Urban GHG emissions and resource flows: Methods for understanding the complex functioning of cities

This paper sums up the recent developments in concepts and methods being used to measure the impacts of cities on environmental sustainability. It differentiates between a dominant trend in research literature that concentrates on the accounting and allocation of greenhouse gas (GHG) emissions and energy use to cities, and a re-emergence of studies focusing on the direct and indirect urban material and resource flows. The availability of reliable data and standard protocols is greater in the GHG accounting field and continues to grow rapidly.

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Introduction

By 2050, the world is projected to be two-thirds urban and one-third rural, which is roughly the reverse of the urban-rural distribution in the mid-twentieth century [1]. Rapid urbanization has led to an emergence of urban sustainability assessment methods that can help practitioners to find solutions for policy development and city planning. These may help to both prioritize environmental aspects, locations or sectors in which to take action, and design policy solutions at different governance levels.

Findings

Two interconnected fields of research can be observed [2]: on the one hand, a dominant trend of literature on the accounting and allocation of GHG emissions and energy use to cities (often called carbon footprinting) and, on the other, a re-emergence of studies focusing on urban metabolism or, in other words, the material and energy stocks and flows through cities.

Both fields of research are inherently linked as they originate from a system approach - the UM field takes the city ecosystem as the fundamental unit of analysis, and much of city GHG accounting literature applies the same notion. For example, they both can consider cities as either producers or consumers (see Figures 1 and 2). The two fields also show considerable divergence, in particular regarding the degree of application of the existing knowledge on the ground. Mutual learning between the carbon inventorying field and UM field is desirable [5].

Urban energy and GHG accounting began in many cities in the 1990s (see, e.g. [6, 7, 8]). The recent introduction of the Global Protocol for Community-Scale Greenhouse Gas Emissions (GPC) [3] – jointly created by the WRI, C40 Cities, ICLEI, the World Bank, UNEP, and UN-HABITAT – aims to overcome the challenge of the much

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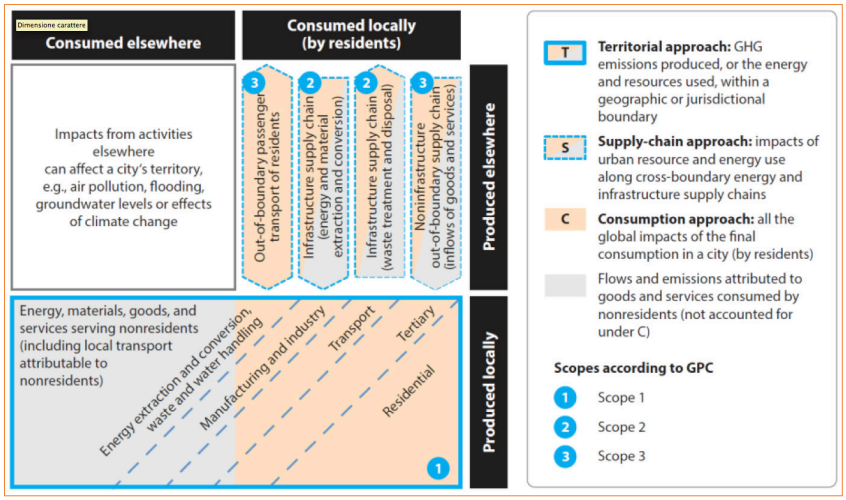
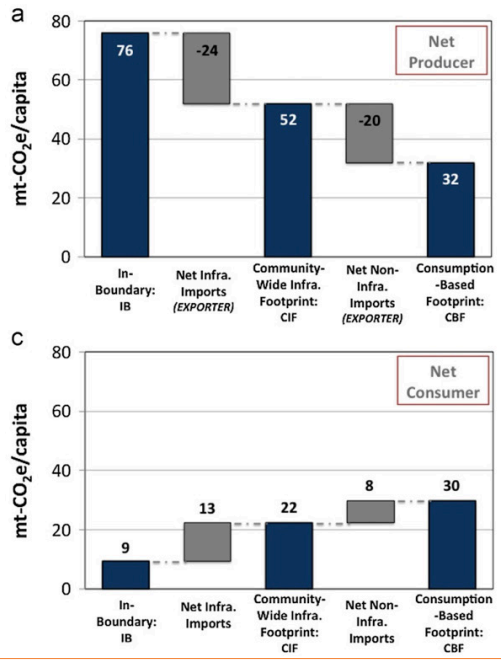
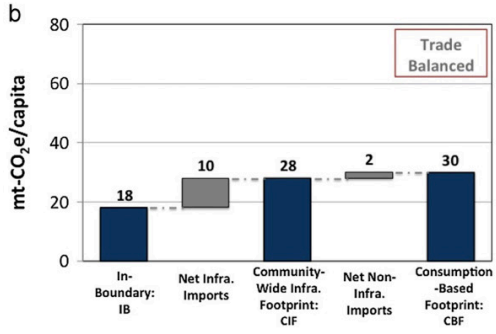


