Review

Sustainable cities targeted by combined mitigation–adaptation efforts for future-proofing

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ABSTRACT

This paper examines recent literature on achieving sustainable cities that incorporate a combined mitigation–adaptation approach towards improved urban resilience as a way of future-proofing. A multidisciplinary approach, which integrates scientific as well as ecopolitical frameworks, is found to benefit this sustainability discourse.

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1. Introduction

The concept of 'future-proofing' is not new to sustainability. Richards and Bradbury (2007), for instance, are among several published authors to refer to future-proofing within the context of the built environment. Authors have considered solar irradiation, temperature, humidity, and daylighting in simulations of buildings in order to examine the potential impact of climate change, particularly in terms of overheating in summer months (Jentsch, Bahaj, & James, 2008). Coley, Kershaw, and Eames (2012) examine non-structural adaptations as a way of reducing risk associated with incorrect climate change projections, such as higher temperatures. Georgiadou and Hacking (2010) argue that future-proofing is needed in planning and design to establish more flexible, resilient

buildings (urban design) in the longer term. Georgiadou, Hacking, and Guthrie (2012) more recently set forth a conceptual framework for future-proofing that targets the energy efficiency of buildings (future-proofed energy design) within the context of low carbon development (LCD). Again, within a long-term perspective, they refer to future-proofing (of buildings) in terms of design processes (for example, energy efficiency measures and low carbon technologies). Among their considerations is accommodating risks and uncertainties associated with energy consumption.

The chief stance advocated in the current paper is that urban resilience works as a multidisciplinary approach to achieving effective future-proofing of urban climate change. Resilience is considered as a future-proofing tool to assess adaptation to climate change. The concept of resilience has evolved over the years to become a concept that integrates traditional ecological resilience with social resilience, and most recently urban resilience. Moreover, it is posited that a combined mitigation–adaptation perspective is most useful for the realisation of improved urban resilience. This is discussed in the following pages based on current research and findings. First, the authors consider resilience

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as a multidisciplinary concept adopted from ecology. Then, a consideration of the framework for achieving a combined mitigation–adaptation strategy is presented. Finally, recommendations are made for cities experiencing change. Resilience and other considerations are revisited at the end of the paper, when suggestions are made for enhanced adaptation (or enhanced resilience) to climate change in cities in light of what has already been published in the literature.

2. Resilience for future-proofing

It is integral to consider cities as sites where human populations converge and expand, as important sites for social action and development. Holling (1973) develops the concept of resilience by contrasting it with system stability. According to him, *resilience* is a measure of system persistence and the ability to absorb disturbance and change whilst maintaining relationships between system components, such as populations or state variables. Instability in the form of large fluctuations has the ability to introduce resilience (a capacity to persist). When resilience is applied to the management of resources, there is a need (1) to keep options open, (2) to view events at a regional scale (rather than a local context), and (3) to emphasise heterogeneity (p. 21). Such a resilience-based management approach tolerates uncertainty, and does not require a precise prediction of the future, but only some capacity to devise systems able to absorb and accommodate future events.

Rather than simply returning to a preexisting state, this can mean transforming to a new state that is more sustainable in the current environment. Urban resilience is a general quality of the city's social, economic, and natural systems to be sufficiently future-proof. It is noteworthy that reducing reliance on carbon-intensive energy consumption allows urban economies to accommodate better the effects of energy price fluctuations, of the extinction of hydrocarbon resources, and, importantly, of policies and demands increasingly set by international and national governments for low carbon transitions.

Resilience, which has been previously defined by biologists and adopted by sociologists to include society, can be understood from a climate change perspective in terms of the social limits to adaptation (Adger et al., 2009). The word resilience has developed from two paradigms (Pickett, Cadenasso, & Grove, 2004), one of equilibrium (or the extreme equilibrium view of resilience), which is 'the ability of systems to return to their stable equilibrium point after disruption' (p. 373); while the other paradigm (the non-equilibrium view) is more inclusive, dynamic, and evolutionary. It defines resilience as 'the ability of a system to adapt and adjust to changing internal or external processes' with an emphasis on 'staying in the game'. It is imagined that instability in the form of large fluctuations has the ability to introduce resilience (a capacity to persist). Such an approach tolerates uncertainty, and does not require a precise prediction of the future, but only some capacity to devise systems able to absorb and accommodate future events (Holling, 1973). The latter approach to resilience can be adopted to include *social resilience* to refer to 'the ability of a community to respond to a change adaptively' (Satterthwaite, Huq, Reid, Pelling, & Romero Lankao, 2007, p. 11). For instance, where extreme climatic conditions (random events or influences) occur, populations are exposed to fluctuation that can reduce their stability, but enhance their resilience, since they are better able to absorb chance climatic extremes.

