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Inventories and reduction scenarios of urban waste-related greenhouse gas emissions for management potential

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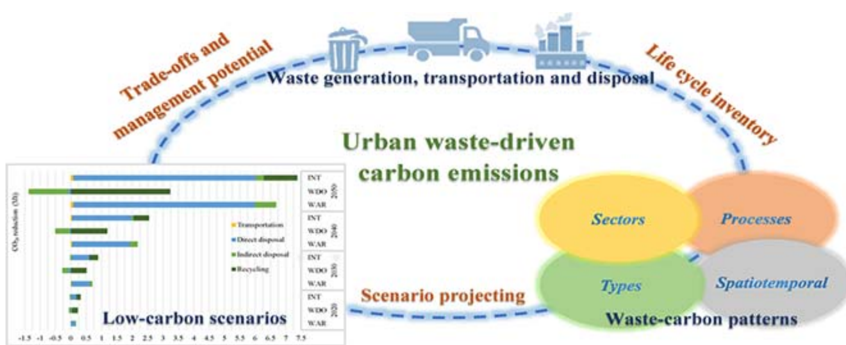
HIGHLIGHTS

- Life cycle inventories are adopted to model urban waste process-based carbon emissions scenarios.
- Scenarios and sensitivity analysis imply pattern, waste-carbon nexus and reduction strategies.
- Stakeholders' trade-offs are needed in techno-economics and environmental substitution effect.
- Trade-offs and management hierarchy benefit to waste-carbon mitigation.

GRAPHICAL ABSTRACT



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ABSTRACT

Waste-related greenhouse gas (GHG) emissions have been recognized as one of the prominent contributors to global warming. Current urban waste regulations, however, face increasing challenges from stakeholders' trade-offs and hierarchic management. A combined method, i.e., life cycle inventories and scenario analysis, was employed to investigate waste-related GHG emissions during 1995–2015 and to project future scenarios of waste-driven carbon emissions by 2050 in a pilot low carbon city, Xiamen, China. The process-based carbon analysis of waste generation (prevention and separation), transportation (collection and transfer) and disposal (treatment and recycling) shows that the main contributors of carbon emissions are associated with waste disposal processes, solid waste, the municipal sector and Xiamen Mainland. Significant spatial differences of waste-related CO_{2e} emissions were observed between Xiamen Island and Xiamen Mainland using the carbon intensity and density indexes. An uptrend of waste-related CO_{2e} emissions from 2015 to 2050 is identified in the business as usual, waste disposal optimization, waste reduction and the integrated scenario, with mean annual growth rates of 8.86%, 8.42%, 6.90% and 6.61%, respectively. The scenario and sensitivity analysis imply that effective waste-related carbon reduction requires trade-offs among alternative strategies, actions and stakeholders in a feasible plan, and emphasize a priority of waste prevention and collection in Xiamen. Our results could benefit to the future modeling of urban multiple wastes and life-cycle carbon control in similar cities within and beyond China.

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1. Introduction

1.1. Motivation

In the past century, the averaged surface temperature data shows a global warming of 0.85 °C, which is likely to rise by a further 2.6 °C to 4.8 °C during the 21st century (IPCC, 2014). To curb global warming, human activities have been recognized as major contributors to greenhouse gas (GHG) emissions. Urban production and consumption are estimated to account for about 70% of the global GHG emissions (UN Habitat, 2016), in which waste sector produces about 3% of the total GHG (Hoornweg et al., 2011; Amoo and Fagbenle, 2013; Marshall and Farahbakhsh, 2013; IPCC, 2014; Yang et al., 2017). Nevertheless, waste-related carbon emissions vary from city to city, especially in developed and developing countries. Many cities in developed countries have observed a stabilizing or even declining trend of waste-related carbon emissions in recent years (ISWA, 2011; Marchi et al., 2017), when compared with the ascending GHG emissions resulting from urban waste disposal in developing countries (Friedrich and Trois, 2011; Noor et al., 2013; Hoa and Matsuoka, 2017). Therefore, it is indispensable to investigate reduction potential of urban waste-related GHG emissions for the mitigation and adaption of global climate change in developing country.

China, with an urbanization rate of 57.35% (NBS, 2017), currently has become the largest emitter of GHGs in the world. It is therefore urgent for China to achieve relevant emissions reduction goals through efficient waste management on an urban scale (Guan et al., 2009; Liu et al., 2017; Yang et al., 2013). Low carbon regulations imply the reduction of waste disposal and material utilization via optimization of operating pathways, and benefit to the reuse of all resources from waste streams (Seadon, 2010; Zaman, 2014; Petit-Boix et al., 2017). Hence, research into urban waste management requires deserved concern in responding to high carbon dilemma. Many studies have analyzed the carbon emissions of single solid waste in a city, with less concern on multiple waste types from generation to the final disposal process (Sanna et al., 2014; Liu et al., 2017; Dong et al., 2017). Moreover, further discussion on the modeling reduction potential of waste-carbon emissions for waste regulation and low carbon city target is required.