FIGURE 1 Approaches to accounting methods used to measure the environmental impacts of urban systems. The sectors within the city's territory (diagonal fields) provide goods and services that are either consumed locally (peach) or elsewhere (grey). The cross-boundary supply chains shown are examples, and their impacts may be associated with inflows (peach) and outflows (grey)
GPC stands for Global Protocol for Community-Scale Greenhouse Gas Emissions [3]
Source: [2]

contested incoherent approaches between cities, and is designed to replace earlier protocols. However, systematizing different approaches and methodologies remains a challenge, in addition to the practical problems of widespread implementation. International consensus on methodologies for the accounting of cross-boundary emissions is currently sought.

Urban metabolism has a longstanding history and has made a major contribution to methods for accounting for material and energy flows, providing a basis for the optimization of the city "ecosystem" (see, e.g., [9, 10, 11, 12]). However, it has been limited by the lack of standardized methods and paucity of data. Due





Graphical illustration of mathematical relationships derived in [4]: (a) Routt, a net-producing community reports $GHG^{CIF}>GHG^{CBF}$, (b) Denver, a larger metro community, estimated to be roughly trade-balanced reports $GHG^{CIF}\approx GHG^{CBF}$, (c) Sarasota, a community dominated by residences (net-consumer) reports $GHG^{CIF}<GHG^{CBF}$

FIGURE 2 City typologies according to GHG emission balances: net producers, net consumers, trade-balanced cities in the US
Source: [4]

to data intensity and complexity of this field, there are relatively fewer applications of the method than in the energy/GHG accounting field, and most studies lack repeated data collection over time, or limit themselves to the study of single flows.

Territorial-based approaches may help best in understanding urban and regional planning needs, supply-chain approaches may help to identify the role of the process chain, whereas consumption-based approaches may reveal policy needs for behavioral and macro-economic changes [13]. A complementary use of all the approaches is warranted.

A fundamental problem for all approaches is the definition of the urban system's boundary to use in the accounting. Cai and Zhang [14] exemplify this effect with a case study in the city of Tianjin (see Figure 3).

Conclusions

- The methods reviewed can not only aid in understanding of policy options by providing more transparency, but also affect the perception of responsibility for impacts.
- While the data situation is improving rapidly in the climate and energy fields, comprehensive data for quantifying urban resource flows is as yet rarely available. The availability of reliable data and standard protocols (such as the GPC) is greater in the GHG accounting field and continues to grow rapidly. This is likely a reflection of the greater interest and momentum that urban responses to climate change currently have on the policy agenda, in contrast to the aspects of a wider resource use.
- One promising field emerging in the literature is

