Environmental Impact Assessment Review 69 (2018) 82–93

Contents lists available at ScienceDirect

Environmental Impact Assessment Review

journal homepage: www.elsevier.com/locate/eiar

Assessing direct and indirect emissions of greenhouse gases in road transportation, taking into account the role of uncertainty in the emissions inventory

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ARTICLE INFO

Keywords:
GHG inventory
Uncertainty
Vehicle transportation
Global warming potential
Direct and indirect emissions

ABSTRACT

Greenhouse gas (GHG) concentration in the atmosphere has increased since the beginning of the industrial era, with dramatic effects on climate change. Transportation is one of the main sources of GHGs, with more than two-thirds of transport-related GHG emissions attributable to road vehicles. Any policy that aims to reduce GHG emissions needs robust measuring methods that guarantee the quality and reliability of primary data and estimates. However, these estimates are subject to uncertainty, both at the stage of compiling accounting tables and at the stage of using this information to formulate a specific policy question.

This paper considers how to reduce uncertainty in estimating GHG emissions from road transportation, with specific reference to a regional emissions inventory in Italy. We propose the application of a use-chain model that can tackle uncertainty in measuring GHG emissions by enhancing the quality of the emissions data registry in the inventory. This new metric, which we call emission value at risk (VaR), draws from methodologies and concepts employed in the insurance and financial sectors. Moreover, additional assessments are performed, integrating the inventory data with those available in the regional energy balance and disaggregated sectoral economic dataset. The results show that a sound accounting method enables uncertainty in emission data to be taken into account, thus improving the design of appropriate strategies to reduce GHG emissions.

1. Introduction

The increase in greenhouse gas (GHG) concentrations is attributed to the burning of fossil fuels and the intense urbanization process worldwide (IPCC, 2014). The consequence of this increase is global alteration of the climate, which causes adverse phenomena such as floods and droughts, modifications in the level and the patterns of precipitation, and heatwaves in cities.

On 12th December 2015, negotiations among the Conference of Parties (CoP21) concluded with the adoption of the Paris Agreement, a global climate deal to reduce carbon emissions and slow global warming. Article 2 of the Paris Agreement (UNFCCC, 2015) aims to "*[hold] the increase in the global average temperature to well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase to 1.5 °C above pre-industrial levels, recognizing that this would significantly reduce the risks and impacts of climate change […].*"

Paragraph 13 of article 4 states that "*[…] in accounting for anthropogenic emissions and removals corresponding to their nationally determined contributions, Parties shall promote environmental integrity, transparency, accuracy, completeness, comparability and consistency, and ensure the avoidance of double counting […].*"

Accurate estimates of GHG emissions are undoubtedly vital, both to measure and record emissions over time consistently and to provide reliable input to policy making processes and tools, especially with regard to adaptation to climate change.

The consistency and reliability of estimates can only be attained when uncertainty is minimized— inarguably, it is not possible to fully eliminate uncertainty, as any measurement contains some element of doubt inherent in the data/estimate. Researchers should, therefore, report not only the outcome of measurement but also the width of the possible error (i.e., the interval) and the level of certainty (i.e., the confidence interval) associated with the estimated value. According to the Intergovernmental Panel on Climate Change (IPCC) guidelines (IPCC, 2006), compiling a GHG inventory is a two-step process: (i) data collection, which involves the evaluation of existing sources of data and the planning of new emission measurements and surveys; (ii)

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https://doi.org/10.1016/j.eiar.2017.11.008
Received 3 July 2017; Received in revised form 28 November 2017; Accepted 28 November 2017

uncertainty assessment, which must be applied to all relevant source and sink categories, GHG gases, and inventory totals. The second step is indeed crucial, not only in inventory compilation but also in the use of data drawn from the inventory.

Transportation is a hugely important source of GHGs within the European Union (EU), responsible for 20% of emissions[2] (EEA, 2015). Moreover, the sector has shown a 21% growth in emissions since 1990 (EEA, 2014). Road vehicles are the main contributors to GHG emissions within the transportation sector. Reducing emissions from transportation is thus a key element in any comprehensive strategy to reduce global GHG emissions.

Effective medium- and long-term solutions require the integration of a climate change reduction strategy in public policies, to enable new ideas on how to transport people and goods, how to provide energy, and how to build cities (EEA, 2015). Specifically, adapting a transportation infrastructure is difficult, because it involves different actors, ranging from vehicle producers and infrastructure managers to passengers. The European Commission's Transport White Paper (EC, 2011) aims to outline strategies for changing people's behavior by applying a “fuel-efficient driving style and making use of ICT” to decrease business travel.[3] Innovations in transportation and in technologies, such as the transition to electric cars or more investment in modern public transportation networks, are the means to social and economic progress. However, technological improvements are expensive. According to European Commission[4] estimates, for the next 40 years, it would be necessary to invest an additional EUR 270 billion per year in order to have “low carbon” EU energy and transportation.

