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Energy landscapes and urban trajectories towards sustainability

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ABSTRACT

An urban energy transition is needed to address the two global environmental challenges of urbanisation and increasing carbon emissions. Urban energy landscapes represent the spatial patterns of urban energy systems which are visible in the built environment. Spatial regularities in the way systems of energy provision and use are organised are manifest in urban energy landscapes. Energy uses may vary in relation to the structures of the built environment, and the perceptions that coevolve with technologies.

This paper presents evidence from three case studies of urban energy landscapes in Hong Kong (PRC), Bengaluru (India) and Maputo (Mozambique). The cases suggest a variety of patterns (uniform, fragmented, scattered) in terms of how different fuels and electricity are provided and who has access to them. Qualitative research among policy makers reveals different trajectories towards sustainability. The paper concludes with the suggestion that the spatial organisation of urban energy systems shapes potential trajectories of change for an urban energy transition. This would call for forms of spatial planning that promote flexibility as a means to foster sustainability innovations. However, further evidence will be required to evaluate whether this exploratory analysis can be generalised beyond the three cities studied.

1. Introduction

The urban energy transition is a key sustainability science frontier (Droege, 2011). With over 70% of the population thought to be living in urban areas by 2050, environmental challenges are necessarily urbanisation challenges too. The urban energy transition is a multidimensional challenge that must address three interrelated, but sometimes competing, objectives. First, the decarbonisation of the built environment will require an overall reduction of both embodied and operational GHG emissions from urban areas (Karvonen, 2013). Urbanisation is highly correlated with higher consumption of energy and higher Green House Gas (GHG) emissions (Seto et al., 2014). Thus, an urban energy transition must transform spatial patterns in human settlements to reduce carbon emissions. Second, concerns for urban energy security emerge from a preoccupation with resource availability and the need to guarantee such resources to reproduce urban economies (Hodson and Marvin, 2009). This is particularly true for poor cities where processes of urban expansion threaten simultaneously their resource base and their capacity to provide appropriate services (Godfrey et al., 2012). Third, universal energy access in urban areas is still an elusive goal, particularly related to the lack of recognition of energy as a basic service and a limited understanding of how energy supports people's livelihoods (Singh et al., 2014). Progress towards sustainable energy has been steady but limited, with circa 210 million people in urban areas lacking access to the electricity grid, and now 500 million in urban areas lacking access to modern cooking fuels (OECD/IEA, 2010; SE4ALL, 2015). New methods of evaluating the multi-dimensional nature of energy access demonstrate that, even when they are connected to the grid, people may lack energy access if they cannot afford a continuous service or if the service is of intermittent or bad quality (SE4ALL, 2015).

Energy planning can play a key role in facilitating an urban energy transition towards sustainability. There is abundant research documenting the multiplicity and richness of climate change action in urban areas (Bulkeley and Betsill, 2005; Bulkeley and Castán Broto, 2013; Castán Broto and Bulkeley, 2013; Hoornweg et al., 2010; Rosenzweig et al., 2011; UN-Habitat, 2011), but there is no clear evidence that these actions are indeed linked to an urban energy transition (Bulkeley et al., 2014a; Rutherford and Coutard, 2014; Seto et al., 2014). While there is evidence of planning actions that deliver GHG emission reductions in specific contexts (Crawford and Davoudi, 2009; McGregor et al., 2013) a piecemeal approach dominates energy planning and governance at the local level. There are no blueprints or clear action plans for an urban energy transition. Rather, urban sustainability trajectories depend on city-specific conditions. Such city-specific conditions include both endogenous and exogenous factors, from the regulatory context to the practices of energy use and the systems of provision in place. Urban sustainability trajectories also depend on the spatial factors that shape the adoption of sustainability innovations such as the clustering of innovators and the possibilities

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for innovation diffusion. Despite scholarly calls to consider the urban geographies of sustainability transitions (e.g. Bulkeley et al., 2010; Coenen et al., 2012; Coenen and Truffer, 2012; Hansen and Coenen, 2014; Hodson and Marvin, 2012; Rutherford and Coutard, 2014; Truffer and Coenen, 2012; Vogel, 2015), to date there has not been a systematic study of the spatial organisation of urban energy systems and its relation to an urban energy transition. In this vein, a key aspect of the urban energy transition is how the spatial organisation of energy services in urban areas shapes potential trajectories of change. Current urban and energy policy may be challenged if there is a mutually reinforcing link between space and innovation in urban energy transitions.

Urban energy landscapes is a concept that helps to study urban energy through its manifestation in visible patterns in the built environment. Urban energy landscapes reveal some of these city-specific conditions and hence, they may provide a useful perspective for rethinking the urban energy transition. This paper presents an analytical framework to understand urban energy landscapes, combining insights from socio-ecological perspectives that look into the dependence of urban areas from resource flows and socio-technical perspectives that emphasise the coevolution of behaviour and the built environment. The paper uses three qualitative case studies to demonstrate how the framework of urban energy landscapes can be applied first, to characterise the heterogeneity of spatial patterns in terms of the organisation of urban energy systems; and second, to understand how these spatial patterns relate to the urban sustainability transitions. In particular, the evidence suggests that there is a close relationship between urban energy landscapes and the trajectories of urban change in the cities studied. The paper concludes with a call for a global analysis of urban energy transitions, grounded on the insights from landscape perspectives.

