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Mary J. Thornbush

Vehicular Air Pollution and Urban Sustainability

An Assessment from Central Oxford, UK

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Preface

This brief seeks to bring together research in transport and air pollution, decarbonisation and energy conservation, and the use of urban greening to achieve low-carbon cities and urban sustainability. It does this from an interdisciplinary perspective, where geography and planning meet plants and the biosciences as well as planning and urban design. Environmental sustainability is examined from ranging scales, from microclimatic investigations to global perspectives, as with global warming. Various countries in the developed and developing world are considered as a part of the published literature, but the case study focus in this brief is Oxford, UK. The Oxford Transport Strategy (OTS) serves to converge past and ongoing (longitudinal) research as representative of a European city that has undergone an environmental transformation in its transport scheme in order to achieve reduced traffic congestion, better air quality, and a more sustainable urban environment, including improved human and environmental health for its buildings and the built environment more generally.

As such, this brief encompasses a long-term perspective on transport changes implemented in the Oxford city centre in 1999 and the ramifications for the current environmental situation and future of the city. The Environmental Monitoring of Integrated Transport Strategies (EMITS) project is conveyed in detail, including reports and published works, as a measure to assess environmental change (in congestion, air quality, and human and environmental health). The focus on improved health, to encompass both human and environmental health, conveys the interlinked nature of air pollution as an environmental issue, and the necessary approach (of human and physical holistic investigations) to understand the problems and attempt to reach solutions. Moreover, as a longitudinal study (published more than 15 years after the implementation of the OTS in the Oxford city centre), this work is representative of sustainability studies that are concerned with the long-reaching ramifications of decisions and policy-setting. Not only does this brief examine environmental change in the long term, but it also encourages that further longitudinal studies are conducted to investigate the outcomes of current decision-making.

Although it can be argued that a traffic redistribution occurred, from the city centre towards the city fringe and onto quieter roadways, post-OTS Oxford represents a model of what can happen when decisions are made to clean up the urban environment. It is true that Oxford is an ideal setting for the OTS because of its established public transport system (already in place before the OTS) and park-and-ride (P&R) system, and it is also a walkable city with cycling (in addition to bus) lanes. Nevertheless, restrictions on private vehicles promoted a greener approach to transport that is still evident today, with new bus fleets that deploy hybrid technology. There is no going back for Oxford, and it is now a green city and a healthier urban environment. Oxford has come a long way since the burning of coal at its colleges and the darkening of its building exteriors from these coal emissions. Today, it is a place where hard-core cyclists traverse the streets, confident pedestrians navigate its walks, and full-up buses pass-by on streets in the historical city centre. Its buildings have also gained a new appearance, looking brighter and less decayed, and also somewhat greener in places.

Readers interested in following the progression of the urban environment, since the OTS, are welcome to read the following pages. It is anticipated that environmentalists, planners, urban designers, architects, geographers, policy-makers, and more, will be interested in the material integrated in this brief, drawing from the main fields of environmental issues, urban studies, and sustainability. It is hoped that this brief reaches a varied audience, from students, researchers, and academics to practitioners, professionals, and government. Whether one is familiar with Oxford and the OTS or not, it is hoped that this read will intrigue and promote innovative forward-thinking in its audience. Not only is Oxford a special place, but it is also a world city of culture and heritage as well as a hub for knowledge. The author anticipates that this brief will stimulate the imagination of its readers as well as be an impetus for world change. It is possible to make cities increasingly better places to live in—places where the air is healthy and the atmosphere is welcoming, and well-structured places that are connected in time to progress as well as history. Environments where people can feel connected with each other and nature. Environmental health and sustainability mean this; they require that people think about the long-term beyond their own lifetimes and that they operate in unison with the natural environment. Human health and environmental health are one in the same, destroy one and the other is ultimately destroyed. Transformations, such as healthy and sustainable living, can begin through small (local) actions. Contributions that together are for the greater good and well-being of humanity and the Earth.

I am extremely grateful to S.E. Thornbush for providing me with editorial support. Thanks also to those people at the Oxford City Council and Oxfordshire County Council who contributed in some way to this work.

Contents

Chapter 1
Introduction

Abstract In this introductory chapter, the author addresses the need for sustainability approaches that adopt a long-term standpoint in city planning and design. Furthermore, transdisciplinary approaches are encouraged to improve links between the traditional disciplines, from an academic perspective, as well as to promote collaboration between non-academics involved in the development of cities. Top-down approaches to urban governance have often been adopted, as with European frameworks leading European cities. Air pollution regulations have targeted air quality in cities spurred by a concern for human and environmental health. The OTS represents one of these initiatives to improve environmental conditions in the Oxford city centre. As such, it is the chief case study presented in this brief, and will be revisited in more detail in the next chapter. This chapter conveys the rationale for this work, and presents the longitudinal approach adopted in this volume.

Keywords Longitudinal study · Long-term planning · Sustainability · Transdisciplinarity · Environmental health

Sustainability concerns long-term planning and assessment: to meet the needs of today without compromising the ability of future generations to do the same. It touches upon many different aspects of natural resource management and environmental governance, and is a transdisciplinary concept that can be approached from different perspectives within environmental studies and science. In addition to being multidisciplinary, sustainability is multifaceted in that different scopes need consideration. Further to environmental considerations are economic and social as well as political components that are interrelated. Political-economic considerations, for instance, can affect policy and represent a top-down approach to governance and environmental management. These can interact with socioeconomic systems and affect people at various scales.

Pollution regulation is such a political-economic decision (top-down) brought upon entities by governments. Such policy can affect environmental conditions and this is particularly notable where populations are concentrated in cities. Typical

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European cities are known for their traffic congestion for many reasons, including as transportation nuclei. Amidst traffic in many European cities can be found cultural stonework forming historical buildings as part of tangible cultural heritage. Many (European) cities come to mind to exemplify this, including Rome, Paris, London, Athens, and so on. This brief considers Oxford specifically as representing these cultural urban centres. Oxford is relevant to sustainability because of its continuing struggle (as with many other European cities, even World Heritage Sites) with air pollution.

