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# Editorial: Assessing greenhouse gas emissions at city and regional levels: challenges and methods

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Editorial on the Research Topic
Assessing greenhouse gas emissions at city and regional levels: challenges and methods

Accurate quantification of greenhouse gas (GHG; i.e., $CO_2$, $CH_4$, and $N_2O$) emissions is essential to climate-change mitigation and evidence-based policymaking and is therefore crucial for the development of effective mitigation strategies (Dogniaux et al., 2025). However, multi-decadal records of global atmospheric GHG concentrations (https://gml.noaa.gov/aggi/) indicate persistent and substantial knowledge gaps in constraining emissions and sinks, particularly over emission hotspots, from regional to global scales. Although a wide range of instruments and approaches has been deployed to quantify GHG fluxes at field and landscape scales, observed concentration dynamics—which represent aggregated signals over multiple spatial extents—continue to reveal considerable uncertainty and potential bias in emission estimates across scales, especially for hotspots spanning urban areas and broader regional domains (Hu et al., 2023). One reason is that city- and regional-scale assessments remain comparatively underdeveloped, in part due to limited access to comprehensive observations and scalable methodologies. Addressing this gap will require advances in both data acquisition and methodological innovation to enable a more integrated understanding of emissions. Recent advances in atmospheric inversion frameworks and eddy-covariance observations have made substantial progress; however, further work is needed to identify and quantify the key drivers of emissions, particularly in densely populated urban environments and heterogeneous, resource-diverse regions. The Research Topic "*Assessing greenhouse gas emissions at city and regional levels: challenges and methods*" brings together timely contributions that examine how complementary approaches can be applied and integrated to quantify GHG emissions with reduced uncertainty, especially over emission hotspots. Collectively, these studies underscore a significant implication: integrating multiple data sources and combining "top-down" and "bottom-up" approaches can effectively reduce uncertainty and provide actionable evidence to support policy design and evaluation from cities to nations (Figure 1).

Within this Research Topic, the contributions can be broadly categorized as "bottom-up" and "top-down" approaches. Han et al. and Feng et al. represent the bottom-up perspective. Han et al. employed an updated STIRPAT framework to predict China's future anthropogenic $CO_2$ emissions through 2100 under multiple Shared Socioeconomic Pathway


FIGURE 1
The graficical overview for this collection.

(SSP) scenarios. The authors also incorporated nature-based $CO_2$ sinks to derive carbon neutrality capacity (CNC), revealing pronounced spatiotemporal disparities across regions. Their analysis suggests that China could ultimately achieve its carbon-neutrality objective (CNC > 100%) before 2060, contingent upon increasing the share of clean energy to more than 80%. By using the same STIRPAT model, Feng et al. also quantified the driving forces and spatiotemporal heterogeneity of carbon footprint pressure in China's Yangtze River region from 2000 to 2021. These studies underscore the need for region-specific mitigation policies and demonstrate that well-designed strategies using bottom-up models can help reduce estimation uncertainty, quantify key drivers, and project regional climate mitigation trajectories.

The remaining studies in this Research Topic, by Ma et al. and He et al., employed top-down approaches. Ma et al. leveraged nighttime light observations in the Yellow River Basin of China to estimate multi-scale spatiotemporal patterns of $CO_2$ emissions from 2000 to 2022. Their results indicate clear spatial heterogeneity among cities, with an overall gradient described as "lower reaches > middle reaches > upper reaches." Given that nighttime light products are publicly available and readily scalable, this work provides a practical approach to city-scale greenhouse gas accounting, particularly in contexts where GHG measurements are limited. He et al. used an unmanned aerial vehicle (UAV) AirCore system over the Shengli Oilfield (China) to quantify $CH_4$ emissions at the facility level. By integrating three-dimensional $CH_4$ concentration measurements with a Gaussian dispersion modeling framework, they achieved emission estimates for hotspot facilities with relatively low uncertainties (3.7% and 1.1% for the two study areas). These findings highlight the potential of advanced technologies, such as UAV-enabled atmospheric observations, in constraining GHG emissions from hotspots.

Collectively, the studies in this Research Topic showcase advanced methodological capabilities and provide policy-relevant insights. The studies demonstrate the potential to reduce uncertainties in GHG emission estimates across scales, sectors, and hotspots by highlighting the complementary strengths of bottom-up and top-down approaches. Bottom-up projections illustrate how alternative development pathways, particularly those embedded in SSP narratives and mitigation strategies, can materially influence carbon-neutrality outcomes. Conversely, top-down studies demonstrate how scalable observational platforms, such as UAVs, can improve the detection and quantification of emissions, especially from urban and industrial hotspots. Looking forward, this Research Topic suggests that effective climate change mitigation will require a more robust and diverse methodological toolbox. This toolbox should explicitly integrate observations, models, and policy frameworks across spatial scales. By doing this, it can improve future emission projections, inform targeted interventions, and ultimately support the attainment of carbon-neutrality goals in an increasingly complex and rapidly changing society.

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