2. Background and literature review

2.1. Urban energy landscapes reveal the spatial organisation of urban energy systems

Urban energy systems have a spatial dimension. In a seminal book, Owens (1986) conceptualised the relationship between energy systems and spatial structure in three links: development of spatial structure in relation to the nature, location and availability of energy sources; the structuration of energy requirements in relation to the spatial structure; and the constraints that energy sources, spatial structure and energy requirements pose on the development of energy innovations and alternative energy systems. Since then there has been a steady body of scholarship on sustainable urbanism studying how urban morphology (the granular structure of urban areas in blocks or groups of buildings) and urban form (its distribution in zones) impact the embodied and operational energy of the built environment, from influencing heat demands to shaping users' behaviours (recent examples include: Howard et al., 2012; Rode et al., 2013; Salat, 2009; Wong et al., 2011; Zanon and Verones, 2013; Zhou et al., 2013). This literature has particularly challenged an emphasis on singular models of urban development, such as the compact city, which are often applied uncritically without recognising the variety and specificity of human settlements (for a seminal critique see: Jenks et al. (1996)). Instead, this body of research shows that sustainable urban forms can be achieved in multiple ways and with attention to city-specific context (Williams et al., 2000).

Urban energy landscapes display the spatial patterns of urban energy systems which are visible in the built environment. Landscape is the territorial expression of socio-ecological relations, in this case, how urban dwellers manage and use energy and how uses relate to resource and ecosystem exploitation (Castán Broto et al., 2014, 2007). Urban energy landscapes relate to the spatial organisation of multiple energy services depending on how people use energy (for lighting, thermal comfort, communications, cooking, transportation), and how energy services are provided (whether this is for the generation of electricity, gas provision or for the direct use of fuels for heat or mechanical power). Urban energy landscapes are experienced as a continuous arrangement of artefacts that mediate the transformation of energy resources to provide different, but simultaneous, services. For example, buying street food for dinner may require a lighting system, cooking devices and perhaps, a system of communications to pay for the meal when using a credit card. Even when using similar technologies, the experience will be completely different in each city, from Munich to Marrakesh. From the built environment structures that support both cooking and selling, to the lived experience of the city and how cooking is shaped by a specific culture, urban space shapes energy uses and the means that support their provision. Urban energy landscapes engage with the specificity of urban energy systems and the heterogeneous spatial arrangements that emerge within particular places. Yet, we can describe certain regularities in urban energy landscapes as emerging at the intersection of systems that enable the circulation of different energy resources to the place in which they are needed; and how different artefacts interact with social expectations in a complex sociotechnical process.

Why does it matter to understand the structure of urban energy landscapes? On the one hand there are best-practice models of development which focus on a one-size-fits-all solution without proper consideration of the implementation contexts. On the other, there are rich studies which immediately point towards the complexity and uniqueness of each urban area. Yet, in the context of an urban energy transition, one which engages with the global challenges of urbanisation and sustainable energy, we need tools to manage this complexity, opening up spaces to learn from similarities and differences. Urban energy landscapes engage with cutting edge critiques of urban sustainability that emphasise the multi-scalar nature and contingency of urban processes (e.g. Coutard and Rutherford, 2010; Marvin and Graham, 2001), exploring how simple spatial organisation variables may explain complexity in urban energy systems.

2.2. Urban change trajectories emerge from the coevolution of human and biophysical systems

Co-evolution is a concept that explains the uniqueness of the landscape perspective. It refers to processes of interaction between evolving human and biophysical systems that account for the changes in both systems (Norgaard and Kallis, 2011). Coevolution occurs when change over time in seemingly separated systems (human and biophysical) leads to a mutual response (Weisz, 2011). In an urban setting, coevolution refers to the coupling of social systems with particular configurations of the built environment that enable resource transformation. Coevolution challenges traditional understandings of energy because it breaks assumptions about the causal mechanisms that mediate ecologies, technology and society. For example, many studies in urban morphology research accept Owens' two directional assumptions about the influence of the availability of energy resources on spatial structure and about the influence of spatial structure on energy requirements (Owens, 1986). However, a coevolutionary perspective suspends assumptions about the causal directionality between two systems, i.e. one causing the other. Instead, coevolution presupposes mutual influence between social practices, technology and the built environment, and the ecosystems that sustain them (Brand, 2005). Coevolution emphasises systemic change that emerges from the variation between individuals within the system but there is no assumption of progress in that change (Fracchia and Lewontin, 1999; Weisz, 2011). Thus, coevolution does not imply any teleological explanation about the organisation of social, technological and ecological systems. Instead, coevolutionary analyses look at the interconnected string of historical factors and events that explain the contemporary situation.

The sequence of states that over time leads to the current state of

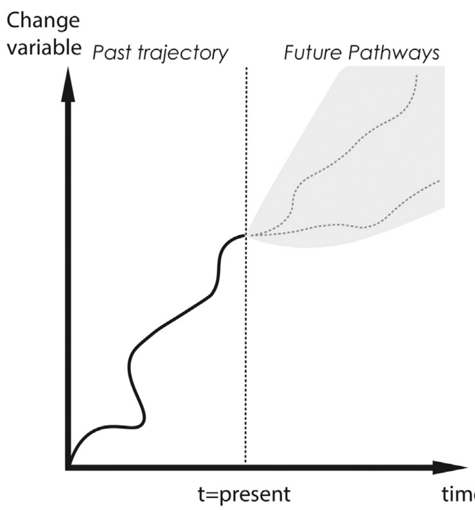

Fig. 1. Past trajectories of urban change and future pathways.

urban energy systems can be thought of as an urban trajectory (Fig. 1). In terms of how people use energy, for example, this trajectory can be thought of as a 'chain of experiential needs', through which multiple elements of the urban energy system become interconnected (Brand, 2008). At a given point in time, the urban energy landscape represents the development of past trajectories, resulting from the coevolution of ecological, social and technological systems. Trajectories are embedded in broader contexts, or pathways, that help articulate future visions (Hodson et al., 2015; Rydin et al., 2013). Pathways refer to a wide diversity of imagined urban futures that emerge from critical junctures- or path bifurcations- and that are likely to shape the direction of travel and close off alternative destinations (Smith and Kern, 2009; Vohora et al., 2004). Pathways emphasise future possibilities and alternative courses of action (e.g. Marletto, 2014; O'Neill et al., 2015; Rydin et al., 2012; Turnheim et al., 2015). Pathways are thus linked to multiple and competing values that shape change trajectories (Leach et al., 2010).