Current studies have examined the climate risks associated with sea level rise, water resources, and human health, whilst studies of energy, transport, and the built environment are less investigated (Hunt & Watkiss, 2011). An integrated approach could stimulate dialogue between architects, planners, and insurers in future

adaptations to the impacts of climate change in buildings and other sectors in cities (Crichton, 2007). According to the author, particularly buildings need to be rethought from a resilience perspective to withstand natural hazards, which are likely to be more frequent and severe, and should be adaptable to other uses defined by changing social needs. The 2010 World Development Report (World Bank, 2010b) highlights a number of important principles for such strategies:

- 'No-regrets' actions that would provide benefits irrespective of climate change, such as energy and water efficiency.
- Reversible and flexible options to keep the possibility of wrong decisions as low as possible.
- Safety margins or redundancy.
- Long-term planning based on scenario analysis and an assessment of alternative urban development strategies under a range of possible future scenarios.
- Participatory design and implementation based on local knowledge about existing vulnerability and fostering ownership of the strategy by its beneficiaries.

It is important to consider interdisciplinary approaches to low carbon cities, as advocated by Alberti et al. (2003), who argue that the natural and social sciences cannot continue to operate separately for a complete understanding of (or unified approach to) human-dominated ecosystems due to interactions between humans and ecological processes, and propose instead an integrated framework of *consilience* for 'unity of knowledge across fields' (p. 1178), including the unity of sciences and humanities in urban ecology. A recent approach to cultural ecology has been a new ecology (Head, 2010), which should comprise of a theoretical framework that is inclusive of technology (and technical expertise) within the sociopolitical economics of adaptation. Geographical research could be particularly influential in the development of climate policy (Bailey & Compston, 2010).

Whilst the anticipation of the external (natural or economic) shocks is vital for prioritising certain fields or directions and for arranging operational responses, the city's overall vulnerability is ultimately determined by its physical shape and the quality of its socioeconomic infrastructure. A dilapidated and inefficient capital stock; buildings built in the absence or in violation of construction regulations; poorly maintained urban engineering systems; under-developed public services; social inequality; polarisation and deprivation are all factors that leave cities badly exposed. It is not possible to make resilient cities overnight; rather, resilience is purposefully and progressively accumulated by improving the quality of both the social well-being and the physical stock, while incorporating into all capital investment decisions relevant principles and considerations. As Newman, Beatley, and Boyer (2009, p. 7) note, '[i]n a resilient city every step of development and redevelopment of the city will make it more sustainable: it will reduce its ecological footprint (consumption of land; water; materials; and energy, especially the oil so critical to their economies; and the output of waste and emissions) while simultaneously improving the quality of life (environment; health; housing; employment; community) so that it can fit better within the capacities of local, regional, and global ecosystems'.

3. Achieving sustainable cities that incorporate a combined mitigation–adaptation approach towards improved urban resilience

3.1. Increasing urbanisation

Urban communities are vulnerable to the negative impacts of climate change. Urban areas concentrate people and infrastructure, often in hazard-prone areas. They experience some of the largest

impacts from both gradual climatic changes and abrupt weather occurrences, and it is the poorer and socially deprived populations who usually suffer most. There is, therefore, a need for cities to embrace socially-oriented policies of improving resilience and preparedness to cope with negative environmental impacts.

Among important factors to be considered in urbanisation is the increasing world population in combination with a human preference for city-living, the human-altered environment and its potential to interact with humans, and how change (such as in climate and environment) can impact urban resilience. For example, it is expected that around 2030 half of Africa's collective population will become urban (UN-HABITAT, 2010). Wheeler (2009) identifies challenges to sustainability of urban expansion and communicates his vision for smaller-scale community development; land, resource, and population management within regions; regional identity and bioregional stewardship; improved regional equity and social welfare; economic development that promotes the social and ecological welfare; governance systems that are inclusive of regions; local participation in governance; and new forms of leadership. However, in addition to being the location for problems, such as land change and other environmental concerns, cities are 'microcosms of that global environmental change and offer opportunities for enriching both ecology and global-change science' (Grimm et al., 2008, pp. 759–760), and can set the stage for solutions. For example, Dodman and Satterthwaite (2008) argue that a concentration of both people and hazards in urban areas offers opportunities to reduce vulnerability and improve the quality of life.

Cities accommodate consumers of goods and services, and are often blamed for climate change, since they are notable sources of demand. Dodman (2009, p. 186) argues that 'attempts to blame cities for climate change serve only to divert attention from the main drivers of greenhouse gas emissions – namely unsustainable consumption, especially in the world's more affluent countries'. He conveys on the basis of his research in the UK that greenhouse gas emissions are highest per capita in the rural northeast as well as Yorkshire and the Humber and not London and the West Midlands, which are both highly urbanised. Dodman (2009, p. 196) blames high consumption lifestyles in high-income countries; for example, the US and Canada account for a fifth of global greenhouse gas emissions. America's throwaway economy is considered to be a major contributor to climate change through waste production and the release of greenhouse gases (Sheehan & Spiegelman, 2010, chap. 28). For example, 44% of these emissions were found to come from the provision, use, and disposal of products and packaging, which is more than energy used in buildings, transport, and in the provision of food (p. 4). A large disparity in wealth is even more remarkable within nations; for example, in India, people with relatively high earnings generate four times more carbon per year than people who earn less per month (Dodman, 2009, p. 197). This argument is also set forth by Satterthwaite (2008), who notes that individual and institutional consumption needs to be considered as drivers of generation. For example, as industries are moving out of cities, this establishes a disjuncture between the spatial situation of demand and production, even though they may both be triggered by consumption in cities. Wood (2007) is similarly critical of urban development that continues to be inspired by a profligate lifestyle, which he argues was the main cause of the problem to begin. Most recently Swilling (2011) argues for the reconfiguration of cities, including urban infrastructure, for their sustainable use of resources.

