Journal of Cleaner Production xxx (2015) 1–7

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Communal carbon metabolism: methodology and case study

Yi Lu [a], Bin Chen [a, b, *], Tasawar Hayat [b, c], Ahmed Alsaedi [a, b]

[a] State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, PR China
[b] NAAM Group, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia
[c] Department of Mathematics, Quaid-i-Azam University 45320, Islamabad, Pakistan

ARTICLE INFO

Article history:
Received 3 May 2015
Received in revised form
30 October 2015
Accepted 31 October 2015
Available online xxx

Keywords:
Carbon metabolism
Urban community
Carbon emission
Household consumption
Structural analysis

ABSTRACT

Urban communities are key unit in advancing low-carbon city. The perspective of carbon metabolism in urban communities can help in exploring the characteristics of metabolic behavior and structure, interactions among urban environment, communities and households, and thus unveiling the intrinsic drivers of carbon emissions. A conceptual model of communal carbon metabolism was developed to trace the metabolic behaviors in urban communities and applied to a typical community in Beijing. Results show that the communal metabolic system was mainly dominated by the carbon supply of household-induced energy from urban environment. Sectors of energy and household were the most active participators of the well-structured metabolic system, which should implement low-carbon strategies to mitigate local emissions.

1. Introduction

The carbon cycle has received particular attention because of its huge contribution to the global warming (Grace, 2004). The greenhouse gas emissions of human activities, especially urbanization, is one of the tricky problems that impede the sustainable development of society (Prato, 2008). Cities play an important role in the global carbon cycle since more than 80% of carbon emissions embodied in diverse materials and energy flows can be tracked from urban areas (Churkina, 2008).

It is feasible to investigate carbon emission and cycle process in urban areas on a metabolic perspective, which is the metaphor borrowed from the natural world to describe the processes of resource supply, nutrition exchange and waste disposal in an open system. Stocked or embodied in these cycling resources, carbon emission trajectory has drawn increasing attentions in terms of urban metabolism. Pataki et al. (2006) figured out the drivers of fuel emissions and carbon cycling in urban ecosystem with regard to carbon balance. Chen and Chen (2012) stimulated the carbon metabolic processes and inter-sectoral interactions in Vienna with network environ analysis, unveiling the real donor and controller of urban emissions. Kellett et al. (2013) adopted the urban metabolism approach to model the carbon stock, intake and export by sector at urban neighborhood scale. Kennedy et al. (2014) developed a multilayered indicator for the metabolism of megacities, where the energy-induced carbon emissions were considered as a challenge megacities confronted. Zhang et al. (2014) investigated the spatial pattern of carbon emissions in Beijing to highlight the role of urban expansion in changing the urban metabolism. Zhao et al. (2014) estimated the carbon flows in Nanjing that was greatly affected by the energy consumption, urbanization, rural activities and trade. Since both of the final demand and individual behavior are key drivers to address the increasing urban emissions, the interface between urban carbon metabolism and other metabolic processes at the smaller scale is of great significance for fulfilling emission mitigation targets.

Urban communities as the cell of urban systems can be considered as household settlements that undertake the function of domestic living, public infrastructure, commerce and transportation in urban areas, which affect the low-carbon future (DECC, 2009). It can be expected that the scale of urban communities will keep rising in response to the accelerating urbanization and expanding population, in which processes energy consumptions and carbon emissions will also increase consequently. The concept of low-carbon community has thus been developed to avoid potential mitigation pressures (The Climate Group, 2010). So far, many countries such as Australia (Moloney et al., 2010), Canada (Rogers

* Corresponding author. State Key Joint Laboratory of Environmental Simulation and Pollution Control, School of Environment, Beijing Normal University, Beijing 100875, PR China. Tel./fax: +86 10 58807368.
E-mail address: chenb@bnu.edu.cn (B. Chen).

http://dx.doi.org/10.1016/j.jclepro.2015.10.137
0959-6526/

et al., 2008; St. Denis and Parker, 2009; Burch, 2010; Shendell et al., 2012; Kellett et al., 2013), Germany (Hopwood, 2007), UK (Middlemiss and Parrish, 2010; Peters et al., 2010; Seyfang, 2010; Buchs and Schnepf, 2013; Parag et al., 2013; Seyfang et al., 2013; Phillips and Dickie, 2014) and other European countries (Heiskanen et al., 2010) have already simulated carbon trajectories and initiated low-carbon practices at the communal level.

In China, the most massive global carbon emitter in 2010 (IEA, 2013), measures combating climate change have been implemented at local level as well. Solutions to China's low-carbon community have also been widely investigated (e.g., You et al., 2011; Chen and Shu, 2012; Jiang et al., 2013; Zhang et al., 2013; Huang et al., 2015; Lu and Chen, 2015). However, there is still some room to explore the carbon flows in urban communities and their interactions with urban environments for more effective low-carbon management.

