 and Figure 38 scale the CRT-reported enteric fermentation and manure management trend to the BTR 2022 livestock total. This preserves the direction of the CRT trend and aligns the level of the analysis with the BTR (DECC, 2024).

*Table 28. Historical livestock emissions, BTR-anchored trend, 2019–2022*

| Year | BTR-anchored enteric fermentation (Gg CO2e) | BTR-anchored manure management (Gg CO2e) | BTR-anchored livestock total (Gg CO2e) |
|---|---|---|---|
| 2019 | 241.85 | 132.82 | 374.66 |
| 2020 | 213.41 | 128.11 | 341.53 |
| 2021 | 258.41 | 135.76 | 394.16 |
| 2022 | 247.18 | 117.82 | 365.00 |

*Note: The source split is an analytical reconstruction scaled to the BTR 2022 livestock total.*

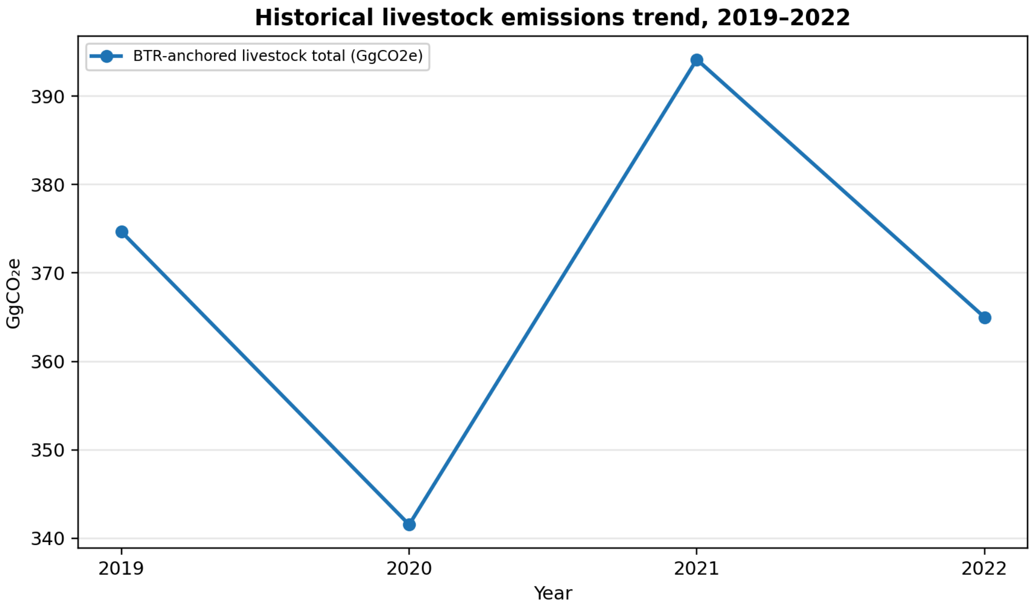


*Figure 38. Historical livestock emissions trend, 2019–2022.*

The reconstructed historical series indicates a moderate decline from 2019 to 2020, a rebound in 2021, and a decrease again in 2022. This pattern broadly supports the BTR's characterization that agriculture and livestock emissions have not shown a major structural increase in recent years. The 2022 level remains policy-relevant because livestock represents a substantial share of gross national emissions before LULUCF removals are considered (DECC, 2024).