The source of air pollution in such cities has changed historically, and is contingent upon energy production. Coal, for instance, was transported along the Oxford Canal since 1791 (Viles 1996), and was a known source of blackening of Oxford buildings as it was burnt in the colleges pertaining to the University of Oxford. Black carbon accumulated on building surfaces, and a dark cityscape developed well into the 1950s. This led to remediation efforts through restorative works at many Oxford colleges from the 1960s. Since the London smog of 1952 and the Clean Air Acts in 1956, coal use was controlled in London, resulting in reduced levels of atmospheric sulphuric emissions (e.g. Brimblecombe 2011). Coal-burning emitted sulphur dioxide (SO_2) and smoke (particulates), but traffic also releases gaseous pollutants, including SO_2, as well as particulate matter (PM, particularly from diesel vehicles).

The historical centre of Oxford has a Medieval layout that tends to produce traffic congestion. This, combined with its affluence, has led to an environmental problem surrounding traffic pollution in particular. Whereas the measures taken by central London have been to charge vehicles, Oxford introduced restrictions based on admittance and promotion of transportation diversity. More specifically, on 01 June 1999, the OTS was implemented in central Oxford. It targeted private vehicles in particular in its attempt to reduce traffic congestion in the downtown core. Streets, such as Cornmarket, became accessible on foot and via cycling, thereby promoting pedestrianisation and non-polluting (engine-free) locomotives, especially cycles. The scheme also offered the option of bussing, and (more recently) investments were made to increase the bus fleet.

As part of the environmental programme to monitor the success of the OTS, the Environmental Monitoring of Integrated Transport Strategies (EMITS) project was instigated. This addressed different variables affected by air pollution, including human health (and respiratory illness in particular) as well as environmental health of the historical buildings that represent a cultural legacy of Oxford, with considerable economic ramifications for tourism. The University of Oxford became involved in the latter research as part of the EMITS project, focussing on three investigative strands: (1) exposure trials; (2) photographic surveys; and (3) interviewing clerks-for-works (Viles, 1996). These approaches to monitoring the environmental health of Oxford provided both qualitative and quantitative assessments of the impact of the OTS on the building fabric in Oxford, with implications for the conservation of its architectural heritage. These findings will be presented in this brief alongside a revisit of already published works for a longer-term perspective on the impacts of the OTS on air pollution (from traffic) in central Oxford.

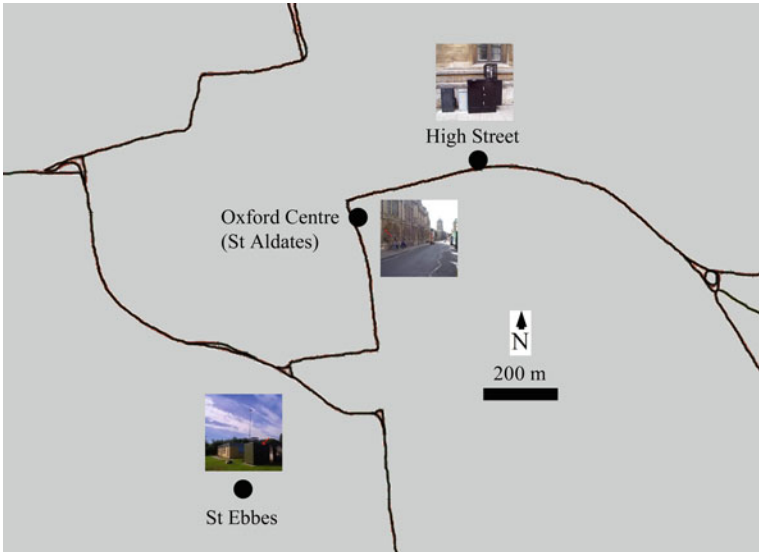

Fig. 1.1 Air quality monitoring sites located in central Oxford (more details on the individual monitoring sites are available from Oxford Airwatch online: http://www.oxford-airwatch.aeat.co.uk/)

It is anticipated that this longer temporal scope will allow for an assessment of the contribution to urban sustainability. Moreover, the state of the buildings can serve as a broader environmental indicator for the Oxford city centre.

Part of the EMITS appraisal involved installation of air quality monitoring sites (Fig. 1.1) in central Oxford situated at roadside locations (High Street and St Aldates) for comparison with an urban background site (St Ebbes). Another monitoring site was located away from the city centre (outside the inner cordon in East Oxford) for a comparison of impacts away from the city centre. As part of the monitoring campaign, traffic counts were taken (both manually and automatically at surveying points) to assess the effect on traffic congestion. These measures allow for a quantitative assessment (pre- versus post-OTS) of several environmental indicators. This has also encompassed ongoing research of building soiling and decay performed in central Oxford.

A major part of this brief is as a longitudinal study of the environmental impacts of the OTS. By presenting the results for air quality and traffic congestion in conjunction with weathering studies, it is anticipated to establish the contribution of the OTS to the (urban) sustainability of Oxford and its cultural resources. This is important to consider because of the ramifications for long-term planning and green design. More specifically, soft-engineering (green) approaches to air pollution control due to traffic in cities represent a relatively cheap and environmentally friendly approach to urban environmental sustainability. Oxford has a long history of green walls through the use of ivies and other climbing plants on building exteriors in its past. This green approach has potential for absorbing pollutant gases (as a carbon sink) and blocking particulates. For this reason, it offers a solution that both remedies the problem of air pollution (through air purification) and becomes a part of the solution as an external form of insulation for solid-wall buildings. In the larger picture, green walls address associated urban problems, such as the urban heat island (UHI) effect and global warming more generally. Because of the increasing concentration of the global population in cities, achieving low-carbon cities contributes towards environmental sustainability as it offsets carbon produced by animal (human) respiration as well as pollution emissions from human activities (such as energy production).

In the next chapter, the OTS is considered in more detail, from its implementation to the initial findings. The results for traffic congestion and air pollution are considered first, followed by a deliberation of the implications for urban sustainability. Next, urban greening will be outlined broadly, with a case study of green walls as part of an environmental history for central Oxford. Such form of urban greening is conveyed for pollution abatement (carbon capture and storage or CCS) within the context of energy conservation provided by improved insulation. The implications for reducing UHI resulting from urban climate in polluted environments, such as Oxford, and in the mitigation of anthropogenic climatic warming is finally addressed.

