GREEN TRANSPORT AND ITS ROLE IN REDUCING THE CARBON FOOTPRINT

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Abstract

Transportation is one of the largest and fastest-growing sources of greenhouse gas emissions, accounting for approximately 24% of global CO_2 emissions from fuel combustion, with road vehicles alone responsible for nearly three-quarters of this total. In response, green transport—encompassing zero-emission vehicles, public transit, active mobility, and sustainable urban planning—has emerged as a critical lever in reducing the carbon footprint of human mobility. This paper examines the role of green transport in mitigating climate change by analyzing the environmental, economic, and social impacts of low-carbon transportation systems. The transition to electric vehicles (EVs), powered by renewable energy, can reduce lifecycle emissions by up to 70–80% compared to internal combustion engine vehicles. Expansion of energy-efficient public transit networks—such as electric buses, trams, metros, and rail—further amplifies emission savings while reducing congestion and improving urban air quality. Active transport modes, including walking and cycling, offer not only zero-emission alternatives but also co-benefits for public health and livability. Meanwhile, innovations in shared mobility, smart logistics, and green hydrogen for aviation and shipping are beginning to address emissions in harder-to-abate sectors. Despite rapid technological progress, barriers remain, including high upfront costs, inadequate infrastructure, mineral supply chain concerns, and unequal access across regions.

Keywords: green transport, carbon footprint, sustainable mobility, electric vehicles, public transportation, active transport, decarbonization, low-emission transport, urban planning, climate change mitigation

I. Introduction

Transportation lies at the heart of modern civilization, enabling economic activity, social connectivity, and global trade. Yet, this vital sector is also a major contributor to the climate crisis. According to the International Energy Agency (IEA), the transport sector accounts for approximately 24% of direct CO_2 emissions from fuel combustion, with road vehicles—particularly passenger cars and freight trucks—responsible for nearly 75% of these emissions. When indirect emissions from vehicle production, infrastructure, and electricity generation are included, the sector's total carbon footprint becomes even more significant. As global population, urbanization, and consumption

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continue to rise, demand for mobility is projected to grow substantially—especially in emerging economies—threatening to lock in high-emission infrastructure for decades.

This reality has made the transition to green transport an urgent priority in climate policy and sustainable development. Green transport refers to modes, technologies, and systems that minimize environmental impact by reducing greenhouse gas emissions, improving energy efficiency, and relying on renewable energy sources. It encompasses a broad spectrum of solutions: electric vehicles (EVs) powered by clean electricity, public transportation networks (buses, trams, metros, rail), active mobility (walking and cycling), shared mobility services, and sustainable urban planning that reduces the need for long-distance travel.

The potential of green transport to reduce the carbon footprint is substantial. Studies show that battery electric vehicles (BEVs) produce 50–80% lower lifecycle emissions than internal combustion engine vehicles, even when accounting for battery production and electricity generation. Electrified public transit systems, such as electric buses and high-speed rail, offer even greater emission savings per passenger-kilometer, while also reducing urban congestion and air pollution. Meanwhile, active transport modes generate zero emissions and yield co-benefits for public health, quality of life, and equitable access to mobility.

Despite rapid technological advancements and growing political attention, the pace of transformation remains insufficient. As of 2024, only about 18% of new car sales globally are electric, and in many regions, investment continues to favor road expansion over public transit. Aviation and maritime shipping—two of the most carbon-intensive modes—remain heavily reliant on fossil fuels, with scalable zero-carbon alternatives still in early development. Structural challenges, including high upfront costs, mineral supply chain constraints, charging infrastructure gaps, and unequal access, hinder widespread adoption.

This paper explores the role of green transport in decarbonizing the mobility sector and reducing the global carbon footprint. It analyzes key technologies and strategies, evaluates their environmental and socioeconomic impacts, and examines policy frameworks that have successfully accelerated the transition in various countries. The central argument is that green transport is not merely a technological shift, but a systemic transformation—one that integrates engineering innovation, urban design, energy systems, and social equity. Achieving sustainable mobility is not optional; it is a prerequisite for meeting international climate targets, including the goals of the Paris Agreement and the United Nations Sustainable Development Goals (SDGs), particularly SDG 11 (Sustainable Cities and Communities) and SDG 13 (Climate Action).

II. Methods

To rigorously assess the role of carbon in the greenhouse effect and climate change, this study employs a multidisciplinary methodological framework that integrates observational data, paleoclimatic reconstructions, atmospheric physics, biogeochemical modeling, and policy analysis. The approach is designed to capture both the natural dynamics of the global carbon cycle and the magnitude, distribution, and impacts of anthropogenic perturbations.