3.2. Governmental intervention towards mitigation

The urgency of the climate and energy agenda for cities is increasingly acknowledged in government priorities. This is evidenced by a recent surge in reports on cities and climate actions
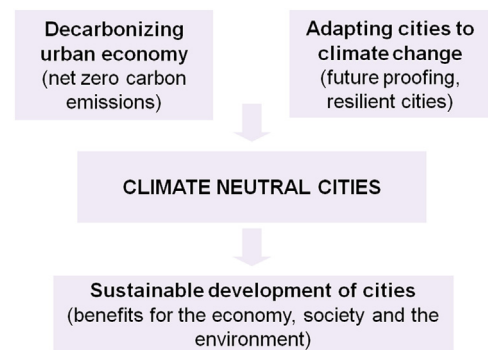

Fig. 1. Climate neutral cities: a synergetic approach to mitigation and adaptation. Based on Golubchikov (2011).

from major international organisations (Bose, 2010; OECD, 2010a; UNEP, 2009; UN-HABITAT, 2011; World Bank, 2010a). Many stress the need to address mitigation and adaptation efforts at the urban scale because of the potential to implement programmes effectively and the concentration of people and industries, which can provide new ideas and innovation that can spread quickly (for example, Dodman, 2009). Actually, both sides of climate policy, mitigation (locally reducing the causes of the climate change) and adaptation (addressing the local negative impacts of climate change), are now considered to be integral parts of a comprehensive urban strategy for climate neutrality (Golubchikov, 2011). Such a strategy suggests that cities not only aim to achieve net zero emissions of greenhouse gases by reducing such emissions as much as possible while offsetting the remaining unavoidable emissions, but also that cities aim to become future-proof, or resilient to the negative impacts of the changing climate, by improving their adaptive capacities (Fig. 1).

Climate mitigation efforts have very much focussed on the energy sector, as well as the transport sector, built environment and densification, urban forestry and greenery (World Bank, 2008). This reflects efforts in relation to both the supply and demand side of power (Table 1). Specific attempts have been made in the energy sector, on the supply side, to improve energy generation efficiency, fuel shifting to less carbon intensive fuels, keeping electricity affordable, as well as developing public and public partnerships. Hydroelectricity, wind, solar photovoltaic, solar thermal, geothermal, tide, and wave are all renewable types of energy that do not involve direct greenhouse gas emissions (albeit there are indirect emissions from building the power installations). Biomass (wood, biofuels, waste) can also be a carbon-neutral source of energy if the burned biomass is renewed in a sustainable way.

3.3. Economic development and emissions

There are strong implications for cities in the quest to curb carbon-based energies. As a concentration of 'activities, people and wealth in limited areas' (Hallegatte, Henriet, & Corfee-Morlot, 2011), cities are both important generators of carbon dioxide emissions and end-users of goods and services, the production of which involves emissions elsewhere. Decreasing end-use energy demands through energy saving and efficiency measures alleviates the need to generate as much energy and, thus, moderates the carbon footprint. But even with efficiency measures, some demand for energy will always be present, while a growing population and economic development bring further pressures. It is necessary to decouple future economic growth from growing carbon emissions by decreasing the relative share of fossil fuels. Ultimately, carbon neutral or zero carbon cities are a way of expressing the zero net carbon balance of cities in an effort to mitigate anthropogenic emissions of greenhouse gases.

Table 1
Energy balance and corresponding policies directed at climate neutrality.

