Energy Policy 39 (2011) 5259–5268

Contents lists available at ScienceDirect

Energy Policy

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

Rigorous classification and carbon accounting principles for low and Zero Carbon Cities

Scott Kennedy*, Sgouris Sgouridis[1]

Masdar Institute of Science and Technology, P.O. Box 54224, Abu Dhabi, United Arab Emirates

ARTICLE INFO

Article history:
Received 8 June 2010
Accepted 21 May 2011
Available online 12 June 2011

Keywords:
Sustainable community
Eco-city
Zero carbon

ABSTRACT

A large number of communities, new developments, and regions aim to lower their carbon footprint and aspire to become "zero carbon" or "Carbon Neutral." Yet there are neither clear definitions for the scope of emissions that such a label would address on an urban scale, nor is there a process for qualifying the carbon reduction claims. This paper addresses the question of how to define a zero carbon, Low Carbon, or Carbon Neutral urban development by proposing hierarchical emissions categories with three levels: Internal Emissions based on the geographical boundary, external emissions directly caused by core municipal activities, and internal or external emissions due to non-core activities. Each level implies a different carbon management strategy (eliminating, balancing, and minimizing, respectively) needed to meet a Net Zero Carbon designation. The trade-offs, implications, and difficulties of implementing carbon debt accounting based upon these definitions are further analyzed.

1. Introduction

Cities in their current form are an evolved solution that increases societal wealth under resource constraints through 'economies' of scale, scope, and innovation. The deliberate design of the urban environment to accommodate constrained access to resources (e.g., electricity, vehicle fuel, food, durables, and consumables) has frequently been lacking, as evidenced by the masterplanned or organic growth cities of the past century. The scale and form of the urban environment has changed drastically with the availability of affordable and energy-dense resources moving from compact urban cores to extensive urban sprawl. However, as the majority of these resources depend directly or indirectly on climate-impacting and reserve-limited fossil fuels, the realization that resource access in the future may become markedly more constrained has led to a number of efforts to explicitly measure and mitigate the fossil-fuel dependence of the urban environment.

1.1. Carbon aspirations and motivation for carbon accounting principles in urban planning

The spirit behind the push for carbon management principles in sustainable urban planning is to reduce drastically the anthropogenic emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs) in order to mitigate the threats of climate change; and as an ancillary benefit to minimize the fossil fuel inputs for a city's needs. If humanity is to meet the constraints imposed by the planetary boundaries (Rockstrom et al., 2009), which for CO_2 atmospheric concentrations means stabilization at 350 parts per million, then drastic cuts in emissions on the order of 95% from all sources will be necessary in the developed world[2] (Metz et al., 2007). As a result, there is a trend for new urban developments and existing cities to announce ambitious targets for carbon emissions and energy reduction. The growing list of eco-city developments includes a diverse set of projects like Masdar City in Abu Dhabi, UAE (Reiche, 2010), Dongtan in Shangai, China (Cheng and Hu, 2010), along with smaller scale greenfield developments like the BedZED community in the UK (Chance, 2009), and ecovillages distributed across the globe (GEN, 2011). Many established cities also aspire to meet carbon objectives with a prominent effort being the Covenant of Mayors of European Cities to reduce emissions by a minimum of 20% (European Commission, 2010). These projects use terminology such as zero carbon, Carbon Neutral, zero energy, and Low Carbon to describe their carbon management goals as shown in the comparison of Table 1.

While there is a thriving literature describing approaches to build and design sustainable cities (Kenworthy, 2006), given the complexity of material and social interactions on an urban scale, we find that currently there are no concrete definitions upon

* Corresponding author. Tel.: +971 2 810 9154; fax: +971 2 810 9901.
E-mail addresses: skennedy@masdar.ac.ae (S. Kennedy), ssgouridis@masdar.ac.ae (S. Sgouridis).

[1] Tel.: +971 2 810 9156; fax: +971 2 810 9901.

[2] The IPCC Fourth Assessment Report Working Group III has estimated that for stabilization at 450 ppm the developed countries would need to reduce emissions from 80% to 95% (Box 13.7, page 776) from the 1990 baseline by 2050. No peer reviewed modeling has been available to us for the 350 ppm target but as it is more stringent than the 450 ppm target the higher range is quoted in the paper.

0301-4215/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.enpol.2011.05.038

Table 1
Comparison of existing eco-city planning.