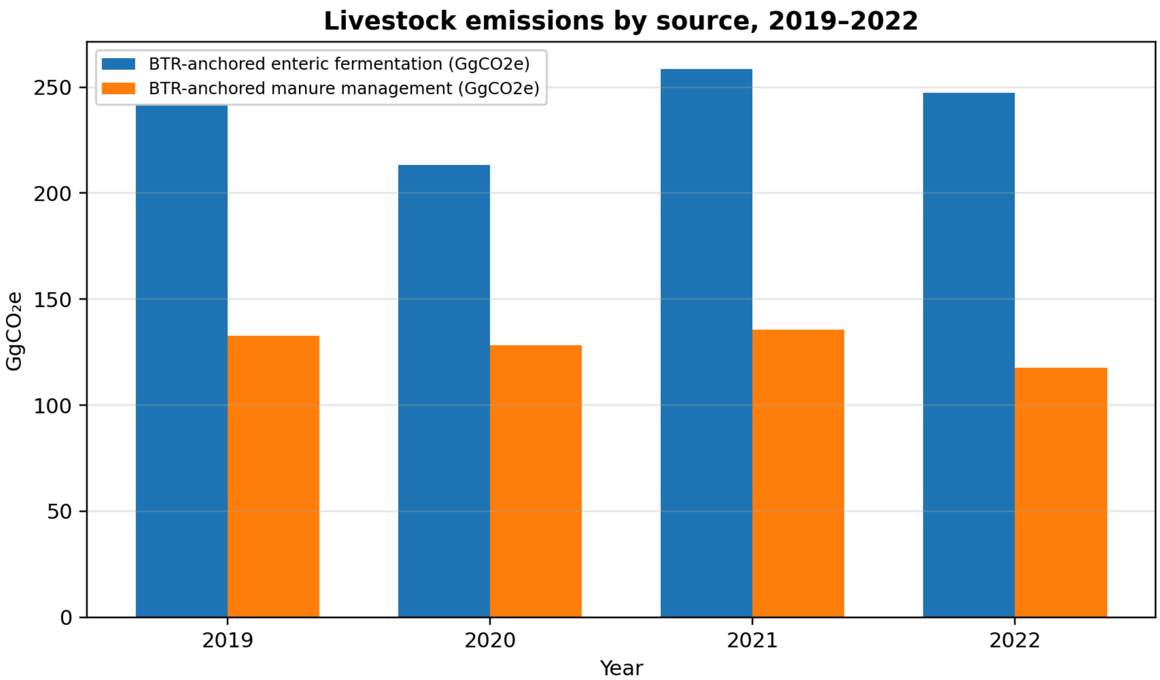


*Figure 39. Livestock emissions by source, 2019–2022.*

The source profile shown in Figure 39 confirms that enteric fermentation dominates livestock-sector emissions. The implication is that the largest mitigation gains will come from productivity, feed quality, digestibility, animal health and breeding measures that reduce methane intensity. Manure management remains important, not only because it reduces methane and nitrous oxide risks, but also because it links livestock mitigation to household energy, sanitation and organic fertilizer production (DECC, 2024).

## 10.3 BAU projections

The projection below applies a conservative 0.5% annual increase from the BTR 2022 livestock emissions anchor. This assumption reflects a moderate BAU trajectory rather than an aggressive expansion pathway. It is consistent with the BTR's statement that emissions from agriculture and livestock have not increased significantly historically and are not expected to increase significantly soon. It also recognizes that livestock productivity improvements and gradual changes in production systems may offset some of the pressure that could otherwise arise from increased demand for dairy and other livestock products (DECC, 2024).

*Table 29. BAU livestock emissions projection, 2022–2030*

| Year | BAU livestock emissions (Gg $CO_2$e) |
|---|---|
| 2022 | 365.00 |
| 2023 | 366.82 |
| 2024 | 368.66 |
| 2025 | 370.50 |
| 2026 | 372.35 |
| 2027 | 374.22 |
| 2028 | 376.09 |
| 2029 | 377.97 |
| 2030 | 379.86 |