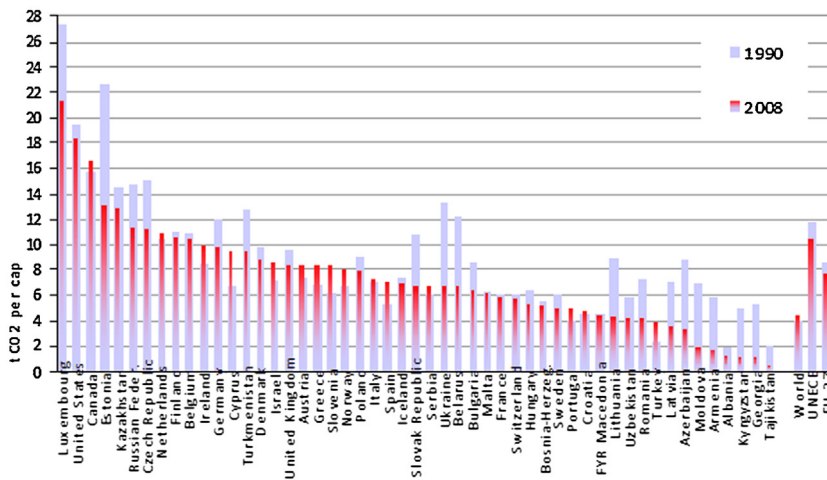| Energy balance formulas (according to International Energy Agency)	Urban-level policies
Supply Production + Imports − Exports = Total Primary Energy Supply	*Reduce CO_2 in supply* Decarbonising energy supply (for example, renewable microgeneration, fuel switch)
Transformation Total Primary Energy Supply − Energy transformation − Losses − Energy Industry Own Use = Total Final Consumption	*Reduce losses in transformation* Efficiency of transformation and distribution (for example, cogeneration, improving efficiency of networks)
Consumption Total Final Consumption = Industry + Transport + Buildings + Agriculture/Forestry + Fishing + Others + Non-Energy Use	*Reduce energy demand* User efficiency and demand management (for example, improving building energy performance, reducing the need for motor vehicle use)

Not all cities follow identical pathways. Romero Lankao (2007) espouses that carbon emissions per capita in cities is very small in low- and middle-income nations in comparison with wealthy urban areas. She shows that per capita carbon dioxide-equivalent emissions for American cities, such as Austin, Boulder, Santa Monica, and Berkeley, and some European cities, including Berlin, are greater than for Mexico City and Rio de Janeiro. This suggests that, for developing countries, including Latin American cities, a priority may be on coping with the implications of air pollution on human health and adaptation to the impacts of climate change, rather than curbing carbon emissions. Furthermore, cities in Latin America may not be able to adopt ecological modernisation as a suitable framework for addressing their environmental problems due to an emphasis on industrial and technological change that overlooks social and political context of an ecological switch-over. The author further argues that even though ecocities stress social and institutional dimensions of sustainability, they still reflect post-modern values that are best-suited to urban development in European and North American cities. Her final stipulation is that equity be considered a carbon-relevant issue, since the wealthy in Latin American cities (and elsewhere, as relayed by others, for example, Dodman, 2009) have higher carbon emissions per capita and are more able to invest in their own well-being, as for example in paying for healthcare to remedy impacts from poor air quality.

Fig. 2 demonstrates the large span in carbon dioxide emissions per capita in the countries included the United Nations Economic Commission for Europe (UNECE) region, which also fully encompasses EU and North American countries, and is overall considered to be the wealthiest region among the UN five regional commissions. It is clear that even though lessons can be learned across countries, individual countries will achieve LCD from different routes based on their national reality, development prospects, as well as aspirations and capacities (Mulugetta & Urban, 2010). For this reason, tailored approaches are necessary for low-, middle-, and high-income countries (World Bank, 2010b, p. 204). Still, developing countries cannot undergo modernisation like developed nations. A case in point is China, which has received recent attention as a nation in a critical period of industrialisation and urbanisation (Zhu & Shang, 2010). Urbanisation can be taken as an opportunity for LCD. It is imperative that China develop a low carbon industrialisation model, since it must coordinate economic development and emissions control whilst continuing to industrialise and modernise (He, Deng, & Su, 2010).

3.4. Renewable energy and conservation

Globally, there is not only an increased interest in renewable energy sources, but also in decentralised energy generation and distribution (Goodier & Rydin, 2010). The call for low carbon energy offers opportunities to shift from large vertically-integrated energy industries to decentralised neighbourhood-scale generation, which can be sufficient to cover all local needs. Increasing use of decentralised energy is also a way to reduce energy transmission losses, since energy systems are more efficient when power lines to

Notes: CO2 emissions from fuel combustion only.

Fig. 2. Carbon dioxide emissions per capita in the EU and UNECE countries in 1990 and 2008.

consumers are as direct as possible and the number of transformation steps minimised. It is, of course, the city and regional levels that can play a key role for decentralised energy. Even when the city government does not own and operate power-generating facilities (although the opposite is often true), it can use a number of levers to promote local green energy infrastructure. For example, the city can purchase renewable energy for city operations; identify strategic sites, where renewable and low carbon energy sources could be located; provide planning incentives and development land; permit the construction of only efficient, and clean power installations; and require new developments to connect to district heating systems. In short, the following options are implemented at the city level for city-scale decentralised renewable and low carbon power supply (Golubchikov, 2011):

(a) switching to lower carbon technologies and promoting district heating and cooling systems with cogeneration and trigeneration;
(b) installing renewable power installations, such as wind turbines, solar farms, energy from biomass and waste plants;
(c) promoting on-site microgeneration of heat and electricity in the buildings sector; and
(d) developing smart grid and efficient municipal energy services.