This study aims to reveal the mechanism of carbon metabolism at local level, and to provide both theoretical and practical guidance for low-carbon management of urban communities. In the following, Section 2 introduces the mechanism of carbon metabolism in urban communities, and develops a multi-scale metabolic model to unveil inherent interactions between urban communities and related systems. Section 3 proposes the accounting method of communal carbon metabolism. Section 4 presents a case study of a typical urban community in Beijing with the systematic analysis on its metabolic behavior and properties. Finally, Section 5 discusses the similarity of multi-scale metabolism and possible solutions to mitigate the urban emissions at communal level.

2. Communal carbon metabolism

2.1. Carbon metabolism nexus among household, community, and city

The concept of metabolism is primarily derived from the biology and ecology, which depicts all physio-chemical processes in organics or ecosystems including resource supplied from external environment, inner-exchange of nutrition and energy, and discharge of product and waste (Smart, 1992). Due to the similarity of the natural ecosystem and human society, the theory of metabolism has been introduced and enlarged into the stock-flow based system studies at urban and household scales, defined as the input–output processes reflecting the environmental impacts at each level (Wolman, 1965; Noorman, 1998).

Urban community embraces functional sectors to consume goods and services imported from the city (e.g., agriculture, industry, and service sectors of the urban system) and exerts environmental impacts on surrounding areas via waste discharges, shaping the urban domestic sector connected to the whole urban system. By this way, we can observe the resource-based and waste-based metabolic processes in communities and their connections with urban areas in view of up-scaling metabolism. Meanwhile, communities consist of households with the intake and output of material and energy flows through the processes of consuming goods and discharging wastes in terms of down-scaling metabolism. Therefore, communal metabolism is the nexus between urban metabolism and household metabolism. Carbon is embodied in the production, transformation, consumption, emission and decomposition of materials and energy in urban communities, including both 1) natural processes as carbon absorption by photosynthesis and emission by respiration of plants and soils, and 2) anthropogenic processes as production and consumption of fuels, foods and services, decomposition of wastes, and the absorption due to small scale carbon capture and storage projects. The nexus among carbon metabolisms at urban, communal, household levels are shown in Fig. 1.

2.2. Communal carbon metabolism model

The communal carbon metabolism is the input–output process of carbon-embodied materials and energy to sustain the urban communities, which is illustrated in Fig. 2. There are 7 metabolic sectors including 1) urban environment (UE) supplying resources and treating wastes, 2) energy sector (Eng) allocating fuels and power to the community, 3) construction sector (Con) providing physical settlements, 4) household sector (Hse) consuming goods and services by communal residents, 5) service sector (Svc) providing public services (e.g. medical treatment, education and commodity retails), 6) waste sector (Wst) collecting and pretreating solid waste and sewage, and 7) landscaping sector (Lsp). Besides, there are 21 of direct and indirect embodied carbon flows connecting the whole metabolic system, which can be divided into three categories:

- Carbon extractions are mainly in terms of building materials, goods, fuels and electricity supplied from the urban system to the communities.
- Carbon exchanges among different functional sectors in urban communities include supply, transportation, consumption and pretreatment of carbon-embodied materials and energy, as well as the absorption of released carbon dioxide by landscaping.
- Carbon emissions include both direct release and indirect emission embodied in the waste discharged to the urban environment.

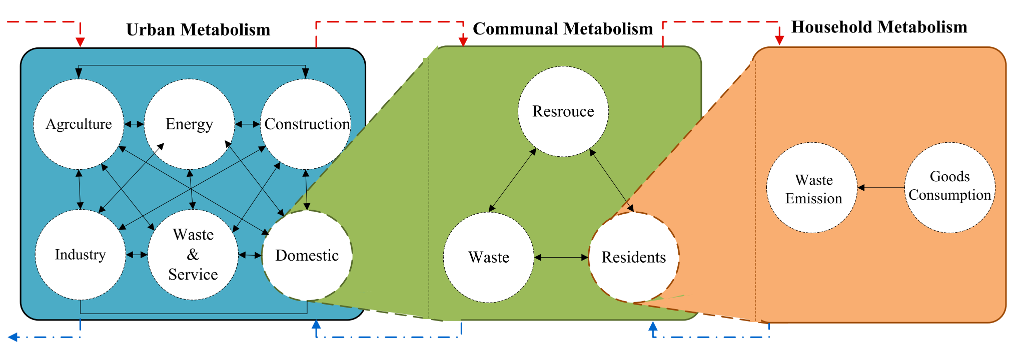

Fig. 1. Multi-scale carbon metabolism model at urban, communal and household levels.