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Chapter 2
The OTS in Central Oxford

Abstract Details are provided in this chapter about the implementation of the OTS and its initial findings. The EMITS project is presented as a measure of success of the OTS, including the achievement of its core aims. The brief focusses on environmental health as assessed using outputs from EMITS. Here, its three strands are relayed, along with details of the buildings monitoring programme, which was central to evaluating environmental health based on air quality and building measures. Findings based on publications by the author are conveyed in this chapter, focussing first upon the assessment of buildings as indicators of environmental health in the Oxford city centre.

Keywords Oxford Transport Strategy/OTS · Environmental Monitoring of the Integrated Transport Strategies (EMITS) project · Environmental health assessment · Air quality · Buildings · Indicators

As of 01 June 1999, the OTS instigated environmental change in the Oxford city centre. The intent of this transport scheme was to reduce air pollution due to private vehicles entering the city centre and aimed to reduce traffic congestion in an attempt to alleviate this air pollution. The EMITS project monitored the success of the OTS and is an integral part of its assessment, including its success in reducing air pollution and impacting human health as well as environmental health, as demonstrated by buildings and structures. This brief focusses on the latter (environmental health), and uses building stone in order to ascertain any environmental improvements of reduced traffic pollution. The research conducted for this portion of the EMITS project included three strands:

1. exposure trials of stone sensors;
2. photographic monitoring surveys; and
3. interviews with clerks-for-works to survey the costs associated with soiling and decay.

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The exposure programme (of exposed limestone sensors) occurred along three major throughways in central Oxford, including Broad, Longwall, and High Streets plus a background site located at a garden site in Worcester College. Small-sized discs were exposed horizontally from wire frames suspended from lighting columns 2.5 m above the ground (Parkhurst and Goodwin 1997). The samples were exposed in this urban setting with annual replacement intervals of up to 5 years. The pre-OTS trials were dated between 1996 and 1999 and were compared with those exposed between 1999 and 2001. With exposure, the stone sensors became discoloured after just 2 years in the urban atmosphere of central Oxford (Parkhurst and Goodwin 1999). Spectrophotometry was used to measure colour change, and conveyed progressive darkening. Optical microscopy indicated that darkening was concentrated within the hollows of this oolitic limestone. This soiling increased with exposure period (Parkhurst and Goodwin 2000), so that those sensors exposed for 5 years were noticeably darker than those exposed for 1 or 2 years.

Thornbush and Viles (2004a) examined the impacts on building stone through sensors of exposed buff, coarse-grained Bath limestone (Stoke Ground Base Bed) discs. Their monitoring programme, using the integrated digital photography and image processing (IDIP) method of colour quantification based on digital photographs and their reflectance, demonstrated that sensor darkening occurred most after 4 years (and least into the 4th year, see Fig. 3 in Thornbush and Viles 2004b, p. 222) of exposure in this polluted environment. Soiling progressed in a linear fashion in the pre-OTS trials, with the fastest rate of darkening along High Street and the slowest at the garden site located in Worcester College. Longwall and Broad Streets showed similar (intermediate) rates of soiling. These results indicated that the level of traffic (light, intermediate, or heavy) did influence the soiling rates and levels, so that by reducing traffic congestion in the city centre it was possible to reduce the soiling of building stone, and this was already indicative of an improved environmental health with less traffic.

The level of reduced surface reflectance over the course of the 5 years of exposure was similar to that discovered by other authors for European cities, such as 30 % after 5.5 to 8.8 years in Oporto, Portugal (Pio et al. 1998). According to these authors (Pio et al. 1998), some 50–70 % of reduced surface reflectance is attributable to vehicular emissions. Stonework is known to darken (becoming grey or black) in urban environments due to soot and black carbon deposits originating from petroleum and coal combustion (Nord et al. 1994). Carbonaceous particles from oil fuels (petroleum from vehicles) are often implicated in urban stone discolouration (del Monte and Vittori 1985). Indeed, vehicular emissions of particulates are known to exceed emissions from power stations in the UK and many other countries (Eggleston et al. 1992). According to Clarke et al. (1996), gasoline vehicles release considerable amounts of black smoke and lead (over 90 %); diesel vehicles are able to release 58 % of particle emissions and some 78 % of SO_2. In Oxford, traffic has contributed to the discolouration of stonework and is responsible for weathering newly restored stonework (Viles 1993). Diesel vehicles, in particular, are linked with decay and implicated in the soiling of stonework (Viles 1996). Nevertheless, Antill and Viles (1998) cautioned that there is no simple relationship between vehicular emissions and limestone decay. Surface roughness is one of many factors that affect soiling and, thereby, stone decay (cf. Thornbush and Viles 2004b), as indicated by patchy (speckled) soiling patterns within the first year of exposure versus a more spotted soiling pattern visible after this time (and especially notably in the 5th year of exposure).

A portable XRF used at the boundary wall of Worcester College, Oxford revealed the chemical signature of traffic pollution deposited at a roadside location. Thornbush and Viles (2006a) compared newly replaced blocks with older ones and discovered a greater concentration of zinc and lead on crusts in comparison to exfoliated blisters. Policies pertaining to traffic emissions, such as lead-free petrol, had an effect on the results, with concentrations of lead being lower on newly replaced blocks. Zinc similarly appeared in low concentrations on newly replaced blocks. However, levels of iron increased, potentially indicating the migration of elements towards the surface of stonework through natural weathering processes. The concentration of metals on recently replaced blocks was more affected by distance from the roadside than height above the pavement. This suggests that traffic pollution is settling close to ground-level and remaining low, but that it is dispersed laterally more effectively and thereby affecting lower portions of walls.

Viles (1994) addressed changes in the pollution regime in central Oxford, focussing on the way that it was affecting a selection of Oxford buildings. She observed that current pollution from traffic deposits lower down on building walls were leading to a yellowy-brownish surface discolouration. In the past, however, coal-related air pollution had a greater dispersion ability and, by comparison, affected higher building storeys. This type of pollution was (black-) carbon-based and blackened buildings, whereas the current emissions from traffic tend to leave a grimy appearance due to oily residues.