Trajectories emphasise the course or direction of change: they explicitly refer to the process of walking a single path. Path dependence occurs when contingent historical events trigger a sequence of events following a relatively deterministic pattern or inertia, that is, the present conjuncture depends on decisions taken in the past (Mahoney, 2000). When socio-ecological and socio-technical systems follow a coevolutionary trajectory they may trigger a self-reinforcing sequence of events that may condition future change opportunities. For example, the discovery of large fossil fuel reserves may lead to the development of institutions, economic interests, lifestyles and technological developments that curtail the possibilities to develop renewable technologies and, over decades, render any development alternative unthinkable (for examples see: Castán Broto (2013), Corvellec et al. (2013)). With the development of infrastructures, institutions and social habits, moving away from fossil fuels may prove an impossible enterprise, which is described as carbon lock-in (Unruh, 2000). In urban areas, carbon lock-in is a key aspect of the obduracy or resistance to change, which is experienced as an obstacle for the planners and city managers who see themselves as bringing spatial transformations (Hodson, 2008). Urban obduracy follows the construction of built environment structures that become fixed and immobile (Hommels, 2000). Obduracy can be explained as a relational property that develops as different elements become intertwined through coevolution (Beauregard, 2015; Hommels, 2005). Thinking of urban obduracy is akin to thinking of what is possible, recognising how future opportunities are constrained by a specific urban change trajectory of urban change (Kirkman, 2009). In this way, coevolution highlights the mutual reinforcement between human and biophysical systems in urban areas.

Urban change refers to the processes whereby the recognisable social and spatial structure of urban areas becomes different, and, in some instances, radically transformed, effectively overcoming carbon lock-in and obduracy. Urban change can be gradual and incremental or radical and transformative (a transition), depending on the speed at which change takes place. There is a consensus now that moving towards a sustainable society is akin to delivering a radical transformation of human-ecological relations, certainly beyond incremental, efficiency-related gains (Haberl et al., 2011; Markard et al., 2012). In urban areas, this entails a substantial modification of the relationship between urban societies, the resource systems that sustain them and the technologies/structures that mediate resource transformations. This differentiates between quotidian forms of urban change, whereby city inhabitants shift different aspects of the urban landscape until it becomes unrecognisable, and what is effectively a rapid reconfiguration of urban infrastructure landscapes in transformative process (Monstadt, 2009).

2.3. The transition to sustainability will be shaped by urban energy trajectories

Attaining sustainability will require a 'great transformation', that is, a radical shift of human-ecological relations and the consequent restructuration of existing systems of production and consumption. Systemic changes require changes in the patterns of interdependence of social, technological and ecological systems (Rotmans and Fischer-Kowalski, 2009).

The same coevolutionary mechanisms that cause infrastructure lock in may play a key role in catalysing a radical change. Of all the possible pathways that a city can follow, transition pathways refer to future opportunities to catalyse new patterns of changes in socio-technical systems leading, for example, to the simultaneous reconfiguration of technologies, supporting infrastructures, business models and production systems, and the behaviour of consumers (Elzen et al., 2004; Geels and Schot, 2007; Markard et al., 2012). Generally, transitions are thought to follow an S-shaped trajectory, which reflects a sequence of events that start in a predevelopment phase, or a latent state in the transition, an acceleration phase and an eventual stabilisation phase, as depicted in Fig. 2, trajectory C (following Rotmans et al. (2001)).

What is coevolving in each case? Much transitions scholarship focuses on the consolidation and disruption of techno-economic complexes in socio-technical transitions (Markard et al., 2012). Although there exist several theoretical strands of socio-technical transitions, they all emphasise aggregation of institutions, social and

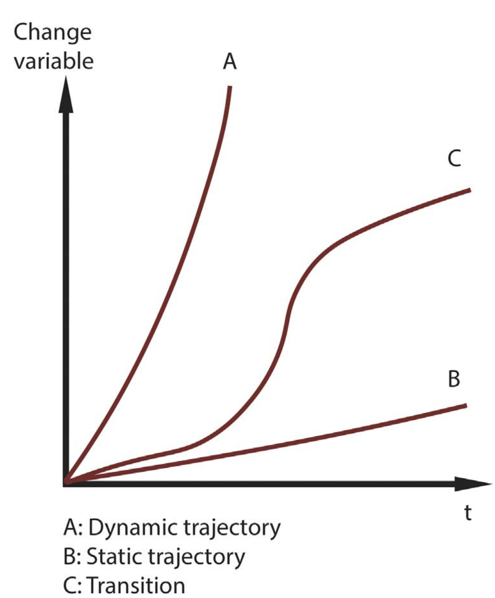

Fig. 2. Alternative urban change trajectories.

technological systems in a regime. Changes in structural conditions may open a window of opportunity for radical change while niche-based innovations may destabilise and ultimately disrupt the regime (for examples see: Elzen et al. (2004), Geels (2005, 2010), Geels et al. (2008), Geels and Schot (2007), Schot and Geels (2008), Turnheim et al. (2015)). Pathways represent alternative trajectories in which a transition could happen, depending on the timing of innovations and whether the dynamics of transition are disruptive or rather, innovations contribute to shift existing trajectories (Geels and Schot, 2007). Pathways are also related to governance processes, the extent to which different actors are aggregated, and whether they can intervene directly in transition processes (Smith et al., 2005). This school of thought provides the tools for analysing trajectories in relation to structural factors, the rate of innovations and the presence of viable alternatives within the regime.

