Global Environmental Change 39 (2016) 285–293

Contents lists available at ScienceDirect

Global Environmental Change

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

A novel analysis of consumption-based carbon footprints in China: Unpacking the effects of urban settlement and rural-to-urban migration

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ARTICLE INFO

Article history:
Received 12 October 2015
Received in revised form 28 May 2016
Accepted 6 June 2016
Available online xxx

Keywords:
Carbon emission
Greenhouse gas
Life cycle assessment
Migration
Human settlement
Propensity score matching

ABSTRACT

Urbanization in developing countries greatly contributes to growing carbon emissions. Although studies have documented the urbanization effect, the science of consumption-based footprint assessments has yet to unpack various effects during the process of urbanization. Based on household expenditure data, this study innovatively proposes a methodology to conceptually and statistically deconstruct the observed urbanization effects on carbon footprint into selection effects and migration effects, which consist of human settlement effects and purposeful changes of migration (such as income and residential location). Applying propensity score matching and regression on the 2010 China Family Panel Study, we find that the apparent carbon-footprint difference between rural residents and migrants is about 1.5 t CO_2e per capita. The migration effects account for about 2/3 of the apparent difference and the remaining 1/3 is due to selection effects. Urban settlement effects and the purposeful changes account for 73% and 27% of the migration effects, respectively. Transport sector is the key driver of carbon-footprint growth: it accounts for 60% of the migration effects. We conclude that travel behavior of rural migrants, currently in scarcity in the lite rature, merits further investigation, and policies should emphasize transit-oriented land use and transportation to achieve low-carbon urbanization.

1. Introduction

Ongoing massive urbanization in developing countries brings about enormous challenges to climate change. In 2014, 54.9% of the world's population lived in urban areas (Heilig, 2015). These urban areas, while occupying about 2.7% of the surface (U.N., 2009), consume about 75% of energy and emit 71 ~76% of greenhouse gas (GHG) (Seto et al., 2014), referred to as carbon emissions in short form. By 2050, the share of urban residents is projected to increase to 66% as urban population grows from 3.9 billion to 6.4 billion (Heilig, 2015). Much of this growth will occur in Asia and Africa. In 2014, China published its first official New Urbanization Plan, which aims to increase the share of urban residents from 54% in 2013 to about 60% in 2020. This means that approximately 85 million new rural residents will flock into cities in seven years. Since a key goal of the plan is to stimulate domestic consumption, this massive rural-to-urban migration has important implications for consumption-based energy use and carbon emissions in China and climate change in the world. Similar rural-to-urban migration in other rapidly developing countries will also urbanize an unprecedented number of people.

To manage energy demand and its associated carbon emissions along with the process of urbanization, we need to first understand how to quantify them. In fast growing economies, the process of urbanization is a complex phenomenon that represents a large-scale migration of rural populations to urban settlements, with better accesses to infrastructures, improved socioeconomic status, and changes in lifestyle. Such a migration is also accompanied with large-scale expansion in urbanized areas. This paper focuses on the urbanization process, from the perspective of the many millions of rural people who are and will be continuing to migrate to cities in China, India and other countries of Asia and Africa. Little is known about the different factors that shape carbon emissions associated migration to cities, with the migrants experiencing large changes in socioeconomic parameters as well as in human settlement (i.e., infrastructure and associated lifestyle changes). The paper focuses on China, where urbanization rate has increased from 26% in 1990 to 54% in 2014 (World Bank, 2016). However, the methods developed here are broadly applicable to urbanization globally.

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http://dx.doi.org/10.1016/j.gloenvcha.2016.06.003

A few studies have compared carbon emissions of residents living in urban and rural settlements. For example, Zhang et al. (2014) aggregated direct carbon emissions from fuel burning and cement manufacturing within rural and urban communities in China and concluded that carbon emissions are 1.8 t per urban person per year and 1.1 t per person per year. In Mumbai, India, urban households were reported to generate an astonishing 17 times as many carbon emissions from direct energy (fuel) and electricity use as rural households (Busa, 2014). These findings suggest that rural population has lower direct carbon emissions per capita than urban population. However, these studies focused on only direct energy use within a prescribed boundary.

Carbon footprinting differs from the direct energy accounting described above, because it combines the direct material-energy and service flows associated with the transboundary life cycle impacts of producing those material-energy flows, goods and services within a certain unit of society. Thus, carbon footprints provide a broader accounting of environmental impacts. Different types of footprints have been defined based upon the different units of society being analyzed (Chavez and Ramaswami, 2013; Lin et al., 2015). For example, carbon footprints that assess the transboundary impact of production within a boundary are termed production-based footprints (PBF); those that track the transboundary impact of community-wide infrastructure-use by homes, businesses and industries within a boundary are called community-wide infrastructure footprints (CIF); while consumption-based footprints (CBF) address the impact of final consumption in a community, which is dominated by the consumption of households. This paper focuses on CBF, because the unit of analysis is the consumer, and we are interested in understanding the impact on personal consumption when rural people migrate to urban areas – resulting in vast changes in socio-demographic parameters as well as in the experience of different human settlements across rural and urban areas.