In 2005, the results of the majority of the EMITS project strands on building stone remained to be published (Thornbush and Viles 2005). Nevertheless, by stringing together reports from 1996 to 2000, it was possible to discern changes in the colouration of roadside walls, with brighter and more enhanced chroma of surfaces being evident. There was also evidence of biological colonisation after the OTS was implemented and also where traffic levels had been reduced. Specifically, nitrogen dioxide (NO_2) levels were particularly lower in association with lower traffic density. It can be gauged from the initial findings that the soiling and decay of buildings, such as at Magdalen College, cannot be simply blamed on traffic in the late 20th century. Local coal-burning prior to that was a significant factor that blackened building façades. Nevertheless, the timing of traffic peak densities (with a peak of 1724 vehicles per hour in 1969; Thornbush and Viles 2005, Fig. 1, p. 46) around the time of restoration works (e.g. in 1975 at Magdalen College) could implicate the role of traffic in low-level surface darkening of buildings. The OTS, however, reduced traffic levels to below 1957 levels and resulted in a reduction of NO_2.

Thornbush and Viles (2006b) noticed more biological colonisation in a cleaner environment. Their study using scanning electron microscopy conveyed the migration of fungi from hollows onto the surface of oolitic limestone after the OTS. This was evident on High Street, for instance, and the reverse trend of more pronounced soiling and less microbial cover was apparent on Broad Street. These results suggest that cleaner environments trigger more biological colonisation, which can then become a problem of enhanced biological weathering over chemical weathering.

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Chapter 3
Reduced Traffic Congestion and Air Pollution

Abstract The OTS had an environmental impact associated with reduced car traffic and improved air quality, particularly of SO_2 and carbon monoxide (CO). The effect on reductions in atmospheric pollutants and improved air quality is explored in this chapter. By examining records of change associated with specific traffic records and mean annual measures of pollutants, including NO_2, oxides of nitrogen (NO_X), SO_2, CO, ozone (O_3), and particulate matter (PM_{10}), it is possible to relate trends over 15 years (between 1997 and 2012) and evaluate the impacts on buildings. Specifically, this study reveals that the soiling building surfaces was reduced following the OTS and that building decay features stabilised. This occurred when there were also reduced levels of traffic on some streets and improved air quality (at Oxford Centre, High Street, and generally at St. Ebbes) in the Oxford city centre. Reduced concentrations of all measured pollutants (except O_3 at the urban background site, with the least reductions in NO_2 and PM_{10} and greatest reductions in NO_X, SO_2, and CO) indicate a cleaner urban atmosphere since the OTS. As O_3 was the only traffic pollutant that was slightly increased in the post-OTS atmosphere, its impact on building stone merits more research.

Keywords Environmental impact · Urban atmosphere · Air pollution/Atmospheric pollutants · Traffic pollution · Reduced congestion · Building stone · Soiling and decay

Urban sustainability has been linked with reductions in traffic and air pollution, with a reduced dependency on motor vehicles and more walking and cycling (e.g. Tight et al. 2011). Indeed, several authors have stressed the need to reduce excess travel by car, as is evident in suburbia (Frey et al. 2006). Oxford's Blackbird Leys, for instance, failed to have a sufficient level of dwelling density (of at least 40–50 dwellings per hectare or dpha) with a density of only 25.5 dpha (Frey et al. 2006, Table 1, p. 262), reducing support of community services such as public transport. Sustainable mobility can be measured through reduced levels of carbon dioxide (CO_2) from transport, which can be accomplished through more use of public transport, walking, cycling, and local tripping (Hickman et al. 2013). A variety of efforts are recognised as necessary to improved local levels of traffic congestion and

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air quality, including the use of cleaner vehicles and more active travel (Jensen et al. 2013). This can be achieved in several ways, from technological solutions (e.g. hybrid and electric vehicles or EVs) to con-straining interventions (e.g. schemes and policies), with holistic assessment methodologies employed for evaluation.

Maximum levels of nitrogen (and SO_2 peaks) in cities located within southern Europe are produced through the process of midday nucleation episodes, corresponding with maximum insolation and O_3 levels (Reche et al. 2011). On the other hand, PM values can be affected by non-exhaust suspended particulates (e.g. mineral and brake metallic particles) as well as midday atmospheric dilution. For this reason, it was found that intense street cleaning reduced kerbside PM_{10} concentrations by 3 μg/m^3, achieving mean daily levels of 54 μg/m^3 (Amato et al. 2010). It has been observed, for instance, that between 2005 and 2009 there was a 40 % reduction in the number of days that the European daily limit for PM_{10} was exceeded in European cities (Keuken et al. 2012). These authors concluded that the reduction of traffic volume is most effective for the improvement of air quality in inner-urban roads. Indeed, stricter NO_X and PM vehicle emissions (in Europe) led to improved air quality in 20 European cities (Giannouli et al. 2011). Specifically, the 2008 EU Ambient Air Quality Directive legally imposed limit concentrations for atmospheric pollutants, including PM and NO_2, leading to traffic-reduction strategies, such as London's Low Emission Zone that discourages the use of the most polluting vehicles (Henderson 2012).

Such a targeted approach is needed, as cycles (for instance) are unpolluting, whereas heavy goods vehicles (HGVs) are most polluting. Research comparing cities in Spain, namely Madrid and Barcelona, discovered that substituting old petrol and diesel vehicles with hybrid cars reduced NO_2, SO_2, and PM_{10} concentrations by as much as 37 % for NO_2 in Madrid and 18 % in Barcelona when 30 % of hybrid vehicles were introduced; PM_{10} concentrations were also reduced by 12 and 14 %, respectively in Madrid and Barcelona; but, O_3 increased by 3 % in Madrid and as much as 24 % in Barcelona (Gonçalves et al. 2008). In addition to traffic-abatement strategies, it is evident that new technologies (such as hybrid cars as well as fuel cells, e.g. Edwards et al. 2008, and the use of cleaner or alternative fuels (e.g. Jiang et al. 2010)) can improve urban air quality. It has been suggested, for instance, to deploy TiO_2 as a photo-catalyst in the photochemical conversion of NO_X to nitrates (Hüsken et al. 2009). Others (e.g. Heeb et al. 2011) concur with such a technological fix, including three-way catalysts, in addition to traffic-reduction measures that have worked in western European cities (Colvile et al. 2001). This conveys that technology should not be held up as a panacea for the problem of urban traffic pollution, but that it should be upheld as a sociotechnical approach, as delineated later in this brief.