There is a distinct but complementary school of socio-ecological transitions to sustainability which focuses on the coupled transformation of human and ecological systems (Fischer-Kowalski and Haberl, 2007b). Using socio-energetic metrics, this school focuses its analysis on the fundamental transformations of societal relationships with energy (Haberl, 2001; Haberl et al., 2001). If we describe human history as a history of nature appropriation, transitions entail fundamental transformations of our relationships with nature. Socio-ecological theories of transition take a long-term, geological perspective to characterise fundamental changes in the use of energy (Fischer-Kowalski, 2011; Fischer-Kowalski and Haberl, 2007a, 2007b; Krausmann et al., 2008). They often speak of three moments of transition in human history, although they are not simultaneous in the whole world. The agrarian revolution entailed moving from hunter-gather societies which depended on the passive utilisation of solar energy towards a society that monopolises land to harness solar energy and the application of hydraulic or animal power. The industrial revolution, in contrast, generated fossil-fuel dependent societies associated with industrial technology. The sustainability revolution should involve a transformation of the same magnitude as previous revolutions. This form of analysis puts in perspective the scale of change required to attain an urban energy transition. Also, it applies a relatively simple set of metrics to characterise the socio-ecological transitions in relation to society's use of energy.

3. Methodology

Building on these two perspectives, the urban energy landscape approach adopted here attempts to engage both the socio-technical and socio-ecological dynamics of transitions. Scale differences in both theories can be bridged by situating transitions in a specific context, as different processes of transition may be nested within each other (Rotmans and Fischer-Kowalski, 2009). The urban context, in particular, points towards the heterogeneity of transitions, their non-progressive character and the difficulties in attributing change to deliberately managed processes (Bulkeley et al., 2010; Rutherford and Coutard, 2014). The case studies discussed below have different characteristics in terms of what changes (socio-ecological perspective) and how it changes (socio-technical perspective). The concept of energy landscapes, in particular, directs attention to the mechanisms that enable the circulation of energy resources in the networked city, and how the spatial patterns of the city shape specific choreographies of energy use, that is, different sequences of action around energy services.

The analysis deploys well-established comparative urbanism methodologies. These methodologies look into patterns across cities to understand both the influence of common factors (such as globalisation or global energy markets) on local development (Boudreau et al., 2007) and to compare the historical development of long-term trajectories (Kloosterman and Lambregts, 2007). In this paper, comparison is used for an additional purpose, that of differentiating the ways in which local, spatial factors shape specific energy patterns. This resonates with an emerging approach in comparative urbanism that attempts to develop multiple, individualised comparisons to gain insight through the development of analogies, rather than just generalising across cases (Nijman, 2007). Hence, while this paper focuses on spatial factors as a common driver of urban energy transitions, the interpretative study of those factors as they manifest in visible patterns, or landscapes, emphasises the contingent character of those transitions.

The analysis focuses on three contrasting examples: Hong Kong (PRC), a compact city with relatively low carbon per capita but high levels of energy consumption; Bengaluru (India), a sprawling city whose energy demands are growing rapidly; and Maputo (Mozambique), a city with excessively low consumption per capita, where access to modern fuels continues to be a challenge. Each case study was developed with a combination of spatial analysis, archival research, and participatory mapping of energy systems (except in Hong Kong, where this was not possible). The combination of methods are intended to create an exploratory and multi-dimensional account of different urban energy landscapes. Simultaneously, semi-structured interviews were conducted with representatives of governance institutions, public utilities, business innovators and NGOs in each city to analyse the current urban trajectories towards sustainability, as it is perceived by key actors in the urban energy system. For reasons of space, this paper focuses on the comparison of the case studies, focusing on explaining the relationship between spatial patterns of energy provision and use, and the possible change trajectories.

4. Results

Fig. 3 presents a hand-drawn representation of the urban energy landscapes in each of the cases studies. The purpose is to represent socio-energetic relations as they relate to the experiences and perceptions of producers and consumers of energy, rather than giving a geographical representation of the location of different infrastructures. The energy landscape is characterised in each case by the relationship between the resource flows that support a system of provision, and the specific uses of energy that it supports. In particular, the focus is on understanding how the cases of Hong Kong (People's Republic of China), Bengaluru (India), and Maputo (Mozambique) illustrate urban energy landscapes, how they reflect urban variability and how they relate to specific material, institutional and cultural systems of energy provision and use in each location. Further analysis of urban energy landscapes and trajectories focused on understanding the mutually reinforcing link between spatial organisation and the production of innovation in each case.

4.1. Hong Kong

Hong Kong is today a global city characterised by an LED lighted-skyline looking over the 'Fragrant Harbour' in Victoria Bay. Electricity, lighting and, more generally, energy are central to the operation of one of the largest cities in the world. In 1997, with the transference of Hong Kong to the People's Republic of China, Hong Kong SAR became China's first 'special administrative region'. The energy system in Hong Kong is characterised by a legacy of autarky developed during British rule that led to the development of a stable electricity regime supported by the dominance of two territorial monopolies: the Hong Kong Electric Company (HEK) Ltd and CPL Power Hong Kong (CPL) Ltd (Moss and Francesch-Huidobro, 2016).

Hong Kong's energy system is today characterised by its dependence from imported fossil fuels. HEK and CPL supply electricity to Hong Kong, mainly from power plants that burn coal or gas. Both companies import fuels (coal from Indonesia and gas from Oman and Australia) and, since devolution, CPL imports nuclear energy from mainland China. The operation of both HEK and CPL is regulated by 10-year Scheme of Control Agreements (SCAs), due to expire in 2018.