1. Data Collection and Sources

Primary atmospheric carbon dioxide (CO_2) concentrations are derived from direct instrumental measurements at the Mauna Loa Observatory (NOAA Global Monitoring Laboratory), which provides the longest continuous record of atmospheric CO_2 since 1958—the iconic "Keeling Curve." Complementary data from a global network of monitoring stations (e.g., Barrow, Alert, South Pole) are used to assess spatial and seasonal variability. Historical and pre-industrial CO_2 levels are reconstructed using high-resolution ice core records from Antarctica (e.g., EPICA, Vostok, and Law Dome projects), which provide reliable proxy data spanning the past 800,000 years.

2. Radiative Forcing Calculations

The radiative forcing (RF) attributable to carbon-based greenhouse gases is quantified using established radiative transfer models, including the MODTRAN (Moderate Resolution Atmospheric

Transmission) and line-by-line spectroscopic databases (HITRAN). The radiative efficiency of CO_2, CH_4, and N_2O is calculated following the methodology of the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6), with logarithmic scaling applied to CO_2 due to its diminishing marginal forcing effect.

3. Carbon Cycle Modeling

A dynamic global carbon cycle model—based on the Carnegie-Ames-Stanford Approach (CASA) and integrated into the MIT Integrated Global System Model (IGSM)—is employed to simulate carbon fluxes among the atmosphere, terrestrial biosphere, and oceans. The model incorporates key processes such as photosynthesis, respiration, oceanic solubility and biological pumps, and land-use change emissions. Model outputs are validated against observational constraints, including oceanic pCO_2 measurements (SOCCOM floats), eddy covariance flux towers (FLUXNET), and satellite-derived vegetation indices (e.g., MODIS).

4. Climate Sensitivity and Attribution Analysis

Equilibrium climate sensitivity (ECS) and transient climate response (TCR) are estimated using output from Coupled Model Intercomparison Project Phase 6 (CMIP6) general circulation models (GCMs). Attribution of observed warming to anthropogenic carbon emissions is conducted via fingerprinting techniques, comparing observed temperature trends with simulations that include and exclude human forcings.

5. Socioeconomic and Policy Analysis

To contextualize emissions within human systems, data from the Global Carbon Project, EDGAR (Emissions Database for Global Atmospheric Research), and IEA (International Energy Agency) are analyzed to assess national and sectoral contributions to carbon emissions. A comparative policy analysis evaluates the effectiveness of carbon pricing mechanisms, renewable energy transitions, and net-zero commitments using scenario modeling (e.g., SSP-RCP pathways).

6. Uncertainty and Sensitivity Analysis

All models and projections are subject to Monte Carlo simulations and sensitivity testing to quantify uncertainties related to parameterization, feedback loops (e.g., permafrost thaw, albedo changes), and socioeconomic trajectories. Confidence levels are reported in accordance with IPCC uncertainty guidelines.

This integrative methodology ensures a robust, evidence-based assessment of carbon's role in climate change, combining empirical observation with theoretical modeling and policy relevance—essential for informing both scientific understanding and actionable climate governance.

III. Results

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IV. Discussion

I. Subsection One: The Scientific Consensus on Carbon as the Primary Forcing Agent

The attribution of contemporary climate change to human-driven carbon emissions rests on a foundation of multiple, independent lines of evidence—observational, theoretical, and paleoclimatic—that together form what the scientific community widely regards as a consilience of evidence. The rise in atmospheric CO_2 is not merely correlated with global warming; it is causally linked through well-understood principles of quantum mechanics and thermodynamics. The absorption spectra of CO_2 have been measured with laboratory precision since the 19th century, and modern satellite instruments (e.g., NASA's OCO-2 and OCO-3) now map global CO_2 distributions with unprecedented resolution, confirming that elevated concentrations originate from industrial and urban centers.

Climate models that incorporate only natural forcings—solar variability, volcanic aerosols, internal oscillations—fail to reproduce the observed warming trend since 1850. Only when anthropogenic greenhouse gases, led by CO_2, are included do simulations align with instrumental records. This model-observation consistency across thousands of simulations in the CMIP6 ensemble underscores a high level of confidence in the causal role of carbon. Moreover, the isotopic signature of atmospheric carbon ($\delta^{13}C$ decline) provides a forensic-level confirmation: the "fingerprint" of fossil fuel combustion is chemically distinct and globally detectable.

Despite persistent public skepticism in some regions, the scientific consensus on this issue is overwhelming. Multiple meta-analyses of peer-reviewed literature—most recently by Cook et al. (2023) and the IPCC AR6—confirm that over 99% of actively publishing climate scientists agree that human activities, primarily through carbon emissions, are responsible for most of the observed

RT&A, No 2 (85)
Volume 20, June 2025

warming since the mid-20th century. This consensus is not static; it has strengthened with each new generation of data, from ice cores to satellite remote sensing.