Local authorities, such as Oxfordshire County Council, have established technological (e.g. Euro Standards) and socioeconomical measures to reduce vehicular emissions that are linked with European Legislation, such as Euro Standards for vehicles, enhancing mobility and reducing traffic emissions, including NO_X, SO_2, CO, and PM (Lumbreras et al. 2008). The exception, however, is that vehicular emissions of CO_2 are released from the combustion process in association with more vehicular mobility. For this reason, these authors have suggested fleet renewal, which has the potential to reduce emissions by 16.04 % (as projected for Madrid, Spain between 2004 and 2012). However, for reduced emissions of CO_2 either biofuel use or reduced mobility are noted as the most effective solutions. For instance, some authors have proposed the conversion of CO_2 by physiochemical approaches, such as synthetic methanol, syngas produced from flue gases and synthetic fuels from photochemical production (Jiang et al. 2010). Others have advocated fleet renewal, such as those 10 % of diesel and petrol vehicles in Madrid that managed to establish maximum reductions of NO_X (Gonçalves et al. 2009). Within this consideration is vehicle type, specifically higher emissions from HGVs, which produce higher emissions of NO_X (and, consequently, more NO_2), as observed in the Netherlands (Velders et al. 2011). This is making it difficult for the Netherlands to comply with the emissions standards for HGVs imposed by Euro-III and Euro-V.

EU Air Quality Directives have led to annual mean concentration standards of 40 μg/m^3, which has affected the UK National Air Quality Strategy for 2005 and 2010 (Stedman et al. 2001). Reduction measures derived from such international and national policies expect reductions in NO_X from road traffic; however, it was anticipated that these would be exceeded for NO_2 in 21 % of urban major road links in 2005 and 6 % by 2009, especially in London. NO_X released from diesel engines, including buses, are particularly deleterious to human health (Parkhurst 2004). The OTS involved the closure of High Street to through-traffic; pedestrianisation of several streets, including Cornmarket Street; reduced traffic flows in several streets, such as Broad Street; etc. These changes established new traffic routes and bus priority in the city centre, and represented the most significant transport change in over 25 years (Dudley 2003). According to Dudley (2003, p. 448), it was considered to be a success because it achieved its objectives. More specifically, when it was evaluated in 2001 by the Director of Environmental Services, traffic flows in the inner cordon were down 17 % from 1998 to 2000. Moreover, bus passenger use increased by 8–9 % in the first six months after its implementation.

This chapter assesses the (environmental) impact of an urban congestion reduction scheme implemented in a European city in order to reduce air pollution and improve urban environmental health. The OTS was implemented on 01 June 1999 in the city centre of Oxford, UK. Its purpose was to restrict access, particularly of private vehicles (part of car traffic), into the historical core in order to reduce problems of congestion and pollution. The purpose of this chapter is to present (longer term) traffic counts and air quality data since the implementation of the OTS, including recent data. Effectively, therefore, this chapter considers transport through the address of air pollution, as is a critical aspect of environmental health and urban sustainability. This study revisits the success of the OTS in central Oxford within the inner cordon based on a deliberation of improvements in (1) traffic congestion and (2) types of traffic (transport mode) as well as (3) air quality. The scheme will be assessed in terms of its contribution to urban sustainability as regards transport, with Oxford as representative of an urban area.

Information about the OTS was accessed online through the websites of Oxfordshire County and Oxford City Councils. Road counts were obtained from Table A—Annual Average Daily Traffic Flows (Oxfordshire County Council 2013a). Traffic counts were compared for roadways near the monitoring sites located in the city centre. Table B—Manual Classified Counts (Oxfordshire County Council 2013b) was examined with a focus on centrally located roadways within the inner cordon. Information on cycling monitoring was obtained from Table C—Automatic Cycle Counts (Oxfordshire County Council 2013c). A final Congestion Monitoring Report from 2012 was also acquired from Oxfordshire County Council (2013d). In addition to these online resources, the Department for Transport has 191 count points in Oxfordshire along specific routes (Department for Transport 2013), including High Street (Speedwell to Longwall Streets) and St. Giles (Hythe Bridge/Worcester Streets to St. Giles), which were examined.

Air quality monitoring results were acquired from various annual data summaries obtained from Oxford Airwatch (Oxford City Council 2013a) for 1997–2012. Data were available for NO_X, NO_2, PM_{10}, SO_2, CO, and O_3. Pre-OTS (1997–1998) and post-OTS (1999–2012) data were compared. These data were derived at three automated monitoring sites, namely Oxford High Street, City Centre, and St. Ebbes, located in the city centre (Oxford City Council 2013b). The Oxford AUN automatic monitoring site is located at the Town Hall in St. Aldates and is a roadside site that started monitoring air quality on 15 April 1996. It records CO, SO_2, and NO_X. Traffic is restricted on this street between 0730 and 1830 hours, when the road is used only by buses and taxis. The sampling intake point is situated approximately 2 m from the kerbside and 3.5 m above ground level. The Oxford High Street automatic monitoring site is based in front of All Souls College on High Street, and is also a roadside site that commenced monitoring air quality on 23 June 2003. It measures NO_X and PM_{10} some 2 m from the kerbside and 1.5 m above ground level. Traffic is also restricted here (on High Street) between 0730 and 1830 hours, with access only to buses and taxis at this time. Finally, the Oxford St. Ebbes automatic monitoring site is situated at St. Ebbes First School on Whitehouse Road. This is considered to be an urban background site that was established on 09 July 1997. It measures NO_X, O_3, and PM_{10}. In addition to these urban monitoring sites, there is also a fourth one based outside of the city centre at the Green Road roundabout; it will not be considered here because of its location in the outer cordon rather than the inner cordon, which is the focus of this study for the Oxford city centre.