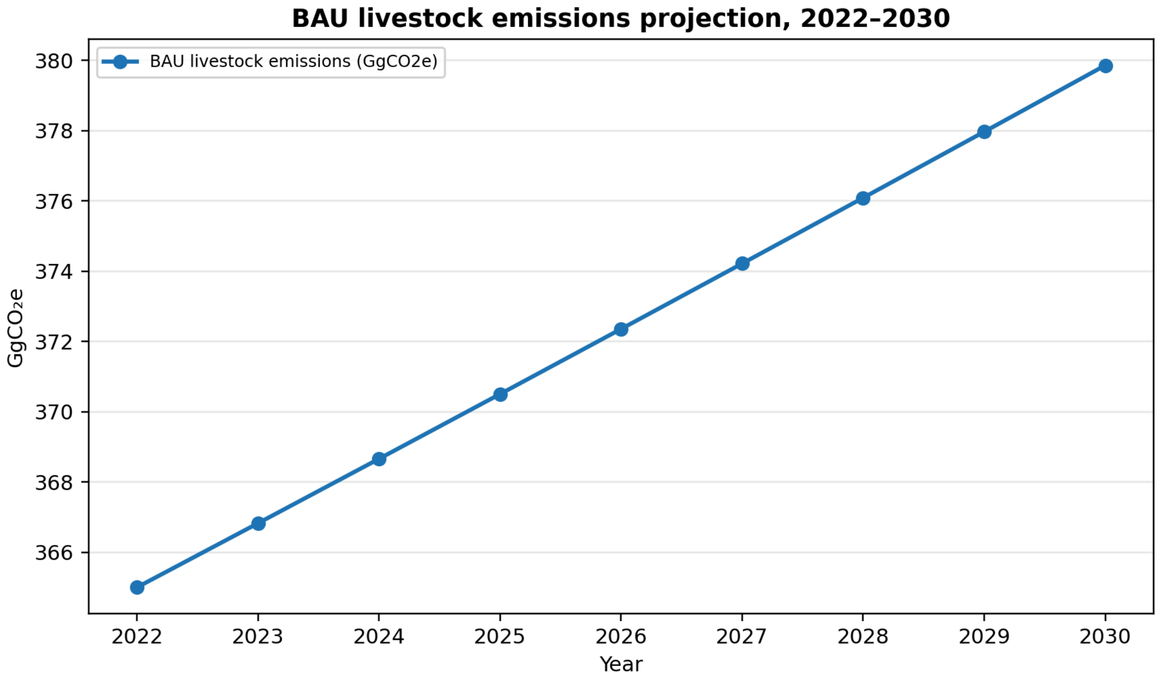


*Figure 40. BAU livestock emissions projection, 2022–2030.*

Under the BAU pathway, livestock emissions increase from 365.00 Gg $CO_2$e in 2022 to approximately 379.86 Gg $CO_2$e in 2030 (see Table 29 and Figure 40). The increase is small compared with high-growth scenarios that might be used in more rapidly intensifying livestock systems. However, even a stable livestock emissions pathway requires active management because the sector is dominated by methane, a powerful greenhouse gas, and because Bhutan's carbon-neutral development pathway depends on keeping non-LULUCF emissions from expanding faster than forest removals and other mitigation measures (DECC, 2024).

## 10.4 Emissions mitigation scenarios

The three scenarios presented below are analytical estimates based on progressive reductions against the BAU pathway. The scenarios are also shown in Table 30 and Figure 41.

*Table 30. Livestock mitigation scenario projections, 2022–2030*

| Year | BAU livestock emissions (Gg $CO_2$e) | Scenario 1: Dairy and feeding efficiency (Gg $CO_2$e) | Scenario 2: Manure management and biogas (Gg $CO_2$e) | Scenario 3: Integrated low-carbon livestock (Gg $CO_2$e) |
|---|---|---|---|---|
| 2022 | 365.00 | 365.00 | 365.00 | 365.00 |
| 2023 | 366.82 | 363.16 | 362.24 | 358.57 |
| 2024 | 368.66 | 361.29 | 359.44 | 352.07 |
| 2025 | 370.50 | 359.39 | 356.61 | 345.49 |

| | | | | |
|---|---|---|---|---|
| 2026 | 372.35 | 357.46 | 353.74 | 338.84 |
| 2027 | 374.22 | 355.51 | 350.83 | 332.12 |
| 2028 | 376.09 | 353.52 | 347.88 | 325.32 |
| 2029 | 377.97 | 351.51 | 344.90 | 318.44 |
| 2030 | 379.86 | 349.47 | 341.87 | 311.48 |