The effects of rural-to-urban migration on CBF constitute two components. First, human settlement effect refers to changes in infrastructure and technology, accesses to goods and services, and lifestyle, which can shape personal consumption when rural residents (RR) move to urban areas and become rural-to-urban migrants (RUM). For example, RR usually burn solid fuels for cooking, and rely on non-motorized transportation for travel whereas most of residents in urban areas use natural gas or electricity and adopt motorized transportation (either public transit or private vehicles). Similarly, easy access to air and freight transport in urban areas can also lead to better access to diverse goods and services, and result in changes in lifestyle (e.g., increased air travel) and different consumption patterns. When RR become RUM, they simultaneously experience socio-demographic changes such as changes in household income, employment, and residential location, which are purposes for people to migrate. That is, these are the purposeful socio-demographic changes linked with migration. Rural-to-urban migration effect is the combined effects of purposeful socio-demographic changes and changes in human settlements. The focus of this paper is to develop a novel methodology to unpack these two effects.

Previous studies have shed light on the CBF effects, identified the roles of socio-demographic factors and human settlements, but have not decoupled these effects. Using an expenditure survey in China, Golley and Meng (2012) found that income has a positive association with CBF. Baiocchi et al. (2010) explored the CO_2 emitted from different lifestyle groups based on geodemographic consumer segmentation data in the UK. Using a multivariate regression, they found large disparities in CO_2 emission between the highest lifestyle group (educated families living in urban areas) and the lowest lifestyle group (struggling families). Jones and Kammen (2011) developed a consumption-based accounting model to capture the CBF from household expenditures on transportation, energy, water, waste, food, and other goods and services in 28 US cities, and concluded that population density has a significant and negative association with CBF. In another study of US household surveys, Jones and Kammen (2014) concluded that households in urban core cities tend to have lower CBF than those in suburban cities. However, the research design as such, while revealing differences across the human settlements (different population densities or suburb to core city), does not separate the effects of income from factors relating to physical infrastructure between urban and suburban areas. Heinonen et al. (2011) employed a similar approach to compare the differences in carbon emissions among different human settlements in Helsinki. They found that city dwellers generate 25% more GHGs than rural residents, using a household expenditure survey conducted in four types of municipalities in Finland: rural, semi-urban, cities, and the Helsinki metropolitan area. They showed that modest savings in energy and transportation related emissions in the urban core are overshadowed by high expenditures in other goods and services such as airline, potentially linked to income effects.

These studies explored correlates of carbon emissions at the aggregate level of cities or regions. However, aggregate studies are vulnerable to a fallacy: a statistical inference based on group data may contradict an inference based on individuals from the groups (Oakes, 2009). For example, Ala-Mantila et al. (2014) innovatively used a disaggregate analysis to study the relationships between urbanity and CBF in Finland. Without controlling for any socioeconomic characteristics, on average, residents in rural areas have lower CBF (12.0 tCO_2e/capita) than residents living in the Helsinki metropolitan area (12.5 tCO_2e/capita). After controlling for household size and income in a multivariate model, the CBF of rural residents turns out to be 12.5% higher than residents living in the Helsinki metropolitan area. The erroneous outcomes resulting from data aggregation are often ignored in the environment literature.

More importantly, differences in infrastructure did not emerge as important in these studies of developed economies, since infrastructure differences between rural and urban human settlements are not as profound as they are in rapidly developing economies. In developing countries, energy, transportation access and systems in rural areas can be starkly different from urban areas; for example, lack of electricity and use of coal-burning heating stoves in rural areas versus better energy supply and often district energy systems in urban areas. Focusing specifically on China, several CBF studies have reported carbon emissions for rural and urban China. These studies employed aggregate data from governments to estiamte the average CBF of urban and rural Chinese. For example, using energy consumption data and expenditure data from Statistical Yearbooks from 1992 to 2007, Liu et al. (2011) found that in 2007, total carbon emissions from all urban households were about 2.6 times as many as those from all rural households, although there were more rural people than urban people in 2007. Minx et al. (2011) also reported that a large gap in per capita consumption between urban households and rural households in 2007. Qu et al. (2015) employed data from Statistical Yearbooks for 17 years to study the trend of carbon emissions and found that per person carbon emissions for urban and rural people were 2.4 t and 1.1 t in 2011. They also showed that urbanization, income, and household size contribute to the variation in carbon emissions. Others have applied the trade balance approach to cities. For example, Lin et al. (2015) reported that the average CBF of a resident in Xiaman was 6.4 t CO_2e per capita in 2010. Few studies have computed CBF using household expenditure surveys, similar to methods used in American and European CBF studies (Heinonen et al., 2011; Jones and Kammen, 2011). Employing the Urban Household Income and Expenditure