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Urban energy systems within the transition to sustainable development. A research agenda for urban metabolism

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ABSTRACT

The way we make sense of urban areas stands at a critical point. To reduce energy use in cities, we need to manage the way energy flows into, through and out the city. This paper starts with an overview on energy use at different levels of aggregation which allows us to outline emerging issues on urban metabolism for further research regarding urban energy systems. The research agenda focuses on five aspects: energy services, drivers for energy services, waste, data and dynamic modelling and governance. We give indications regarding the direction we think we should aspire to follow. The variety of themes within urban energy systems demands a coordinated and multidisciplinary research effort to improve our understanding of how the research of urban metabolism can contribute to achieve sustainable development.

1. Introduction

In 1900, 15% of a global population of 1.5 billion people lived in cities (Girardet, 2008). At the end of the twentieth century urban areas in the world have grown considerably. According to the Department of Economic and Social Affairs of the United Nations (UNDESA) (2014), in 1990 there were 10 so called “megacities” with more than 10 million inhabitants, representing less than 7% of the global urban population. By 2010, the number of megacities was 27, the population they contained grew to 460 million, and these agglomerations accounted for 6.7% of the world’s population (Kennedy et al., 2015). Since 2008 cities host more than 50% of the inhabitants of the planet with the share expected to increase up to 67% by 2050 (Rosenzweig et al., 2010; UN-HABITAT, 2012). Furthermore, cities are located on less than 5% of the Earth’s land surface and yet use around 80% of the resources (Madlener and Sunak, 2011; CIESIN, 2015; UNEP 2015), and are responsible for approximately 80% CO_2 global emissions (IEA, 2008; Seto et al., 2014).

Cities exist in all shapes and sizes, this diversity could also lead to potential initiatives to decrease CO_2 emissions by reducing urban energy use and make energy use more sustainable (Girardet, 2008; Beatley, 2000). Cities can make material or waste exchanges possible between industries. The collection of recyclable or reusable wastes from homes and businesses in urban areas is generally cheaper, per person served (UNCHS, 1996; Mega, 2010). Urban planning enables the changing nature of buildings and the city to capture these benefits. As an example, changing infrastructure and urban planning can lead to a decrease in car use in dense urban areas, and by doing so reducing health risks to city dwellers (Jackson, 2003; Heath et al., 2006; de Hartog et al., 2010; Tight et al., 2011).

There are also fundamental political reasons that give cities a key role in the battle for sustainability. Cities are places of political contention (Bakker, 2003; Heynen et al., 2005). Cities represent the possibility to develop new regulatory structures and spaces of governance (Brenner, 2002). Cities are important because they are spaces where democracy can be practiced. However, this does not mean that cities have affinity with democratic practices (Low, 2009). The concept of democracy can be interpreted in various ways and research on how this concept can be materialized on cities deserves still more attention among scholars (Purcell, 2007; Beaumont and Nicholls, 2008). Although we have not found literature that relates the introduction of democracy with an increase in sustainable development, we believe that these discussions, however interesting, do not undermine the fact that democratization (understood as a process where individuals are involved in political decision making) is of a major relevance in advancing towards sustainable development. Bailey (2007), gives some examples on how cities began implementing community-wide urban energy studies in a bottom-up manner for greenhouse gas (GHG) accounting. Furthermore, the social economy within each locality creates a dense fabric of relationships that allow local citizens to work together in identifying and acting on local problems or in taking local initiatives (Korten, 1995). Table 1 shows a number of examples and initiatives around the world where cities are trying to make changes in order to

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Table 1
Initiatives of cities aimed at leading the transition to sustainable development.

Initiative	Scope	Year of Adoption	Cities Involved	Objective
Covenant of Mayors for climate and energy	European	2008	6800	Implement EU climate and energy objectives
C40 Cities	Global	2005	83	Exchange of best practices in order to address climate change in megacities
Global Sustainable Cities Network	European–Asian	2013	60	Knowledge-sharing
Sustainable Cities International	Global	1996	7	Tackle urban issues through peer learning exchanges.
Red Ciudades	Latin-America	2012	60	Build sustainable urban spaces.
ICLEI Local Governments for Sustainability	Global	1990	1000	Make cities and regions more sustainable.
South African Cities Network (SACN)	South Africa	2005	9	Knowledge-sharing
100 Resilient Cities	Global	2013	100	Become more resilient to the challenges that are part of the 21st century
Asian Cities Climate Change Resilience Network (ACCCRN)	Asia	2008	50	Build inclusive urban climate change resilience

shift towards sustainable development.