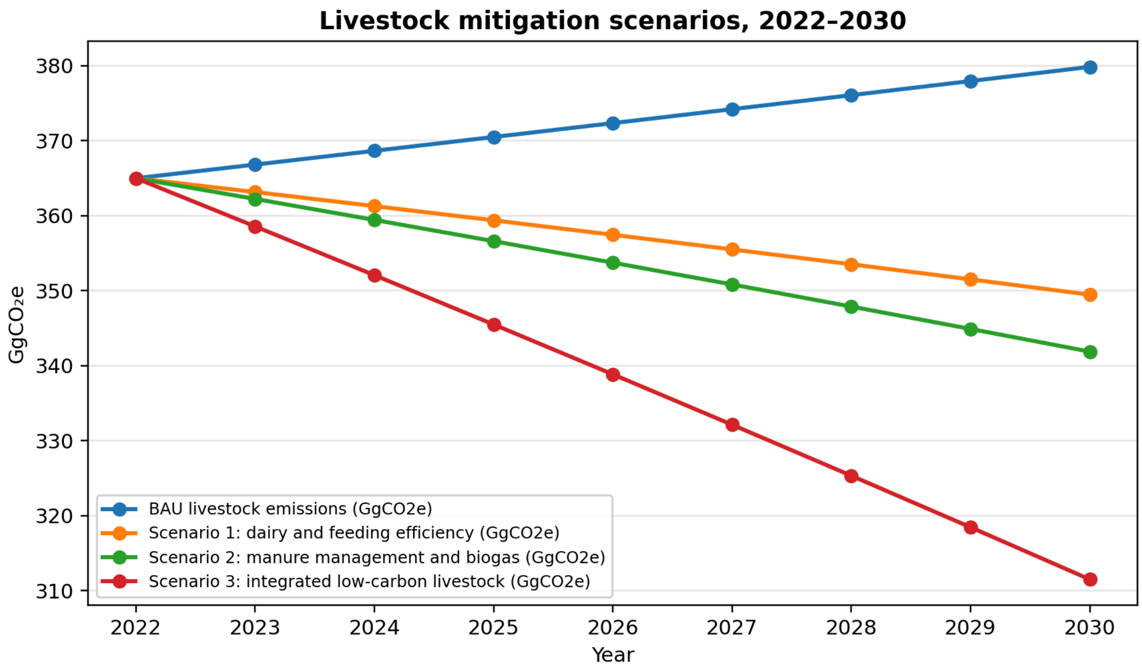


*Figure 41. Livestock mitigation scenarios compared with BAU, 2022–2030.*

### 10.4.1 Scenario 1: Improved dairy production and feeding management

Scenario 1 focuses on reducing enteric methane intensity through improved dairy cattle production, breed improvement, better nutrition and expanded stall feeding where appropriate. This scenario is directly aligned with the BTR's description of the Low Emission Development Strategy for Food Security, which includes improved dairy cattle production through breed improvement and feeding management. It also reflects ongoing actions such as the use of sex-sorted semen to increase improved milch cattle and stall-feeding practices to ensure better nutrition and manure management (DECC, 2024).

Higher-productivity animals can produce more milk per unit of methane emitted, while improved feed quality can reduce methane intensity by improving digestibility and shortening the time required to reach productive output. In practical terms, the scenario would include breed improvement, veterinary and animal-health services, targeted feed and fodder planning, better winter and dry-season nutrition, farmer advisory services, and record-keeping systems that link productivity with emissions intensity. Because enteric fermentation accounts for most livestock emissions, even moderate improvements in emission intensity can produce meaningful sector-level reductions.

In this scenario, reductions rise gradually to 8% below BAU by 2030. By 2030, projected emissions are 349.47 Gg $CO_2e$, compared with 379.86 Gg $CO_2e$ under BAU, yielding an annual reduction of 30.39 Gg $CO_2e$. Cumulative reduction over 2023–2030 is estimated at 135.17 Gg $CO_2e$. The environmental sustainability benefits include more efficient land and feed use, better manure capture under stall-feeding systems, improved dairy productivity, and reduced pressure to expand animal numbers solely to increase output.

### 10.4.2 Scenario 2: Manure management and biogas expansion

Scenario 2 focuses on manure management, household and farm-scale biogas, and improved use of organic manure. The BTR reports the installation of 8,687 small and medium biogas units and identifies biogas production as part of the Low Emission Development Strategy for Food Security. It also notes that the strategy aims to create renewable energy sources and reduce the use of firewood, while improving manure management and livestock productivity (DECC, 2024).

The scenario targets methane and nitrous oxide from manure management while also generating energy and circular-economy benefits. Manure management emissions are smaller than enteric emissions in Bhutan's livestock inventory, but they are more directly linked to technology and handling practices. Improved manure collection, covered storage, biogas digesters, composting of digestate, and safe application of organic manure can reduce unmanaged emissions and improve nutrient recycling. Where households currently use fuelwood or fossil fuels for cooking, biogas can generate additional mitigation co-benefits outside the livestock inventory boundary by displacing traditional energy sources.

In this scenario, reductions reach 10% below BAU by 2030. By 2030, projected emissions are 341.87 Gg $CO_2e$, giving an annual reduction of 37.99 Gg $CO_2e$ relative to BAU. Cumulative reductions from 2023 to 2030 are estimated at 168.97 Gg $CO_2e$. The scenario's broader environmental benefits include improved farm sanitation, reduced nutrient losses, greater availability of organic fertilizer, improved soil health, and reduced household dependence on firewood where biogas is used for cooking.