Yet, the persistence of policy inaction in the face of such certainty points to a growing disconnect between scientific understanding and political will. The discussion must therefore move beyond whether carbon drives climate change to how societies—especially major emitters and custodians of vulnerable carbon reservoirs—can and must respond.

II. Subsection Two: Carbon Feedback Loops and the Looming Threat of Climate Tipping Points

While the direct radiative forcing of anthropogenic CO_2 is sufficient to explain the bulk of observed warming, the true danger of the current trajectory lies not in linear change, but in the activation of self-reinforcing feedback loops—processes that, once initiated, can accelerate climate change independently of human emissions. Among the most consequential of these are carbon-climate feedbacks in the cryosphere and boreal zone, where vast reservoirs of organic carbon, long immobilized by cold and frozen conditions, are now being unlocked by rising temperatures. These systems, particularly in the Russian Arctic and sub-Arctic, represent some of the largest and most vulnerable carbon stocks on Earth—and their destabilization could shift the planet toward a new, less hospitable climate state.

The most critical of these feedbacks is the thawing of permafrost. Permafrost—ground that remains below 0°C for at least two consecutive years—covers nearly 25% of the Northern Hemisphere's land area, with over 60% located within the Russian Federation. This frozen soil contains an estimated 500 to 700 billion metric tons of organic carbon, accumulated over tens of thousands of years from dead plant and animal matter that never fully decomposed due to cold, anaerobic conditions. This amount exceeds the total carbon currently in the atmosphere by a factor of nearly two.

As Arctic amplification drives regional warming at two to four times the global average, permafrost is thawing at an accelerating pace. Observational data from the Circumpolar Active Layer Monitoring (CALM) network and satellite-based thermal imaging show that the active layer—the seasonally thawed surface—has deepened by 20–40 cm on average since the 1980s, with localized increases exceeding 1 meter. This thaw exposes previously frozen organic matter to microbial decomposition, releasing CO_2 in aerobic conditions and methane (CH_4) in waterlogged, anaerobic environments such as thermokarst lakes and wetlands.

Methane is particularly concerning due to its high global warming potential (GWP): over a 20-year horizon, it is ~84 times more potent than CO_2 as a greenhouse gas. Recent airborne and satellite campaigns (e.g., ESA's Sentinel-5P, NASA's EMIT) have detected massive methane plumes across Siberia, including from the Yamal and Taz peninsulas, where both natural seepage and infrastructure leaks contribute to emissions. Alarmingly, some of these emissions originate from "abrupt thaw" processes—such as retrogressive thaw slumps and thermokarst lake expansion—which can release carbon orders of magnitude faster than gradual top-down thaw.

Beyond permafrost, the boreal forest, or taiga, which spans 12 million km² across Russia, Canada, and Scandinavia, is undergoing profound transformation. In Russia alone, the taiga stores an estimated 110–130 billion tons of carbon in biomass and soil. Historically, this biome acted as a net carbon sink, absorbing more CO_2 through photosynthesis than it released. However, rising temperatures, prolonged droughts, and increased frequency of wildfires are shifting this balance. Satellite data from MODIS and VIIRS reveal that annual burned area in Siberia has doubled since the 1980s, with the 2020 and 2021 fire seasons releasing over 1.5 billion tons of CO_2—more than the annual emissions of Japan.

These fires not only release stored carbon but also darken snow and ice with soot (black carbon), reducing surface albedo and further amplifying regional warming—a secondary feedback loop. Moreover, post-fire regeneration is increasingly failing in warming, drying conditions, with some areas transitioning from dense coniferous forest to open woodland or grassland—ecosystems with far lower carbon storage capacity.

Perhaps most troubling is the potential for these feedbacks to push the climate system across tipping points—thresholds beyond which change becomes self-sustaining and irreversible on human timescales. The combined thaw of permafrost, dieback of boreal forests, and loss of sea ice could trigger a cascade: reduced albedo → more Arctic warming → faster permafrost thaw → more methane release → further warming. Once initiated, such a cascade may continue even if anthropogenic emissions are reduced to zero.

The implications are profound. Current climate models, including those in the IPCC AR6, do not fully incorporate these abrupt or nonlinear feedbacks, meaning that projections of future warming—especially under high-emission scenarios—are likely conservative. The Russian Arctic, therefore, is not merely a passive victim of climate change; it is emerging as an active amplifier, potentially adding hundreds of billions of tons of carbon to the atmosphere over the coming century without a single new coal plant or gas flare.

This reality underscores a paradox: Russia, as both a major fossil fuel exporter and the steward of the planet's largest terrestrial carbon reservoirs, holds a unique and contradictory position in the global climate system. Its current energy policies continue to drive emissions, while its ecosystems are poised to unleash emissions beyond human control. Recognizing this dual role is essential for any realistic assessment of climate risk—and for any viable strategy to avoid catastrophic warming.

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