Nevertheless, despite all the initiatives and efforts done to mitigate environmental problems associated to urban activities, one of the main questions facing those interested in creating more sustainable communities still is: "how do we set our progress towards sustainable development?" (Sachs, 2015). We argue that in order to set this progress it is relevant to understand processes that mobilize and control the flows of energy through the city. We think that focusing on the concept of urban metabolism offers the possibility to contribute to sustainable development. Several studies have followed the historical development of this concept (Fischer-Kowalski, 1998; Fischer-Kowalski and Hüttler, 1998; Rapoport, 2011; Dinarès, 2014). These studies show that the use of metabolism as a metaphor to understand processes happening in the city has been used since the late nineteenth century. They also show that the study of energy flows through the lens of urban metabolism has been an intermittent process having an increase over the past decades (Kennedy et al., 2011). Although urban metabolism has gained increased attention many issues deserve further attention. Hence, research is a key factor in advancing the field of urban metabolism to the benefit of transitioning towards sustainable development.

With interest in this topic we would like to contribute by offering a conception for this research effort. This paper wishes to help setting a multidisciplinary research agenda on urban metabolism aiming at a sustainable urban energy use. The paper is organized as follows, after a brief introduction, Section 2 reviews how energy is used at different levels of aggregation. Subsequently, Section 3 deepens the discussion of urban energy flows and urban metabolism. In Section 4 we argue that different energy flows are required to fulfill several energy services. Section 5 presents the driving factors for energy services. We proceed to explain a research agenda to understand – and help in the solution of – the energy challenges cities face. Finally, the paper ends with a concluding section.

2. Energy use

The start of industrialization – in the late 1700s – brought an increased volume and variety of manufactured goods into cities. However, industrialization also marked a shift to powered, special-purpose machinery, factories and mass production. Since then, material and energy resources flow into and out cities following the same linear pattern of functions: raw materials extraction, which are processed to manufacture a product which in turn is sold to a consumer. This product is discarded either because it no longer serves its original purpose or because there are new products available. Our understanding of cities and urban areas, in both theory and practice, stands at a turning point. Rather than separate systems by function — water, food, waste, transport, education, energy — we must consider them as a single system. Instead of focusing only on access and distribution systems, our cities need dynamic, networked, self-regulating systems that take into account complex interactions.

Energy is not only key to our economic development and wellbeing, it is also strongly related to many environmental impacts. Meta-analysis of life cycle assessments (LCA) has shown that energy correlates well with most other environmental impacts (except for toxicology) (Huijbregts et al., 2006). Johansson et al. (2012) enumerate four main challenges of energy systems: 1) Elevated greenhouse emissions, 2) Decreasing energy security, 3) Air pollution at regional and local levels and 4) Lack of universal access to energy services. Tackling these challenges would help to achieve sustainable development. Energy is a good measure of the environmental footprint of an urban area. A city can consume energy directly, or indirectly through the embodied energy in imported goods and services. In this article we focus on the direct energy use. While energy use has a direct impact on the environmental quality of an urban area (e.g. air pollution, smog, regional warming, urban heat island effect), energy use is the effect of the type of economic activities, the infrastructure and planning, human activities, as well as geographic factors. The energy use also affects itself indirectly, as the urban heat island effect may increase the need for energy use for air conditioning. Hence, it is important to understand not only the drivers behind the changing energy use, but also the interrelationships between the different factors to accurately understand the dynamics of energy in the urban system, necessitating a systems approach (Pincetl et al., 2012).

2.1. Global energy use

According to the International Energy Agency (IEA, 2014), the world total primary energy supply increased from 256 EJ in 1973 to 561 EJ in 2012. As in 1973, fossil fuels dominate the worlds' energy supply. Oil has the biggest share (31%) although lower than in 1973. Coal and natural gas shares were – in 2012 – 29% and 21.% respectively. The OECD countries have reduced their regional share of total final consumption from 60% to 40%. The rest of the world has increased its share. Asia (lead by China) being the region with the highest growth in consumption, growing from 14.3% in 1973 to 32% in 2012. The related CO_2 emissions due to fuel combustion were 15,633 Mt in 1973 and 31,734 Mt in 2012. The emissions by region have also changed. In 1973 the OECD countries were responsible for 66% of the emissions. By 2012, the share of OECD countries accounted 38%. As in the case of energy consumption, Asia (led by China) increased its CO_2 emissions from 9% to 37% in the same period 1973–2012. The International Energy Agency estimated in 2008 that the world will need almost 60% more energy in 2030 than in 2002 to meet growing demand for energy services. Fossil fuels are expected to account for 80% of the world's primary energy mix in 2030. Oil will remain the dominant fuel, though demand for coal will rise more than demand for any other fuel. China and India are expected to account for 51% of incremental world primary energy demand in 2006–2030. In its 2015 report, the International Energy Agency indicate possible impacts that the Intended Nationally Determined Contributions (INDCs) will have in future