### 10.4.3 Scenario 3: Integrated low-carbon livestock transformation

Scenario 3 combines the measures in Scenarios 1 and 2 into an integrated livestock transformation pathway. It includes improved dairy breeding and feeding, herd productivity improvement, expanded biogas, improved manure handling, climate-smart extension, improved data systems and monitoring, and targeted support for farmers in peri-urban and rural production systems. The scenario is consistent with the BTR's emphasis on the LEDS for Food Security and its improvement plan, which calls for better empirical information on livestock manure management, production systems and feeding practices, capacity building for enteric fermentation estimation, uncertainty analysis, projections and trend analysis (DECC, 2024).

The integrated pathway is the most ambitious scenario because it targets both absolute emissions and emission intensity. It assumes that Bhutan can gradually expand the use of improved breeds, better feeding regimes and stall-feeding where feasible; link manure collection to biogas and organic fertilizer; and develop more reliable data systems for livestock populations, feeding systems and manure management by geographical zone. This is especially important because future inventory accuracy will improve if Bhutan can move progressively from default or expert-judgement assumptions toward country-specific Tier 2 methods for key livestock categories.

In this scenario, emissions fall to 18% below BAU by 2030. Projected 2030 emissions are 311.48 Gg $CO_2$e, implying an annual reduction of 68.37 Gg $CO_2$e compared with BAU. Cumulative reduction during 2023–2030 is estimated at 304.14 Gg $CO_2$e. Because the scenario combines productivity, manure and data-system improvements, it offers the strongest sustainability outcomes: lower methane intensity, better nutrient cycling, improved rural energy access, stronger farm resilience, better animal health and a more credible MRV basis for future reporting.

The summary of the three mitigation scenarios outcomes is shown in Table 31 and Figure 42.

*Table 31. Summary of mitigation scenario outcomes*

| Scenario | 2030 emissions (Gg $CO_2$e) | 2030 reduction vs BAU (Gg $CO_2$e) | 2030 reduction vs BAU (%) | Cumulative 2023–2030 reduction (Gg $CO_2$e) |
|---|---|---|---|---|
| Scenario 1: dairy and feeding efficiency | 349.47 | 30.39 | 8 | 135.17 |
| Scenario 2: manure management and biogas | 341.87 | 37.99 | 10 | 168.97 |
| Scenario 3: integrated low-carbon livestock | 311.48 | 68.37 | 18 | 304.14 |