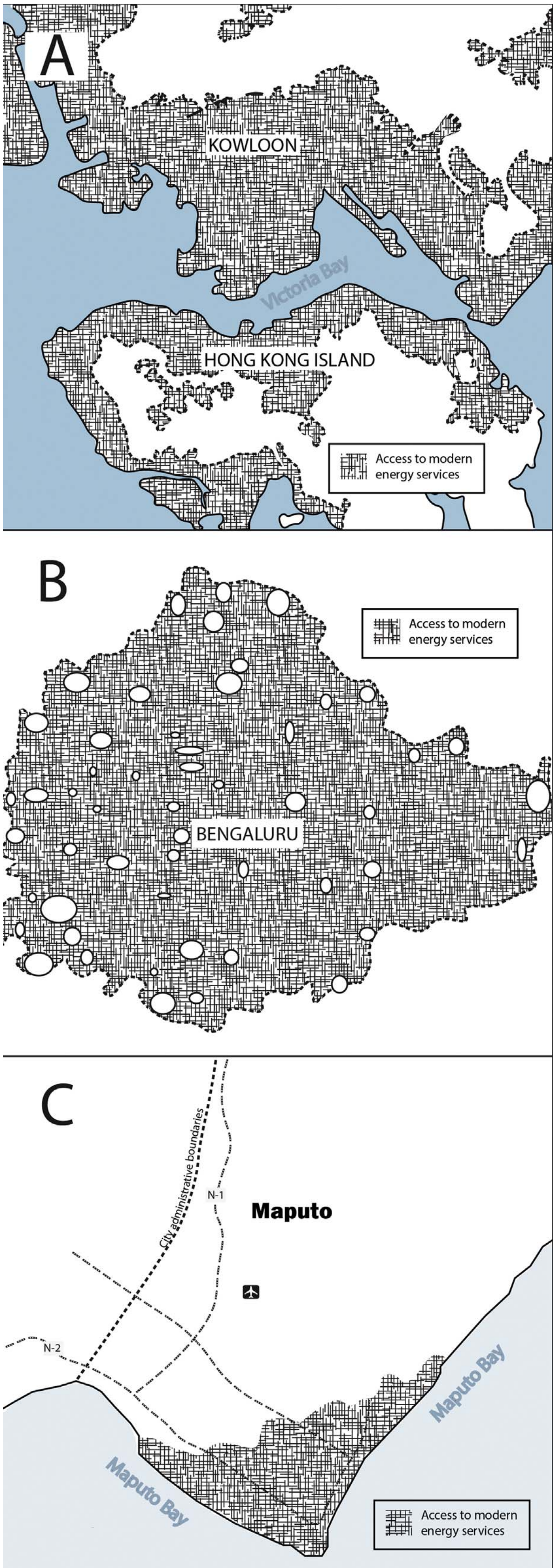

Fig. 3. Simplified representation of Urban Energy Landscapes in Hong Kong (A), Bangalore (B), and Maputo (C).

SCAs determine the rate of return for shareholders as a fixed percentage of average net fixed assets. This mechanism is thought to guarantee investments for a reliable and secure electricity supply at reasonable prices. This system also delivers a relatively homogeneous and reliable electricity distribution system, with relative cheap prices for electricity in comparison with other services within the city. Yet, Civic Exchange, Hong Kong's major think tank on urban sustainability, has warned that SCAs discourage investments in energy efficiency and has led to environmentally sub-optimal decisions (Leverett and Exchange, 2007).

In terms of the spatial use of energy, Hong Kong, is a superb example of a compact city. In the words of one local policy maker, the city became low carbon "by accident", especially because of the population pressure on land has pushed up land prices. Simultaneously, the government has long had a programme for public housing which, due to popular pressures, focused as much on building public transport links as on building houses. The city of Hong Kong provides affordable energy to all its population, with a relatively homogeneous network which depends on fossil fuel imports. Nevertheless energy consumption is quite high. Activists claim that the combination of the current regulatory system and cheap energy prices prevent efficiency gains and innovation in the energy system in Hong Kong, but they also emphasise the history of the built environment as a major factor shaping opportunities for reducing energy consumption (Leverett and Exchange, 2007). Electricity amounts for 54% of energy use, while oil and coal products amount for 29% and town gas and LPG 17%. Most of the oil and coal (89%) is used in transport. In contrast, most of the electricity (93%) and the town gas and LPG (67%) are used in the residential and commercial sectors- the built environment. The consumption of energy in these sectors is very high, despite the relatively good spatial configuration of the city with high rise towers and mixed land use. Electricity consumption per capita, for example, is 5.955 kWh/capita, more than double the average in mainland China, which is even more astonishing when considering the small size of the industrial sector in Hong Kong (responsible for only 5% of the total energy use). This indicates that increases in energy consumption are driven powerfully by consumption. Because of the complete expansion of a networked system based upon fossil fuels, and the reproduction of similar energy intensive practices, Hong Kong has, generally speaking, a uniform energy landscape (Fig. 3-A).

At the moment, Hong Kong policy makers are interested in reducing the dependence from coal. Interviews with city officials also show concerns with decarbonisation and energy security, but overall, there is a manifest resistance to change. Such resistance is most often justified with the argument that there are not renewable alternatives because of the city's geography, the high levels of consumption associated with high urban density and the stratospheric land prices. Experiments with renewables, such as the 800 kW Wind Turbine in Lamma Island, have added to the general view that renewable power generation is not possible. The alternatives considered are fuel switching from coal to natural gas or increasing purchases from power grids in mainland china. Moreover, the research also demonstrated a complete lack of alternative imaginaries for example in housing design, decentralised energy provision, or radical transformations of energy-intensive lifestyles. A survey has suggested that consumers express preferences for the maintenance of the status quo, in terms of quality and price of electricity services (Woo et al., 2014). The emphasis of NGOs and other non-governmental organisations in reproducing energy efficiency strategies and citizen education programmes suggest that there is little appetite for radical innovation within the energy system of Hong Kong.