3.5. Political leadership and policy

Key factors for effective climate policy development and implementation in cities are collective public awareness and individual political leadership (Golubchikov, 2011). Because the combination of these factors varies between different areas, there may be a large spectrum of responses among cities even within the same subnational jurisdiction or in smaller countries (for example, for the case of Sweden, see Langlais, 2009). Even those local governments that demonstrate proactive strategies often face a lack of legal mandate from national governments to implement advanced measures (OECD, 2010a). This may include, for example, limited regulatory and fiscal authority, and lack of control over energy utilities or over strategic transportation development. In their strategies, local governments often go beyond their legislated capacity, which raises concerns over their effective implementation. Moreover, local responses to climate change are often circumscribed by the fiscal capacities of municipalities or regions. Even if substantial achievements can be reached, moderate cost, systematic, and comprehensive climate policies are capital intensive. City governments need to identify sustainable sources of income for these policies. Local fiscal and payment regimes may themselves play a stimulating role to encourage or discourage certain activities, projects or lifestyles, and these may have serious implications for climate neutrality. Some examples are public transport fees, parking fees, congestion charges, property taxes, and development charges. Financial resources can also be sought from the private sector; public–private partnerships may be established in order to share risk and raise private finance for infrastructure and energy efficiency projects. In their turn, national governments must ensure adequate resource mobilisation for the local and regional governments, as it at the national level that different forms of taxes can be institutionalised more comprehensively and effectively.

It is important to monitor and verify any actions taken to reduce carbon dioxide emissions. In OECD's (2010b) outline of the Programme on Green Cities, the following are identified to assess policy impacts: economics (creation of jobs and development of skills; attraction of firms), environment (land use; air, water, and waste; environmental health), technology (transport; climate change/energy), and society (awareness and behaviour). The report Energy Efficient Cities (Bose, 2010) takes into account the Integrated Assessment Framework on Climate Change and Cities: Assessment Tools and Benchmarking Practices, which considers climate, socioeconomic, and technological change. Another report by Mehrotra et al. (2009) provides a framework for the assessment of city climate from a risk-assessment perspective for four cities, including Buenos Aires, Delhi, Lagos, and New York. A new system used for planning at the city scale (devised by the Tyndall Centre for Climate Change Research) is a mechanism for policymakers to use towards the reduction of greenhouse gases, namely GRIP, the Greenhouse Gas Inventory Protocol (Carney, 2009).

3.6. Low carbon transition and social change

Low carbon and climate neutral cities can be considered as part of the more general concept of 'sustainable city'. Climate neutral cities benefit society in many other ways, such as energy efficiency in buildings, sustainable transport, urban green space, reduced urban sprawl, and a managed urban infrastructure. The transition to low carbon and resilient cities cannot, however, be considered as smooth, linear, or even uncontroversial. The very magnitude of the task involved is one that requires long-term and persistent political, economic, and institutional commitments, as well as innovative, creative, and often alternative ways of carrying on businesses, producing and consuming goods and services. What is more, the emerging paradigm of low carbon cities is being challenged before it has become a paradigm on the basis of its technocratic origin. Some may argue that community-level elements of a post-carbon society encourage a European social tradition that promotes individual freedom and social responsibility, human and social rights, balanced social and market models, and establishes cooperation and peace (Carvalho, Bonifacio, & Dechamps, 2011). Others are concerned that the new global consensus about reducing global carbon dioxide is not sufficiently engaged with the principles of participatory democracy, while the political economy of the low carbon transitions is itself not immune of sociopolitical struggles (for example, the imposition of particular development strategies for cities) and often confronts the principles of social justice, equity, affordability, and civic participation, thus, undermining (rather than reinforcing) the more general principle of sustainability.

Cities are capable of instigating change, as evident through Cape Town, Africa as a case study, where greenhouse emission reduction policies have been implemented due to external institutions, including among others academic institutions and nongovernmental organisations (NGOs), even though its energy efficiency strategies were mainly driven by an unexpected energy crisis (Holgate, 2007). An examination of three Canadian cities more specifically conveys sociocultural and institutional barriers to local climate change action in municipalities of Lower Mainland, British Columbia (Burch, 2010). The author extends the problem to other cities in Canada that may be similarly 'struggling with the rapid pace of social change and the ever-evolving advice on climate change provided to them by the scientific community, making a richer understanding of barriers to action a valuable element of future climate change policy design and implementation' (p. 7584). Bestill (2001) understands this problem of local action to climate change mitigation as stemming from an absence of policy changes at higher levels of governance (at the state and national levels). Others have also perceived unsympathetic policy frameworks towards local authorities at the national and European Union level (for example, Collier, 1997). Nevertheless, climate neutral cities can benefit society through energy efficiency in housing, sustainable transport, urban green space, reduced urban sprawl, and a managed urban infrastructure (UN, 2009), so that efforts should continue to be made in achieving low carbon cities.

Table 2
Current dimensions to achieving low carbon cities as a mitigation–adaptation effort.