Traffic congestion for streets located in the city centre appears to be varied. For instance, there is some indication of diminished counts at St. Cross Road (with congestion somewhat reduced from 10,100 automatic counts in 2008 to 9500 in 2010), as depicted in Fig. 3.1. Walton Street appears to have stabilised since 2007 (at approximately 3100 counts) in comparison with the 2002 count of 4700 (see Fig. 3.1). When individual streets are not considered and locomotor type is indicated instead, it is clear that traffic abatement has occurred in the city centre. This is evident on the High Street route (between Speedwell and Longwall Streets) between 2000 and 2012 in Fig. 3.2 for all motor vehicles (Department for Transport 2013). In addition, bus traffic was reduced between 2003 and 2011. Similarly, pedal cycles

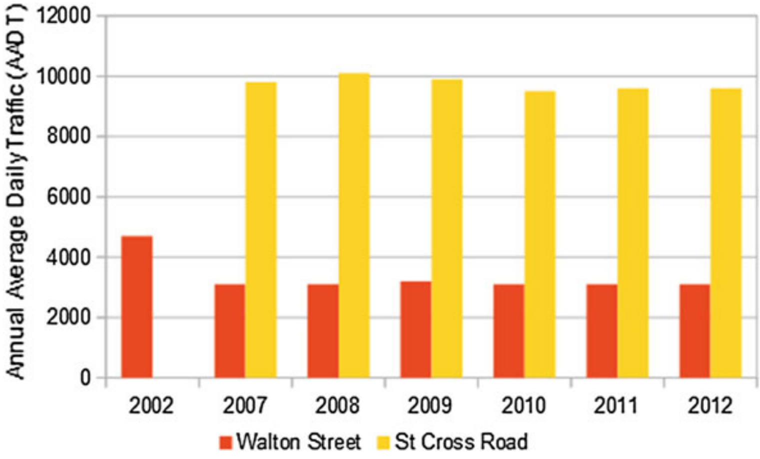

Fig. 3.1 Automatic traffic counts at streets located in the Oxford city centre (adopted from Oxfordshire County Council 2013a)

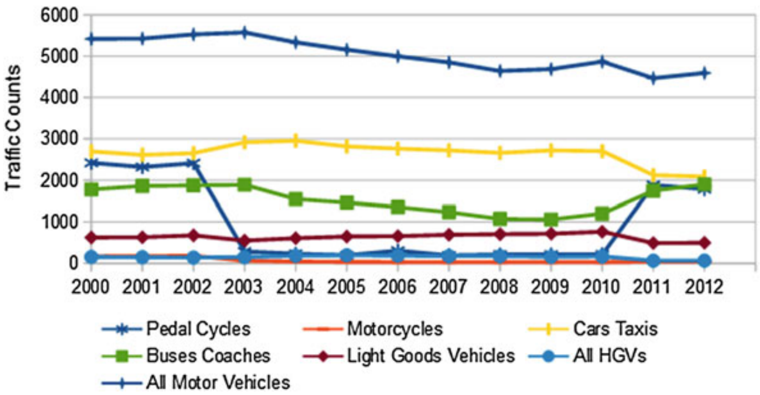

Fig. 3.2 Automatic traffic counts for different transport modes on selected routes: from Speedwell to Longwall Streets (adopted from Department for Transport 2013)

were reduced in number between 2002 and 2011. Otherwise, there were increases between 2002 and 2011 in counts of cars and taxis as well as light goods vehicles (see Fig. 3.2). The central route for St. Giles (between Hythe Bridge/Worcester Streets and St. Giles) has remained stable in terms of all motor vehicles as well as cars and taxis (see Department of Transport 2013); and these transport modes have remained higher in number than other modes shown in Fig. 3.3. In this record, there is also evidence that conveys increased numbers of light goods vehicles and pedal cycles (the latter since 2004). Manual counts at a selection of streets in central Oxford (including Castle, Cornmarket, George, Gloucester, Little Clarendon, Magdalen (East), Pembroke/Brewer, Queen, St. Johns, and Walton Streets plus

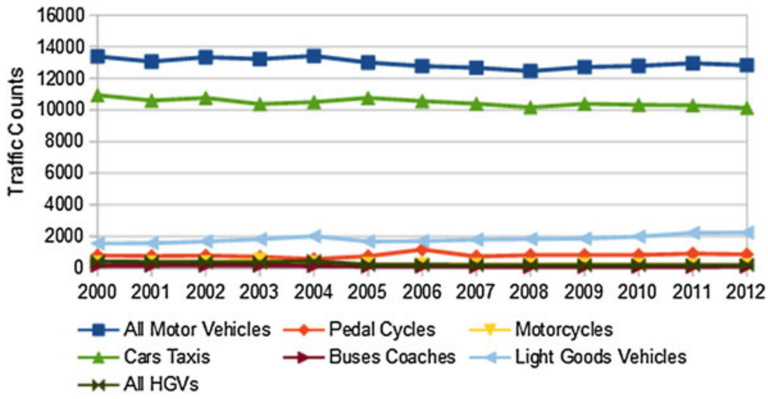

Fig. 3.3 Automatic traffic counts for different transport modes on selected routes: from Hythe Bridge/Worcester Streets to St. Giles (adopted from Department for Transport 2013)

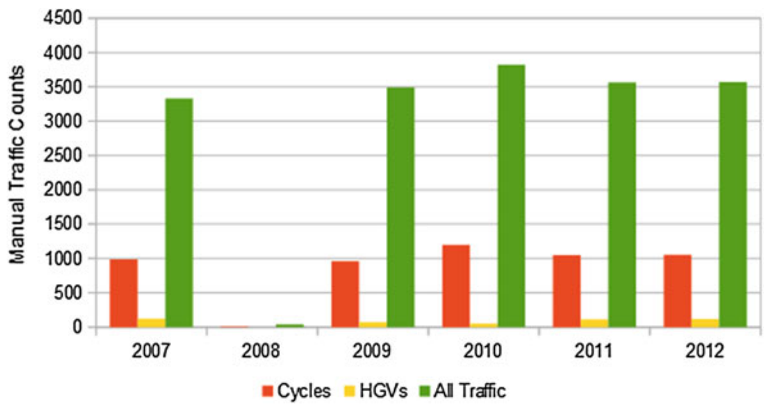

Fig. 3.4 Manual classified traffic counts at a selection of streets in central Oxford (adopted from Oxfordshire County Council 2013b)

Walton Lane) do not show such clear trends (Fig. 3.4). Bicycle counts have increased continuously since 2002, with average weekday (rather than weekend) flow closely mimicking average daily flows between 2002 and 2012 (Fig. 3.5).