4.2. Bengaluru

The city of Bengaluru in the state of Karnataka, India witnessed growth consistently for over a century, from being a 'garden city' for pensioners under the British Empire, to being thought of as the 'Silicon Valley of India' since the 2000s because of the rapid growth of the IT and offshoring industries. With over 8 million inhabitants, Bengaluru is now a mega city. In the early 20th century Bengaluru became one of the first cities to be electrified in South Asia. The installation of the hydroelectric plant of Shivanasamudra in 1906, to supply electricity to the Kolar Gold Fields, accelerated the electrification of Bengaluru, especially the colonial Civil and Military Station and the central neighbourhoods. Until the 1970s and 1980s, hydropower was the main means for power generation to supply Bengaluru. However, with the development of thermal power in the 1970s and the raise of environmental movements against dams, other means of provision were added to the city with thermal plants in Raichur and Bellary. This has led to the development of an extremely fragmented electricity network, both in terms of sources of energy and the means of provision across the city. The reform of the power sector in 1999, following liberalisation doctrines, led to further fragmentation in the governance of the energy services. The reform established an overarching Electricity Regulatory Commission (KERC), a separate entity for transmission called the Karnataka Power Transmission Corporation Limited (KPTCL) and a number of Electricity Supply Companies for different regions in the state (ESCOMs) to substitute a single Karnataka Electricity Board. Fragmentation is thus a characteristic of both the material infrastructure and the governance structure which characterise Bengaluru's energy landscape. Interviews among officials demonstrate that there is no integration between energy management practices and any form of spatial planning, and officials frequently question the relevance of spatial aspects for energy management.

This fragmented energy landscape can also be observed in the patterns of access to energy and energy use. Bengaluru is a profoundly divided city, which, in broad strokes, can be divided in at least three very different groups with radically different energy practices. First, there is the long established middle class which have traditionally contributed to Bengaluru's fame as an industrial and commercial centre and whose energy practices have evolved alongside the urbanisation of the city, with, generally, access to formal systems of electricity and fuel provision following the structure of the city in villages and layouts. Second, there is a rapidly growing cosmopolitan middle class of professionals working in global companies (especially IT and offshoring) who have higher energy-intensive lifestyles and live in gated compounds. This cosmopolitan class may also have green citizenship aspirations, and thus, often rely on individual, high-tech solutions for energy provision. Third, there is a large class of inhabitants that have substandard services in informal settlements, and rely on precarious means to access energy. The 2011 Karnataka Census reports near 20% of the population living in slum conditions, but this figure does not reflect other vulnerable people, including, for example, households living in precarious conditions in tenements and peri urban villages. As these non-homogeneous groups are distributed across the city, the patterns of energy access and use are also fragmented and bear no relation with the landscape of energy infrastructure.

Another factor that shapes Bengaluru's energy patterns is the temporal variations of energy provision and use. For example, the city suffers from supply problems with an intermittent supply of energy, particularly during the monsoon months. Bengaluru's citizens have become accustomed to developing private solutions for their energy supply, but solutions vary in relation to the housing conditions of different neighbourhoods. For example, luxury compounds associated with the growth of the IT and offshoring industries rely on diesel generators and renewable energy as a means to secure energy supplies. At the other end of the spectrum, for the roughly half a million people living in precarious informal settlements portable solar lamps may be their only hope of a reliable lighting service. During most of the year, the city resembles a slice of gruyere cheese, with holes that represent the very poor communities lacking energy access (Fig. 3-B). During the monsoon, however, when the cuts to the electricity system begin, the city resembles an archipelago of richer communities with independent energy supplies, surrounded by a city in the dark. This scattered energy landscape of cold and hot spots resonates with the hypothesis of infrastructure fragmentation vividly explained in Marvin and Graham's Splintering Urbanism (Marvin and Graham, 2001). However, fragmentation is also associated with a changing energy landscape in which innovations are transferred from luxury compounds to informal settlements and viceversa and technologies such as solar water heaters are rolled out in the city in record time (Bulkeley and Castán Broto, 2014; Bulkeley et al., 2014c). Bengaluru's energy landscape is fragmented, but also incredibly dynamic in terms of providing opportunities for low carbon innovation. The case of Bengaluru, however, also shows that the conditions for innovation are not the same ones that enable the provision of universal energy services.

4.3. Maputo

Maputo, the capital city of Mozambique, is the most developed part of a country routinely found at the bottom of UNDP's rank of nations according to the Human Development Index. The provision of services, including energy, was lagged by the long post-independence conflict that lasted until the early 1990s. While progress in human development over the last 20 years has been remarkable (United States Agency for International Development, 2011), infrastructure services are still underdeveloped. For example, firewood and charcoal make up to 81% of the total energy consumed in Mozambique (Cuvilas et al., 2010). The poor state of infrastructure in Mozambican cities, including Maputo, also reflects a context of institutional thinness and weak political involvement of citizens (Jenkins, 2000; Jenkins and Wilkinson, 2002).

The national utility Electricidade de Mocambique (EDM) dominates over electricity distribution markets (Power et al., 2016). The distinguishing characteristic of the energy sector in Mozambique is its orientation towards resource extraction and export markets (Mulder and Tembe, 2008). This is evident for example in the case of the Cahora Bassa dam, built in the 1970s in the province of Tete, the main source of electricity in the country (Ahlborg and Hammar, 2014). Only 15% of the electricity produced by the dam is for national consumption (Sebitosi and da Graça, 2009). Electricity exports from the dam support a wheeling agreement between EDM and the South Africa utility ESKOM and Electricidade de Moçambique (EDM), to palliate the lack of direct transmission infrastructure and provide electricity to Maputo and the relatively more prosperous south part of the country. Maputo thus presents the highest electrification rates of the whole country.

Nevertheless, energy access problems are rampant among local households, which face different alternatives for energy access but whose possibilities are constrained by material, economic, and social factors. Maputo is often presented as two cities: the central area with an overall supply of infrastructure dating back from the colonial era, and the surrounding bairros in subserviced areas. The former is often referred to as 'the cement city' while the latter is 'the reed city' (cidade de caniço), with reference to the materials used to construct huts in colonial times, when the bairros constituted a reservoir of labor for the colonial city. While this separation is constantly challenged by the integration of formal and informal processes in everyday life these two imagined cities represent two different energy landscapes. While in 'the cement city' both electricity and LPG are widely available and used in modern appliances in households connected to networks, the reed city is characterised by the ubiquitous presence of solid fuels, specially charcoal, which is generally used in iron cookstoves in shared yards, where one or several families may cook. Charcoal sustains a network of livelihoods in the reed city, from the large charcoal traders to the local business women who sell fractioned amounts of charcoal in street corners near poorer households.