Dimension(s)	Counter mitigation–adaptation	Pro mitigation–adaptation
Social		
Culture and society	High consumption lifestyle	Reduced consumption lifestyle (simple living approach)
Governance and policy	Solely top-down	Multilevel; bottom-up (community based)
Economic development and social justice	Excludes informal settlements	Considers informal settlements
Technical		
Urban energy infrastructure	Modernisation	Sociotechnical
Building, urban design, and planning	Sprawl	High density
Urban transport	High carbon transport	Low carbon transport
Other		
Resilience	Dualistic	Holistic
Approach	Disciplinary	Multidisciplinary

3.7. Urban planning and sustainability

Since cities are typically seen to be the largest source of carbon emissions (Hunt, Maslin, Killeen, Backlund, & Schellnhuber, 2007), they need to be redesigned to reduce their emissions. This can be achieved through strong legislation, especially building regulations, waste and water management, as well as city planning, planned infrastructure changes, using the latest building technology and alternative (renewable) energy, such as solar and wind integrated into building design and retrofitted, local (in-city) power generation to reduce loss of energy via transportation, city-specific plans particularly for developing countries, and possibly the eventual abandonment of unsustainable (or highly vulnerable) cities. Indeed, the concept of sustainability has been employed to bridge mitigation and adaptation. For instance, Leichenko (2011) recently recognises the need for cities to become resilient to shocks and stresses associated with climate change and that this can be bridged through urban development and sustainability. The author criticises contemporary conceptions of resilience as analogous to 'reducing vulnerability or enhancing adaptive capacity' (p. 166). It is arguable that also required here, in addition to positive social change in conjunction with long-term sustainability, is the need to future-proof cities. For instance, Gonçalves and Bode (2011) refer to future-proofing investments, where value is placed ahead of cost, as where energy savings and environmental quality are concerned in terms of building operation. Urban planning is another way to bridge mitigation and adaptation, as through urban form. Hamin and Gurran (2009), nevertheless, find that half of practices (policies) in the US and Australia present potential conflicts to achieving combined adaptation–mitigation. Indeed, others have similarly discovered that mitigation and adaptation responses often do not address key drivers/determinants and issues, such as consumption patterns and equity underlying adaptive capacity, due to multiscale processes operating at multiple (sectoral, temporal, spatial) levels.

4. Enhancing urban resilience

As outlined in Table 2, to be more resilient in a low carbon world, cities in developed and developing nations need to:

- address low carbon urbanism uniquely for each country and certainly each city;
- adopt inexpensive technological improvements and proven technology, as well as sociotechnical approaches;
- instigate building that is high-density and integrated with public (low carbon) transport and perhaps more inclusive of soft-engineering approaches, such as urban greening and agriculture;
- allocate affording housing and living subsidies to the urban poor residing in informal settlements so that they can afford better livelihoods in cities;
- discard a high-consumption lifestyle and adopt a simple lifestyle in order to affect change in the current (and increasing) divide between the wealthy and poor;
- adopt multilevel government that includes nontraditional leadership (as in communities); and
- direct funding towards research and development, especially multidisciplinary initiatives, for the deployment of site-specific solutions as well as economy-driven solutions, such as that of green jobs.

A case in point is the growth of green roofs. Leaky homes can be improved with increased insulation, as also offered by vegetation. Green roofs integrate the positive effects of vegetation cover directly into the buildings' design. They reduce the over-heating of buildings in summer and provide better thermal insulation in winter, thus, improving the building's own energy performance in addition to the positive effects for the neighbourhood as a whole. For example, traditional roof-tops in North America and Central Europe can reach temperatures as high as 90 °C during the summer, but green roof temperatures stay below 50 °C. This demonstrates that the difference in surface temperature between a green roof and an unplanted roof can reach 40 °C and more (Gartland, 2008). A cooling roof is also beneficial for solar panels, as they currently work best at temperatures up to 25 °C and have a reduced productivity at higher temperatures. Furthermore, green roofs intercept storm-water runoff and reduce the load on the building's drainage system, thereby extending its maintenance cycle. There are interesting examples of compulsory green roofs as posited by a recent by-law that requires the construction of green roofs on public and private buildings in the City of Toronto. In Chicago, government buildings require green roofs; and cities in Austria, Switzerland, and Germany, following the original experiences of Basel and Linz, have introduced either compulsory requirements for greening all flat roofs on new buildings or additional subsidies for such measures for existing roofs (Golubchikov, 2011).

This mitigation approach has the added benefit of urban greening, which will help to absorb atmospheric carbon dioxide through carbon capture by green façades and roofs in addition to other green spaces. Forests, for example, have been promoted as carbon sinks for low carbon cities (Jiang, Chen, & Wang, 2010). They are believed to be an important strategy in global warming mitigation, moving towards the reduction of emissions associated with deforestation and degradation and the improvement of forest management and afforestation. This approach of urban greening has been recently extended to include urban agriculture, which is an adaptive approach, such as food projects (Hopkins, 2010, chap. 33). It exemplifies one of the ways in which cities can become a

more 'self-reliant urbanism' (Hodson & Marvin, 2011, chap. 5, p. 56) and less dependent on acquiring external resources. Living walls adopted in office buildings could also improve the quality of indoor circulated air and, hence, human health. Besides capturing carbon-dioxide gas, plants are also capable of trapping particulate matter, which could reduce the incidence of human cancer in cities.