The OTS was successful at improving the air quality in the Oxford city centre. Indeed, the monitoring sites convey reduced concentrations of pollutants, at both kerbside and urban background locations, including NO_2, NO_X, SO_2, and CO at the Oxford Centre site as well as NO_2, NO_X, PM_{10}, and O_3 at the Oxford St. Ebbes urban background site. Pollutant concentrations are most notably reduced for NO_X (from 213 to 174 $\mu g/m^3$) and SO_2 (from 26 to 4 $\mu g/m^3$) at Oxford Centre (Fig. 3.6). The urban background site at St. Ebbes (Fig. 3.7), however, does not show as much

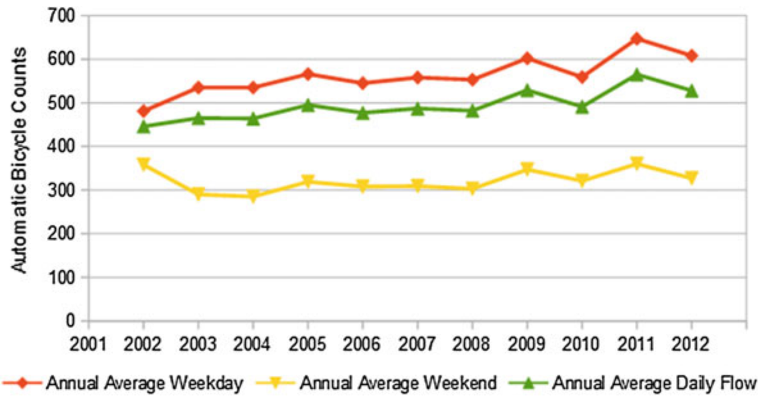

Fig. 3.5 Automatic bicycle counts (adopted from Oxfordshire County Council 2013c)

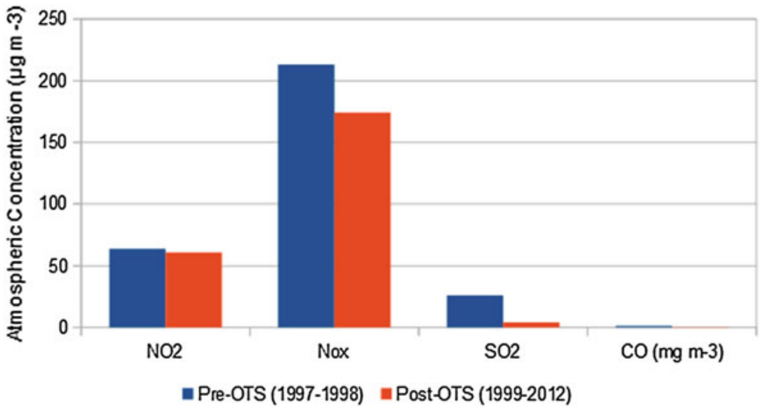

Fig. 3.6 **a** Pollutant concentrations at the Oxford Centre monitoring site (adopted from Oxford City Council 2013a)

of a drop in pollutant levels, as they were already low (e.g. 24–21 µg/m^3 for NO_2; 48–39 µg/m^3 for NO_X; and 19–16 µg/m^3 for PM_{10}). In fact, O_3 saw an increase (from 38 to 43 µg/m^3) during these sampling periods. Importantly, CO, which oxidises to produce CO_2, declined (from 1.3 to 0.3 mg/m^3) where it was measured at the Oxford Centre monitoring site (see Fig. 3.7).

Pollutants with continuous records since 1997 were plotted and appear in Figs. 3.8, 3.9, 3.10 and 3.11. Those that did not have continuous records (e.g. stopped monitoring in 2007, as at the Oxford Centre site) include SO_2 and CO. The former pollutant (SO_2) dropped from 32 to 2 µg/m^3 between 1997 and 2007, and the latter one (CO) also dropped 1.7–0.1 mg/m^3 in this time period. Other pollutant trends are presented separately in Figs. 3.8, 3.9, 3.10 and 3.11. There is a generally reduced concentration of all pollutants, except PM_{10} and O_3, both of which seem to

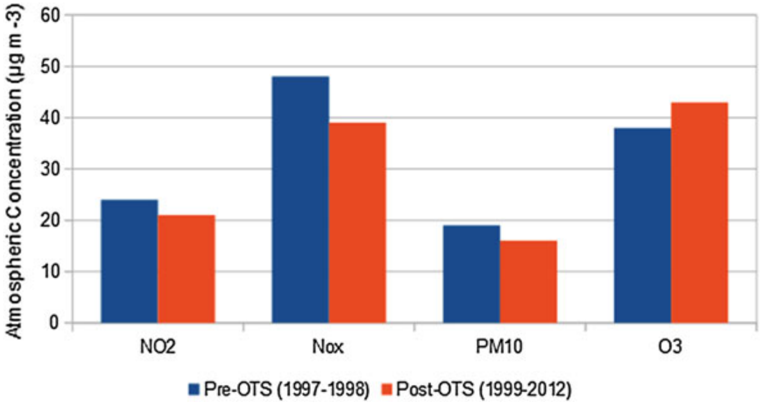

Fig. 3.7 Pollutant concentrations at the St. Ebbes urban background monitoring site (adopted from Oxford City Council 2013a)

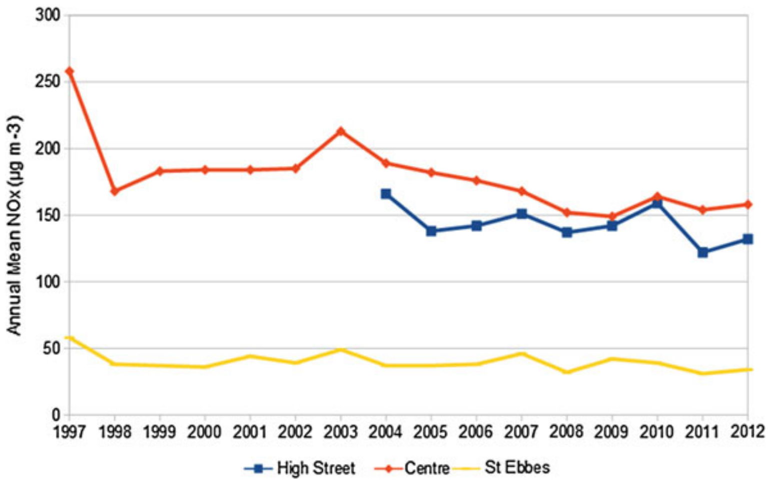

Fig. 3.8 Pollutant concentrations for NO_X (adopted from Oxford City Council 2013a)

show oscillating, but stable, trends (see Figs. 3.10 and 3.11). The data convey a significant effect of the OTS on SO_2 (from 20 μg/m^3 in 1998 to 5 μg/m^3 in 1999) and to some degree CO (from 1.7 m/gm^3 in 1997 to 0.9 mg/m^3 in 1998, but this was pre-OTS; a concentration of 0.4 mg/m^3 was evident in 1999). Decreasing trends were less evident for NO_2 than NO_X (e.g. compare Figs. 3.8 and 3.9), particularly at kerbside sites. It is perhaps unsurprising that pollutant levels remained lower at the urban background site (St. Ebbes) in comparison especially with the kerbside site located at St. Aldates.