Transportation-related GHG data extracted from emissions inventories are the primary source for (i) elaborating environmental accounting tables, which are required to perform statistical analysis, and (ii) research exploring the potential of engine and vehicle technologies, fuel developments, and market and travel demand, and examining the impact of policies to promote changes in the road transportation of the future. However, in order to design effective policies for reducing transportation emissions or to devise adequate mobility plans, there is an increasing need to produce reliable emissions inventories, which in turn depend on appropriate uncertainty assessment. Uncertainty in measurement can stem from several factors: poor air pollution monitoring systems, inadequate traffic models, especially when future projections in space and time are considered, bad expert judgments in choosing model parameters and emission factors, and other objective and subjective factors related to the assessment models. However, uncertainty in developing appropriate transportation policy may also be related to the choice of the GHG emissions price, which affects the results of policy option assessment, for instance in a cost-benefit analysis framework (Nocera and Tonin, 2014; Nocera et al., 2015). The validity of the assumptions underlying the physical quantities of emissions and their economic value strongly influences transportation policies related to GHGs. To our knowledge, only a few studies in the literature deal explicitly with uncertainty analysis regarding GHG emissions. For example, Mensink (2000) implemented two emission validation methods to test the precision of the emission factors and the accuracy of modeled traffic flows and to determine the completeness of the inventory, such as coverage of all sources. Singh et al. (2008) tried to reduce uncertainties in the estimation of GHG emissions by considering the issues related to activity data, such as proper apportionment of the fuel types (i.e., diesel and gasoline) across different categories of vehicles and other sectors (such as railways, take-away sales, etc.) in India. Puliafito et al. (2015) proposed a procedure to improve the inventory of emissions with high resolution, based on a geographic information system for the transportation sector in Argentina. Valenzuela et al. (2017) developed a model to quantify uncertainty of the input parameters related to the marginal abatement cost curve in the transportation sector in Colombia. Alam et al. (2017) estimated carbon dioxide (CO_2) emissions from road transportation at the vehicle category level in Ireland, using an improved bottom-up estimation methodology and various sources that provided useful disaggregated data (such as mileage and fleet disaggregation, speed parameters, and mean trip distance).

In this paper, we tackle the issue of uncertainty in GHG emissions from road transportation, combining data from different sources in order to increase the reliability of the uncertainty measure. Moreover, we propose an original method, an insurance-based approach enhanced through Monte Carlo simulation, to improve the uncertainty estimates. Although the case study is based on one Italian region (Piedmont), the methodology and analysis could be applied wherever a regional emission inventory is available. GHG emissions are measured by the global warming potential[5] (GWP) indicator. The paper specifically investigates how GHG emissions estimates are affected by uncertainty, both at the stage of compiling hybrid accounting tables and at the stage of using this information to address a specific policy question. The uncertainty question is approached using a conceptual model (Section 2) that sets out different methods, depending on the stage at which data are considered: the estimating procedure, data analysis, and data use. All the stages of the conceptual model are described and assessed: uncertainty in data production is managed by using an insurance-based approach enhanced through the Monte Carlo method (Section 3.3); uncertainty in data analysis is addressed by integrating emission estimates with regional energy balances (Section 3.4); uncertainty in tackling a specific policy question is reduced by further integrating ad hoc transportation statistics in a quantitative assessment procedure (Section 3.5). The policy question relates to the indirect impacts generated by economic activities: transportation itself is linked to those production sectors that need their products to be delivered over a long distance, thus generating additional GHGs in the transportation sector. In sustainability policies, this is not a secondary issue. Finally, the outcomes of the tested hypotheses are compared (Section 4) and discussed (Section 5).

2. Theoretical background

Disciplines that need information about the emission of pollutants into the atmosphere make use of measurements. A common source of such measurements is air pollutant inventories, which are mostly compiled at the national level, although in some countries there are also regional inventories. In Italy, the European Directive 2008/50/EC on ambient air quality and cleaner air for Europe was introduced into the national legislation by Legislative Decree no. 155 (13th August 2010). The legislation states that the whole country and its regions (and autonomous provinces) should develop their emissions inventories, with adequate spatial and temporal resolution.

The CORe INventory AIR emissions (CORINAIR) system is the calculation method approved by the European Environment Agency (EEA) to assess emissions. CORINAIR adheres to the IPCC guidelines, which have been used globally by environmental protection agencies for national and regional assessments. According to the IPCC Guidelines (2006), a compiler builds a decision tree in order to select the appropriate methodology: (i) Tier 1 employs a very basic methodology that uses default data; (ii) in Tier 2, both the methodology and the need for data become more demanding; (iii) Tier 3 implies an increase in model complexity and data requirements.

To analyze uncertainty, the models used can be based on simple

[2] Excluding land use, land-use change, and forestry (LULUCF).

[3] E.g., teleworking and virtual meetings.

[4] http://ec.europa.eu/clima/policies/strategies/2050/index_en.htm.

[5] The global warming potential (GWP) allows comparison of the global warming impacts of different gases. As an example, the GWP measures how much energy the emissions of 1ton of a gas will absorb over a given period of time, relative to the emissions of 1 t of carbon dioxide (CO_2) (see https://www.epa.gov/ghgemissions/understanding-global-warming-potentials).