Land use is an important control of global climate. Vegetation cover, for instance, can affect the planet's colouration and the distribution of solar radiation, including reflectance. Green areas covered in vegetation are relatively dark and absorb radiation, rather than reflect it the way that light surfaces do, including cemented surfaces. These hard surfaces are also made impervious to rainfall and prevent the effective drainage of surface water, leading to overland flow and flooding. Greening of these urban areas would not only improve surface drainage, but also reduce the amount of reflected or scattered radiation in cities. Established forests, in particular, can take up carbon dioxide emitted by energy production and animal respiration processes. Importantly, plants absorb carbon dioxide and provide a climatic control in cities. They are able to intake not only carbon dioxide, but also other pollutants and gases, including water vapour in cities. Urban greening is beneficial, not only for the aesthetics of urban environments, which are typically stark in their appearance devoid of natural vegetation, but also for greater biodiversity in these environments as well as reduced climatic hazards, such as heat waves, droughts, floods, and more. It is often overlooked that vegetation can also increase surface roughness in cities (over cement) and somewhat reduce wind speed. In short, urban greening provides many landscape functions that enhance local climate in these environments and could be considered to be mitigation with potential for adaptation.

Today, spatial planning in its various manifestations (regional and urban planning, land-use zoning) finds itself right at the heart of adaptation and mitigation measures. Indeed, urban layout, public transit provision, and integrated district heat-electricity systems are some of the planning considerations that have long been acknowledged among the principal instruments to reduce urban energy intensity (for example, Owens, 1986). Planning is also instrumental in identifying risk-prone zones and in providing spatial strategies to safeguard urban infrastructure. What is no less important is that planning decisions on land use and urban layout have impacts lasting for decades and even centuries. Particular land use and infrastructural patterns create the circles of path dependence, when future investments are predetermined by existing infrastructure, which may lock economies into particular lifestyles and patterns. Spatial planning is important to prevent being locked into high-carbon or hazard-prone conditions that would be expensive or impossible to alter later (World Bank, 2010b).

Building control is a powerful tool to complement planning. Contrary to spatial planning itself, which may be opposed by some political ideologies as excessive public interference (resulting in the scope therefore being limited in certain regions), building control is more easily accepted as a regulatory regime (this has been the case for the US and some post-socialist countries, see Golubchikov, 2004; Stanilov, 2007). Building control may, also, ensure the presence of planning targets in actual construction practices, including in the private sector. Legal provisions can be established such as those, for example, which require that building permits are only issued for projects that are optimised spatially to reduce energy demand, including density and transport considerations; taking advantage of natural heating, cooling, lighting, and shading potentials; and that incorporate building materials and other means for reducing urban heat island effects (for example, cool walls, roofs and paving, increasing green areas). Moreover, urban development projects should be subject to a complete assessment with regard to their environmental standards, which means that the full life-cycles of buildings (all stages from manufacturing of construction materials to demolition and recycling of the materials) are optimised in order to reduce the overall carbon footprint.

Studies have found that multimodel land use and transportation design in planning for building improvements can reduce emissions; higher-density building is also important; energy efficiency can be achieved across a variety of building types; and affordable housing near work should reduce commuting costs (Condon, Cavens, & Miller, 2009). Research performed in the City of Toronto has broadly shown that urban form and density are important considerations (Norman, MacLean, & Kennedy, 2006). Policies that reduce operational energy and high-density development nearer to places of employment as well as increase the use of public transport and reduce private vehicles in the suburbs should be given priority. Alternative fuels and renewable energy should be adopted in order to reduce transportation and operational energy use and greenhouse gas emissions from residential development. A study for the Chicago metropolitan area (Lindsey, Schofer, Durango-Cohen, & Gray, 2011) has found that vehicle miles of travel, energy consumption, and carbon dioxide emissions from privately-owned vehicles are augmented with distance from the central business district, but reduced with residential density. This research suggests that high-efficiency vehicles may help to reduce emissions in cases of urban sprawl.

An examination of implementing climate protection through urban planning for development and energy conservation in Newcastle upon Tyne and transport planning in Cambridgeshire found that sustainability is shaped by governance that extends across geographical scales and urban boundaries (Bulkeley & Betsill, 2005). It is important to establish cooperation between neighbouring municipalities, as many initiatives cross the borders of individual administrative units (for example, infrastructural projects or public transport). Here, the role of regional (subnational) administrations as coordinating, enabling, and funding bodies cannot be overstated (Wheeler, 2009). Cities that have a regional administrative mandate, which is often the case for larger cities, are more capable in facilitating larger projects and territorial cohesion (OECD, 2010a). It is not necessary, however, that city governments form only local or regional institutions. They can also create horizontal national and international networks or associations that complement the vertical regimes of governance. Such interurban associations provide a platform for sharing knowledge and for mutual support, and climate protection measures advocated by these associations are often expressed in agreements. An example is the 2007 World Mayors and Local Governments Climate Protection Agreement, which calls for a reduction in greenhouse gas emissions by 60% from 1990 levels worldwide by 2050 and, in industrialised countries nationally, by 80% from 1990 levels. It also declares a number of commitments for the signatories themselves, although without specific measurable targets.