Most attempts at facilitating energy access have taken place in the reed city. EDM, for example, has succeeded in developing a pre-paid system of electricity retail to facilitate the incorporation of low income households to the electricity grid (Baptista, 2015; p. 1004). In some neighbourhoods the rate of access to a reliable and affordable electricity connection has improved from 50% in 2007 to 70% in 2014. Nevertheless, electricity is still an expensive commodity and most households in Maputo use cheaper solid fuels for cooking, mainly charcoal, which provides a range of local livelihoods and is suited to the courtyard style housing model that dominates the city. NGOs have focused on improving the efficiency of cookstoves and testing the possibilities of LPG in informal contexts. Both institutional representatives and local academics anticipate a rapid transition to modern fuels in Maputo, building on the exiting experiences of infrastructure development and business models oriented towards low income households, but the evidence of such transition is still sparse. This is a zoned energy landscape (Fig. 3-C), in which the history of the built environment divides the city between those areas where modern energy services are taken for granted and the large areas, painted in white, where they are not. Maputo is clearly going through a process of transition, but this is a transition to 'modern' fuels rather than an actual transition to self-sustaining, low carbon sources of energy.

Overall the three cases hereby considered point towards an emerging typology of urban energy landscapes that extends beyond the realm of these particular situations. These patterns emerge from the simultaneous interaction between ecological, social and technological systems. Hence, urban energy landscapes can be read as a function of: 1) the patterns of circulation of energy resources in an urban area; 2) the patterns of energy access and use; and 3) the distribution of energy technologies in relation to build environment structures and public spaces. Fig. 4 suggests four potential archetypes of urban energy landscapes which could describe the relationship between space and energy in different cities: uniform landscape such as in Hong Kong; zoned landscape such as in Maputo; and a scattered landscape characterised by hotspots (Scattered A) or by coldspots (Scattered B) which we can find in Bengaluru at different times during the year. The objective of this analysis is not to show all the possible patterns of urban energy landscapes, but rather, examine the heterogeneity of relations between urban development and energy systems and how they coevolve in different contexts.

Such patterns of urban energy landscapes shape the possibilities for change in determined urban trajectories. In each example discussed above, Hong Kong, Bengaluru and Maputo, we find a different change trajectory which emerges from situated histories of coevolution between ecological, social and technological systems. Fig. 2 in Section 2.3 suggested that we can find three different types of trajectories towards alternative socio-technical systems, from static situations, where a regime change is unlikely, to dynamic ones in which change is continuous. Hong Kong and Bengaluru represent two extremes on the dynamics of systems innovation. Hong Kong follows a relatively static trajectory with little or no change towards a reconfiguration of energy systems (Trajectory B). From the risk-averse discourses of government representatives about their dependence from fossil fuels to the concurrent use of the individual air conditioning unit in every apartment (sometimes in every room), systemic change is unlikely. Bengaluru, in contrast, shows an incredibly dynamic pattern of change, with decentralised innovations being produced and adapted daily to new gated developments and informal settlements (Trajectory A). While Hong Kong can be described as being in a predevelopment phase, Bengaluru is clearly in an acceleration phase but with no stabilisation phase in sight. Maputo is the only city of these case studies which seems to follow a transition trajectory from the use of solid fuel to universal electrification and increased rates of LPG access (Trajectory C).

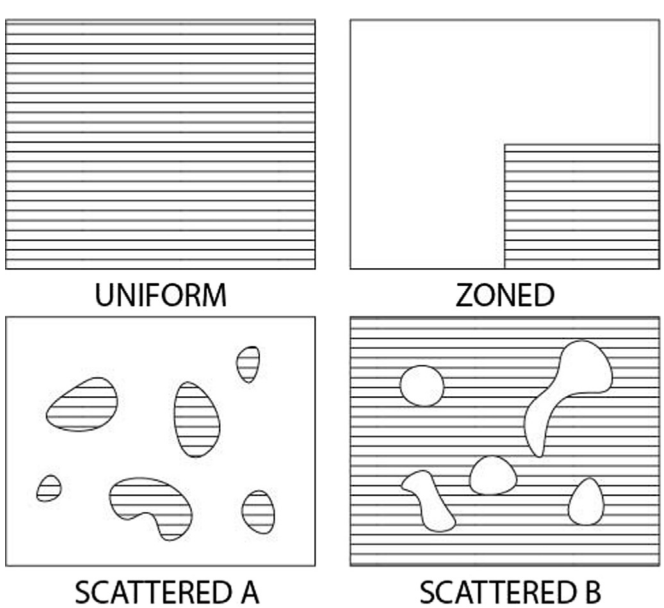

Fig. 4. A typology of Urban Energy Landscapes.

Table 1 summarises the insights from the three case studies discussed above. In the case of Hong Kong it appears that a uniform landscape pattern relates to a static trajectory, whereas in Bengaluru, a scattered pattern relates to a dynamic trajectory. The only situation in which we can anticipate a transition- that is, a change of the socio-technical regime from one technology (charcoal and cookstoves) to another (LPG and modern appliances) is in the case of Maputo, where different energy landscapes emerge in a zoned fashion. This does not imply a causal relationship (e.g. spatial organisation leads to a particular form of innovation) but rather, emphasises how co-evolutionary processes shape simultaneously the urban fabric, the resource systems it depends upon, and the possibilities for innovation within such context. Urbanisation is, in itself, a multidimensional process of change and thus urban areas can always be read simultaneously as places of continuous change or entrenchment of practices in a relatively static manner. Yet, the analysis suggests that there is a mutual reinforcing relationship between the way energy systems are spatially organised in different urban areas and the potential for innovation in sustainable energy, which in turn shapes any possible trajectories towards sustainability.