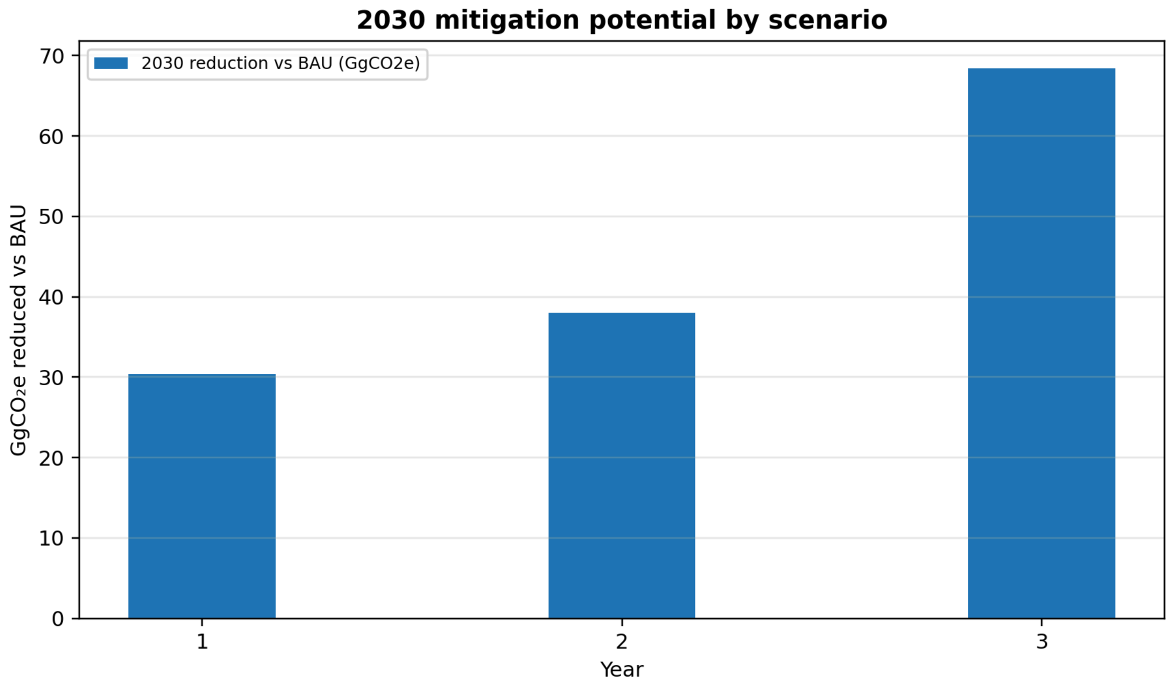


*Figure 42. Estimated 2030 reduction relative to BAU by scenario.*

## 10.5 Strategies for emissions reduction and environmental sustainability

### 10.5.1 Strategy 1: Improve feed quality and animal productivity

Because enteric fermentation dominates livestock emissions, Bhutan should prioritize feed-quality improvement, fodder development, veterinary support, breed improvement and dairy productivity. The objective should be to reduce emissions per liter of milk and per unit of livestock product, rather than simply reducing livestock activity. Extension services can support farmers in feed planning, animal nutrition, record keeping and adoption of appropriate breeds for local conditions (DECC, 2024).

### 10.5.2 Strategy 2: Scale biogas and circular manure systems

The existing installation of small and medium biogas units provides a practical foundation for scaling manure-to-energy systems. Priority should be given to households and farms where stall feeding or semi-confined production makes manure capture feasible. Digestate should be integrated into organic fertilizer systems to replace synthetic inputs where agronomically appropriate (DECC, 2024).

### 10.5.3 Strategy 3: Strengthen manure management evidence

The BTR improvement plan identifies the need for empirical information on livestock manure management practices. Bhutan should conduct rapid assessments and targeted studies to verify manure handling, storage, deposition and treatment practices by animal type, production system and agro-ecological zone. This will improve both mitigation planning and inventory accuracy (DECC, 2024).

### 10.5.4 Strategy 4: Develop Tier 2 livestock inventory capacity

Bhutan should gradually improve its capacity for Tier 2 estimation for key livestock categories, especially cattle. This requires better activity data by geographic zone, feeding system, production system, animal weight, productivity and manure-management practice. Training of technical staff in IPCC tools, uncertainty estimation and projection methods should be treated as part of the mitigation strategy, not only as a reporting activity (DECC, 2024).

### 10.5.5 Strategy 5: Link mitigation with farmer incentives

Low-carbon livestock practices require farmer participation. Incentives can include support for improved breeds, fodder systems, biogas investment, organic manure marketing, training, cooperative services and results-based recognition for farms adopting climate-smart practices. Because livestock is tied to livelihoods, mitigation should be implemented through productivity and income-enhancing measures (DECC, 2024).

### 10.5.6 Strategy 6: Integrate livestock, soil and landscape management

Livestock mitigation should be linked with improved pasture management, soil health, water security and agroforestry where relevant. Better manure use can enhance soil fertility, while improved fodder and perennial biomass can reduce pressure on natural resources. This integrated approach supports mitigation, adaptation and food security simultaneously (DECC, 2024).

## 10.6 Conclusion

Bhutan's livestock sector is a strategically important source of methane and nitrous oxide within the broader agriculture and food-systems profile, but it must be interpreted through the lens of food security, rural livelihoods and low-emission development rather than through an emissions-reduction lens alone. The analysis shows that livestock emissions are dominated by enteric fermentation, while manure management provides a smaller but highly practical mitigation entry point because it can be linked to biogas, organic fertilizer, sanitation and circular nutrient management. The BTR reports livestock-sector emissions of 365 Gg $CO_2$e in 2022, with enteric fermentation accounting for the largest share, confirming that feed quality, animal productivity, breed improvement and herd management are the most important mitigation levers (DECC, 2024).