Recently in London, the Mayor adopted an ambitious target to reduce emissions by 60% by 2025, which relies to no small extent on transport policies. More than 150 policy interventions were examined to reduce transport carbon dioxide emissions. They were grouped into 12 packages, including low-emission vehicles, alternative fuels, pricing regimes, urban planning, investment in public transport, walking and cycling, ecological driving, and freight logistics planning (Hickman, Ashiru, & Banister, 2009). Since each package offers different levels of carbon dioxide reduction, a simulation model was used for scenario-testing. These authors discovered that a combination of low-emission vehicles with investment in public transport, walking and cycling, and traffic-demand management is insufficient for a significant emissions reduction. Interestingly, a power down of energy demand follows from changes in behaviour and lifestyle that include, for example, more transport-related activity (walking and cycling) and less meat consumption (Kemp & Wexler, 2010).

A recent approach to urban planning is the so-called New Urbanist design, which provides an alternative to conventional low-density development (Stevens, Berke, & Song, 2010). Steemers (2003), for instance, acknowledges or envisions the benefits of a compact design for cities and towns with integrated public transport. Increased density is a part of this approach, which could use green standards at a lower cost (HTA, Levitt Bernstein, PRP, PTEarchitects, & Design for Homes, 2007). Some urban systems depend on achieving a critical density based on the mass of dwellings, such as effective deployment of Combined Cooling Heating Power (CCHP) systems. Moreover, a sufficient volume of development would allow energy companies to support low carbon energy technologies that employ renewable sources of energy (wind, solar, woodchip, etc.). This combined with an integrated energy strategy, which includes a green transport plan, would go a long way to promote a low carbon lifestyle. For example, Power (2010, p. 206) specifies a home density of at least 50 homes per hectare, comprising of some 110 people, over the current planning standard of 30 homes per hectare in order to maintain public transport (a regular bus service) as well as shops and schools in towns.

Many authors have also advocated such an approach towards sustainable development, where urban growth that is balanced, compact, and coordinated is geared towards achieving economic, social, and environmental benefits (Nadin, 2006). This can be attained through a more polycentric pattern in cities and towns and the prevention of urban sprawl. Urban planning needs to consider the size of the city and any associated characteristics of its residents. At a certain level of density the negative environmental, energy, climate, and sociophysiological impacts start outweighing the gains. Super-density also amplifies the negative effects of climate on cities, especially in areas with a high concentration of tall buildings (Roaf, Crichton, & Nicol, 2009). Larger cities normally have larger surrounding areas and involve more long-distance travel, such that people's travel performance is connected to a country's spatial-economic organisation (Perrels, 2008). For example, in Finland, medium-sized cities (of around 100,000 inhabitants) have the strongest mitigating effect on transport performance.

There is no consensus on what the optimal level of urban density actually is, nor on whether higher densities should always be encouraged. Moreover, key problems for intensified densities and compact city are that many cities already differ from an optimal density and that the habits and aspirations of a considerable portion of the population are based on low-density models. There is, however, a broader consensus about the harmful effect of sprawl and the benefits of mixed-use development. The latter generally includes integrating housing, work, facilities, and entertainment in close proximity so that both trip distances and car dependence are reduced. Mixed-use development may also be accomplished in lower density townscapes, so that existing low-density areas can be transformed towards mixed-use development, based on a strategy of stimulating urban polycentricity.

Another case in point is the suburb. It is argued that measures associated with a compact-city design have not been explicitly geared towards suburban areas, which have their own unique challenges in this transformation towards low or zero carbon cities, including a slow pace of change (Williams, Joynt, & Hopkins, 2010). The built environment in the suburbs is also challenged by other problems revolving around the retrofitting of existing houses and fragmented property ownership and management. This was addressed by Rice (2010), who examines retrofitting existing suburbs towards sustainable urbanism using a compact city strategy that is promoted by the government of the UK. His analysis reveals that it is both feasible to retrofit the suburbs and that this endeavour is locally viable. It can even in some cases encourage more sustainable lifestyles, amongst them improved accessibility as well as social inclusion and even physical and mental health benefits.

5. Conclusion

Low carbon cities are a mitigation effort that can be employed in urban environments throughout the world. An integrated approach with adaptation could go a long way towards achieving responsive and resilient cities, as with urban greening efforts. Integrated approaches are preferred, as with adaptation–mitigation as well as multidisciplinary understandings, for future-proofing.

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