Urban development	Urban scale (day population size)	Use type	Climatic conditions	Stated objective
Dongtan	Medium (20,000 residents)	*Mixed*, residential, commercial, industrial, agriculture	Temperate	Zero emissions for energy (near zero carbon)
Ecovillages	Small (< 1000)	Residential	Various	Unstated. Focus is on community development and not on carbon reductions
Masdar City	Medium (50,000 residents)	*Mixed*, residential, commercial, agriculture	Arid Desert	Zero carbon
BedZED	Small (< 1000)	Residential	Temperate	Zero carbon buildings; transport not included
Covenant of Mayors, e.g.,	Various	*Mixed*	Various	Low Carbon
London	Large (> 7.5 M)	*Mixed*	Temperate	38%[a]
Paris	Large (> 2.2 M)	*Mixed*	Temperate	25%[a]
Frankfurt	Large (670,000)	*Mixed*	Temperate	31%[a]

[a] Reduction from 1990 baseline (CoMO, 2011).

which these claims can be measured and compared. Therefore, in order to make the ambitious targets of low or zero carbon emissions meaningful concepts in the context of urban planning, a carbon accounting framework needs to be rigorously defined and adapted to the urban scale. We review existing approaches, propose a definition framework, and discuss its implications on urban design and its institutional structure.

1.2. *Existing urban carbon accounting approaches*

The popularized term ‘‘carbon footprint’’ typically denotes emissions of CO_2, and other GHGs expressed in CO_2 equivalent forms, associated with a product, process or region. This term is rarely defined rigorously, even as it has gained widespread appeal as an indicator for the environmental impact or sustainability of a particular activity. Weidema et al. (2008) discuss the usefulness of a carbon footprint indicator, which measures only one type of emission (e.g., CO_2 or GHGs), as compared to a more comprehensive lifecycle assessment approach, which attempts to measure and assess impacts across a wide array of categories. They argue that even with the carbon footprint's limited scope, it can be a meaningful entry point for the public to consider lifecycle impacts.

Wiedmann and Minx (2007) propose a standard definition that encompasses *all* direct and indirect emissions of CO_2. Their definition is general enough that it can apply to individual products and processes or to geographic regions (e.g., a national or regional carbon footprint). However, such a broad definition is difficult to operationalize for a multi-stakeholder, multi-scale environment of a city or of an enterprise. The question of scoping, i.e. of what activities fall within the scope of measurement, is a critical one as it identifies by implication the accountability for and the management of carbon emissions.

Organizational carbon accounting principles as proposed by Rangathan et al. (2004) apply rigorous emissions scoping for organizations and, particularly, private firms. These cannot be easily translated to the urban scale as they determine a firm's responsibility based on activities that are considered operational (i.e. core firm activities) to the firm itself or based on the firm's equity shares in other firms that have their own emissions.[3] Bypassing the allocation question, Kennedy et al. (2009, 2010) applied the scoping of the WRI framework to conduct an inventory of GHG emissions on the urban scale for ten metropolises. They assumed that all direct and indirect emissions that benefit a city's economic activity should be included with the exception of indirect impacts from material consumption. They attempted to quantify total GHG emissions from all urban operations including electricity, heating, industrial fuels, and transportation (ground, marine, and aviation). While useful for establishing a holistic baseline of carbon emissions for established cities, this broad emissions scoping covers sectors that are beyond the direct control of most regional or urban governments while leaving important emissions (e.g., the lifecycle emissions of consumption) unaccounted.

The scoping question (i.e. which emissions should be included in a city's carbon accounting balance) can also be examined from the perspective of lifecycle assessment (LCA). Rigorous methodologies for estimating the emissions and environmental impacts associated with products, processes, and activities are well-established in the field of lifecycle assessment (Curran, 1996). A significant advantage of the LCA approach is the recognition of both direct and indirect impacts over a product's lifecycle. The approach is applicable to more complex systems, such as a household, but the scope needs careful consideration. For instance, a household includes a physical building that has the typical lifecycle phases of construction, use (e.g., heating, cooling, and lighting), and eventual disposal, but it also comprises a host of related activities, such as the occupants' food consumption or the transportation to and from the building. The scope of analysis for a household would be significantly wider than for a more narrowly defined physical building.

For current usage of the label ‘‘zero carbon home’’, the scope of activities is typically chosen very conservatively. For example, one definition of a zero carbon home (6 star rating) is to achieve ‘‘*zero net emissions of carbon dioxide* (CO_2) *from all energy use in the home*’’ (Communities and Local Government, 2006). This definition focuses on the physical building and is strictly operational. It does not account for either the embedded emissions from the building construction or the products consumed by its inhabitants. The same approach is used by Griffith et al. (2007) in assessing the potential for ‘‘zero energy’’ commercial buildings. Defining the appropriate boundaries around the emissions that must be included and those that can be excluded becomes increasingly less obvious as the system of interest changes from

[3] Operational control, which is the most common and recommended approach, implies that emissions from all activities that can be directly affected by the management of a firm and form part of its core business should be accounted for. Equity control share recommends that the allocation of emissions be based on ownership; if a firm partially owns another firm through shareholding, it should account for the second firm's emissions even if it does not have operational control over them.