The three mitigation scenarios show that meaningful livestock-sector mitigation is achievable if interventions are implemented through farmer-centered support systems. Scenario 1, focused on dairy and feeding efficiency, reduces 2030 emissions to about 349.47 Gg $CO_2e$ and provides an estimated cumulative reduction of 135.17 Gg $CO_2e$ during 2023-2030. Scenario 2, focused on manure management and biogas, reduces 2030 emissions to about 341.87 Gg $CO_2e$ and provides an estimated cumulative reduction of 168.97 Gg $CO_2e$. Scenario 3, the integrated low-carbon livestock pathway, combines feeding, productivity, animal health, breed improvement, manure recovery, biogas and MRV improvements, reducing 2030 emissions to about 311.48 Gg $CO_2e$ and generating an estimated cumulative reduction of 304.14 Gg $CO_2e$ during 2023-2030.

The priority strategy for Bhutan is therefore an integrated low-carbon livestock programme that improves productivity while reducing methane intensity. This should include better feed and fodder systems, improved dairy productivity, animal-health services, selective breed improvement, stall feeding where appropriate, manure collection, covered storage, composting, household and institutional biogas, and use of digestate as organic fertilizer. The programme should be implemented through extension services, farmer groups, dairy cooperatives, local governments and targeted financing mechanisms so that mitigation measures generate visible livelihood and farm-management benefits.

A second priority is to strengthen the evidence base for future inventory improvement. The livestock analysis is constrained by differences between the BTR narrative total and detailed CRT extraction. Bhutan should therefore improve data on livestock populations by species, age and production system; feed quality and feeding practices; milk productivity; manure management pathways; biogas performance; and geographic differences in livestock systems. These improvements would support movement toward higher-tier livestock inventory methods for key categories and would strengthen the credibility of future BTRs, NDC tracking and climate-finance proposals (DECC, 2024).

# 11. Conclusion

## 11.1 Integrated mitigation portfolio

The six sectors together define an integrated mitigation portfolio. IPPU offers the largest positive-emissions reduction potential among the emitting sectors; transport is a strategic petroleum-demand and urban mobility sector; waste is a high co-benefit sector for cities, health and water quality; agriculture and livestock are food-security sectors where mitigation must protect livelihoods; and forestry/LULUCF is the foundation of the national sink. The integrated portfolio therefore has two pillars: reducing gross emissions and enhancing removals. Both pillars are necessary because reliance on forest sinks alone would increase long-term risk, while ignoring forest sinks would misrepresent Bhutan's actual climate balance.

## 11.2 Cross-sector MRV and data improvement agenda

The BTR improvement plan highlights activity-data accuracy, country-specific emission factors, capacity building and institutional linkages. This synthesis translates that improvement agenda into sector-specific MRV priorities. Waste needs municipal data on generation, composition, diversion, disposal and wastewater treatment. Transport needs fuel, vehicle stock, vehicle kilometer, public transport and charging data. IPPU needs facility-level production and process data. Agriculture needs rice-water, fertilizer, soil and organic input data. Livestock needs herd, feed, productivity and manure-system data. Forestry needs repeated NFI, land-cover maps, remote sensing, disturbance monitoring and carbon-pool tracking.

## 11.3 Finance and investment pipeline

The mitigation portfolio should be converted into a finance-ready pipeline. Grants and readiness support can fund data systems, feasibility studies, policy design and MRV. Concessional loans can support electric buses, charging infrastructure, wastewater treatment, recycling facilities and industrial efficiency. Results-based finance and carbon finance can support forest conservation, restoration, agroforestry and methane-reduction projects where methodologies are feasible. Public finance should de-risk investments with strong public benefits, while private finance should be mobilized for commercial opportunities.

## 11.4 Environmental and social sustainability

Mitigation should support environmental sustainability rather than narrow carbon accounting. Waste measures should improve public health and water quality. Transport measures should improve access and affordability. IPPU measures should address local environmental impacts and competitiveness. Agriculture and livestock measures should protect food security, soil health and farmer income. Forestry measures should protect biodiversity, watershed services and community values. This safeguards lens is necessary for long-term legitimacy and effective implementation.

## 11.5 Key recommendations and roadmap

The final recommendation is to create a national low-emission investment and MRV platform. The platform should maintain sector baselines, integrate project pipelines, track finance and results, and support future BTR reporting. It should prioritize IPPU and transport for gross-emission reductions, waste for urban environmental benefits, agriculture and livestock for climate-smart rural development, and forestry/LULUCF for sink protection and enhancement. Implementation should be staged from immediate baseline and readiness work to medium-term investment and long-term transformation.

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