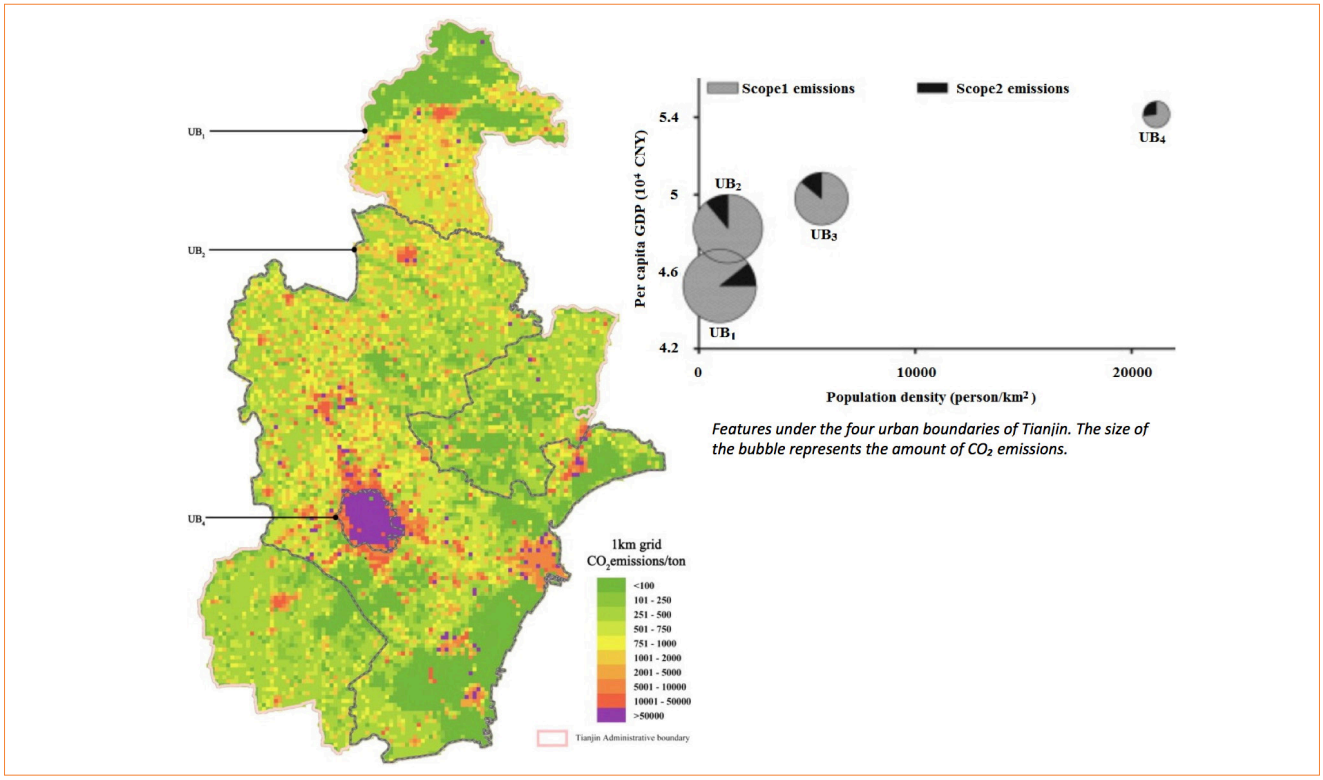


FIGURE 3 Impact of measurement boundary on GHG emissions. More densely inhabited central districts have 60% lower per capita emissions than the city's administrative area. Share of scope 2 is almost double in the city centre
Source: [14]

that of the measurement of synergies (co-benefits) and trade-offs between city sustainability goals.

- A universally accepted definition of what is "urban" is not practical, as cities in different countries exist in very different contexts. However, there is a need to delve deeper into the consequences of considering different boundaries (e.g., administrative vs. land-use) when carrying out research.
- Data collection involves costs and institutional requirements that are unknown or poorly researched in this area. Financially, the setting up of data collection systems by beneficiary cities should be considered over a timeframe of decades. Additionally, cities would benefit from joining national and international efforts to further develop databases usable at city scale, including subnational, multi-region input-output tables that resolve to finer geographical scales [15, 16].
- In both GHG accounting and the urban metabolism field we recognize a dominance of (existing) published research on large global metropolises, rather than on mid-size or small cities, which is where most urban growth is expected over the next decades. Moreover, studies that go beyond a limited number of city case studies are rare, and international comparative approaches are almost non-existent.

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