1.2. Literature review

Accounting for GHG emissions is one of popular tools within urban waste-related carbon management. Previous studies have summarized various assessment methods and their quantifying boundaries available for calculating waste-related GHG emissions, consisting of the carbon trading methodology, GHG inventories and life cycle assessment (LCA) (Gentil et al., 2009; Mohareb et al., 2011; Braschel and Posch, 2013). The carbon trading methodology, associating with the clean development mechanism (CDM) project, provides a cost-effective analysis for accounting for GHG emissions (Potdar et al., 2016; Wang et al., 2016). The GHG inventories introduced from Intergovernmental panel on Climate Change (IPCC), which take post-consumer waste management as a separate sector at the national scale, provide default parameters that satisfy case studies with limited available data (IPCC, 1996; IPCC, 2006). Referring to the recommended IPCC methodologies, other institutions developed inventory assessments and local GHG emission factors (NDRC, 2011; EEA, 2013; MacCarthy et al., 2015). The inventory method only calculates the carbon emissions of the waste disposal process, whereas the LCA follows systematic streams from waste generation, collection, transportation to disposal (Friedrich and Trois, 2011; Itoiz et al., 2013; Chen and Lo, 2016). Thus, the scope of the LCA requires detailed stream-related data, ensuring carbon emission assessments that are more comprehensive and precise than the GHG inventories.

Among the above methods to quantify GHG emissions for urban waste management, the LCA provides a holistic approach for entire life-cycle waste flows and focuses on the emission saving potential of all waste streams. Current studies have highlighted the carbon reduction potential achieved by waste regulation strategies in cities, which can be classified into three waste-related processes, i.e., waste generation, transportation and disposal. First, waste prevention strategies (including minimization and reuse) mitigate carbon emissions by changing the patterns of production eliminated and substituted that generate less waste, as well as avoiding inputs for waste transportation and disposal (Gentil et al., 2011; Cleary, 2014; Wang et al., 2015). Second, GHG reduction for waste transportation is primarily resulted from optimizing collection routes, improving waste collection rates and transport efficiency (Vergara et al., 2011; Merrild et al., 2012). Finally, given that waste disposal is the major source of waste-related carbon emissions, the most improved regulations encompass waste treatment options (Woon and Lo, 2013; Liu et al., 2017; Islam, 2017) and waste resource recycling or recovery (i.e., as secondary materials and energy) (Kothari et al., 2010; Monni, 2012; Chen, 2016). Generally, current research has offered holistic waste management strategies for GHG mitigation in life cycle thinking from waste generation to final disposal. However, the trade-offs are often neglected among waste process-related strategies, considering that the amount and solutions of waste prevention, collection and disposal defining the carbon reduction potential.

Overall, current studies emphasize quantification methodologies using LCA principles and raising emission reduction strategies. However, gaps remain in current research. Most researchers attach importance to municipal solid waste rather than urban wastewater and agricultural garbage. Moreover, the assessment of waste-related carbon emissions has not been well documented, e.g., the influencing factors of carbon emissions and the spatiotemporal pattern of waste-driven carbon. In addition, mitigation pathways of waste-related GHG emissions in current literature studies are focused more on single waste process, especially on waste disposal (Vergara et al., 2011; Liu et al., 2017), thereby delivering limited information of holistic management strategies for all waste streams and their carbon reduction potential in cities. Hence, it is challenging to analyze the weighting and trade-offs of waste generation, transportation and disposal processes in reduction schemes.

1.3. Contribution

This study chooses the city of Xiamen, southeast China, as a case study, with the aim of going one step further to assess carbon emissions for waste management activities, to model alternatives of future waste regulation and to propose feasible low carbon pathways and measures. The LCA and inventory-based scenario analysis method are employed in this study. We adopt life cycle inventory method to offset the undervalue of waste disposal-focused inventory accounting. The life cycle inventory method is suitable for employment in limited data of waste activities and flexible for scenario projection. A popular scenario analysis was involved in projecting the trajectories of waste-driven GHG emissions in Xiamen (Pietzcker et al., 2014; Yang et al., 2017). The main contribution of this work is threefold:

(1) Establishing an accounting framework, i.e., life cycle inventory methodology (processes and boundaries) and four scenarios (including the business as usual (BAU), the waste reduction (WAR), the waste disposal optimism (WDO), and the integrated (INT)), for long-term simulations of waste process-related (i.e., generation, transportation, and disposal) GHG emissions in four sectors.
(2) Evaluating the spatial pattern and 1995–2050 changes of urban waste and its carbon emission consequences by sector, type, process, and space in Xiamen, southeast China.
(3) Identifying the waste-carbon relationships and feasible low carbon strategies for future urban waste regulation, and discussing trade-offs among techniques, economic cost, environmental substitution effect, and management hierarchy.