5. Conclusion and policy implications

The urban energy transition is associated with a conundrum: there is a perceived need for change, but there are clear complications in generating collective, just visions of the future city that can provide direction for such a transition. This is not due to a limited availability of suitable, commercially viable innovations. There are abundant ideas about how to deliver sustainable futures. However, current approaches tend to reproduce existing barriers to low carbon societies and ignore radical system alternatives (Truffer et al., 2010). Systemic challenges are often most visible in urban areas because cumulative problems are exacerbated by agglomeration and density. Urban areas are characterised by complexity, scale and context dependency, relative permanence of the built environment and the intervention of vested interests,

Table 1
Links between urban energy landscapes and urban change trajectories in three case studies.

		Energy Landscapes		
		Uniform	*Scattered*	*Zoned*
Trajectories	*Static*	Hong Kong		
	Dynamic		Bangalore	
	Transition			Maputo

cultural norms and lifestyles (Næss and Vogel, 2012). The urban energy transition relates to persistent problems that are deeply embedded in our societal structures, pertain to multiple actors and are hard to interpret (Lawton, 2007). Furthermore, there is no ‘ stopping rule’ for the urban energy transition (Lawton, 2007): there is no end to delivering universal and sustainable energy services in cities like Hong Kong, Bengaluru or Maputo. Transition studies have described transitions as fundamentally political processes, that require a pluralistic treatment of the subject matter and which are governed through negotiation and dialogue (Smith and Stirling, 2007). Effective governance will be appreciative of the complexity of urban issues, their uncertainty and the asymmetries of power, thus seeking to mobilise both deep analysis and broad data while facilitating processes of learning and experimentation (Turnheim et al., 2015). Nevertheless, content- as much as process- is the matter of transitions governance (Brand, 2005; Næss, 2015; Wilkinson, 2012). Transitions management is as much about building arenas for dialogue as it is about generating concrete ideas and proposals for change (Loorbach and Rotmans, 2006).

Without challenging the approach of transitions management, the urban energy landscape perspective points towards the collective making of energy infrastructures and urban areas. Strategic planning projects interact with both institutions' grand ideologies about energy provision and citizens' mundane practices of energy use. Urban energy landscapes emerge from the coevolution of socio-ecological and socio-technical systems and thus, point towards the complexity of urban processes at work. Those landscapes find expression in the spatial configuration of energy systems, and the opportunities that this opens up for sustainability action and innovation. This has a very direct policy implication: urban energy transitions cannot be managed without reference to a profound understanding of the history of the built environment and the cultures of energy provision and use associated with it.

Clearly, patterns of spatial organisation will bear influence, at the very least, on the consequences a sustainable energy transition will have and how it will unfold in urban settings (Bulkeley et al., 2010, 2014a; Coutard and Rutherford, 2010; Hodson and Marvin, 2010; Rutherford and Coutard, 2014). This relates not just to the potential to achieve emissions reductions, but also to the need to influence patterns of energy access across urban areas. A landscape perspective on urban energy follows an engagement with the increasing interest on the role of urban areas in both socio-technical and socio-ecological transitions (Gierlinger et al., 2013; Hodson and Marvin, 2012; Marletto, 2014; Rohracher and Späth, 2013; Romero-Lankao and Dodman, 2011; Vogel, 2015). On the other hand, critical studies of urban sustainability follow the realisation that there is an intimate relationship between the spatial aspects of transitions and how transitions are governed, with context-specific social and political consequences (Bridge et al., 2013; Bulkeley et al., 2014b; While, 2010).

Scholars of sustainable urbanism have most often focused on the performance of built environment and spatial structures against sustainability criteria (Jenks et al., 1996; Næss, 1993; Newman and Kenworthy, 1999; Williams et al., 2000). However, planning for a sustainable transition means moving beyond predicting the shape of a sustainable city. This is akin to thinking of urban space as the object of transition (Næss and Vogel, 2012). This approach moves away from the hypothesis that urban archetypes influence energy systems (cf. Newton, 2000), and focuses instead on urban energy landscapes as archetypes that emerge from the coevolution of societies, technologies and ecologies. The analysis suggests a relationship between the spatial organisation of urban energy landscapes and the potential trajectories of change in urban areas. If proven true, this finding means that an urban energy transition requires urban environments that allow for change and flexibility rather than uncertain predictions about how future cities will look like (Lawton, 2007; Rydin et al., 2008). Linking the spatial organisation of urban energy landscapes to the processes of innovation that can generate an urban energy transition will reinvigorate current thinking about one of the greatest challenges of our time and consolidate a trend towards experimentation in sustainability governance (Bulkeley et al., 2014c). This has a direct implication not just for planning, but also for the development of energy and urban policy that reflect the fundamental idea that spatial diversity relates to the production of innovation.

By drawing the link between space and innovation, this paper aims to stir urban governance discussions on the context-specific nature of transitions and how they unfold uniquely in each city. The research clearly points towards the consideration of heterogeneous urban energy landscapes, the mutual reinforcement of energy infrastructure and urban development, and the importance of experimental approaches to test alternatives within a given context. However, policy recommendations from the analysis of the relationship between spatial organisation and innovation in urban energy landscapes should be adopted with caution. Fostering innovation is not akin to foster universal access to sustainable energy in an equitable way. In terms of future research, systematic and quantitative analyses can complement the present exploratory analysis of three case studies. Qualitative case studies reveal the structure of urban energy landscapes in specific settings. However, the concept of urban energy landscapes can be deployed beyond specific case studies, to analyse the spatial organisation of urban energy systems and how they shape city-specific conditions for an urban energy transition. For this, a global perspective on urban energy landscapes is needed.

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