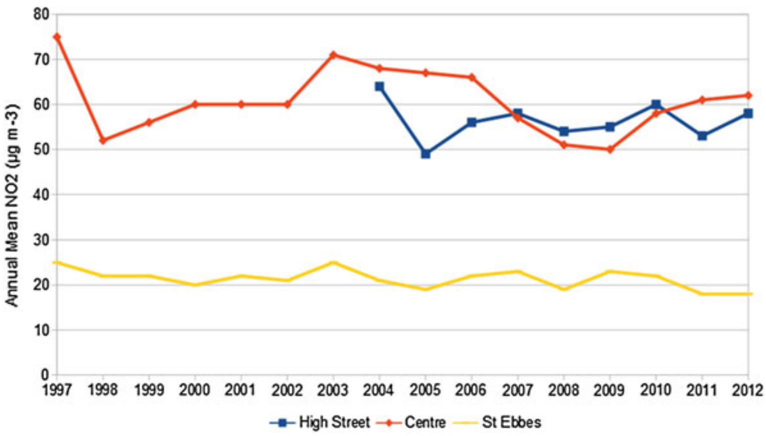

Fig. 3.9 Pollutant concentrations for NO_2 (adopted from Oxford City Council 2013a)

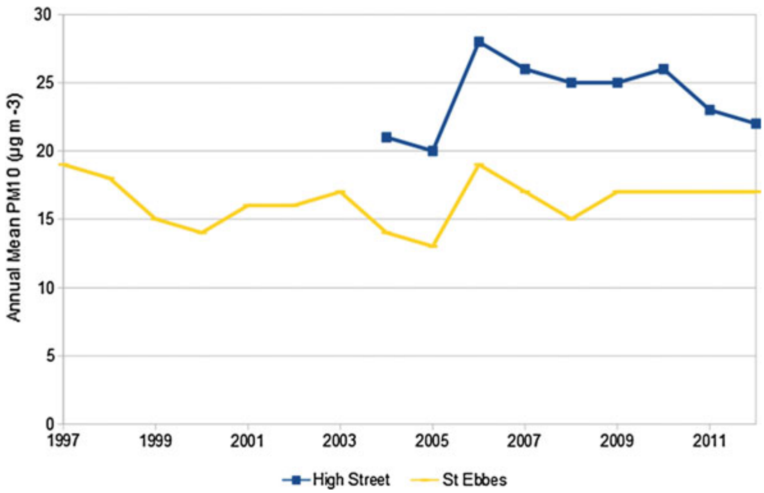

Fig. 3.10 Pollutant concentrations for PM_{10} (adopted from Oxford City Council 2013a)

Pollutant thresholds noted by Oxford City Council (2012, p. 12) of 40 $\mu g/m^3$ were breached in all cases annually between 1997 and 2012 at kerbside sites (see Fig. 3.9), but never once at the urban background site. However, the concentrations for this pollutant denote a severe drop between 1997 and 1998 immediately before the implementation of the OTS evident at the Oxford Centre site. PM_{10} remained below the mean annual objective threshold at both the High Street kerbside site and the urban background site (see Fig. 3.10).

These findings concur with the view that the OTS was successful in attaining its objectives of reducing traffic congestion and improving air quality (e.g. Dudley

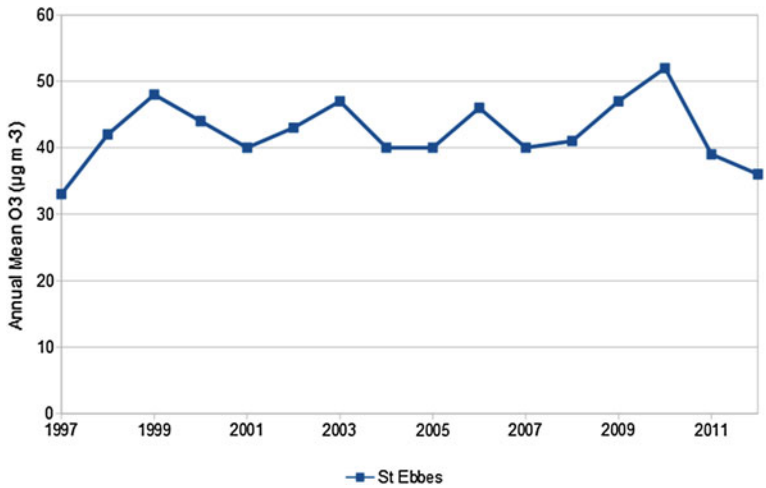

Fig. 3.11 Pollutant concentrations for O_3 (adopted from Oxford City Council 2013a)

2003). However, there are questions of how representative these measures are. For instance, traffic counts are affected by the time of survey during the week, day, and season; and, whenever possible, these should be controlled in the monitoring process. Moreover, the results are based on monitoring sites for air quality, which are point samples and could be affected by air currents, dispersion via air currents, and dilution. For instance, PM is not only locally sourced and can be transport long distances outside the urban environment, and this can also be true for sulphur and NO_X (Ilacqua et al. 2007). Pollutant concentrations may be unevenly distributed and unrepresentative of actual exposures. They may be concentrated in urban street canyons.

There are other factors that can affect the results of such transport strategies, such as duration. Modelled findings (e.g. by Lasry et al. 2007) convey that short-term action plans are insufficient to solve the problem of ozone peaks in European cities in the Berre-Marseille area, so that longer term traffic-abatement strategies are needed. Moreover, the time of the year may impact the average journey time, as demonstrated in Oxford by faster inbound morning peak journey times during the summer period between July and September during the University of Oxford vacation period (Oxfordshire County Council 2013d).

As noted by Parkhurst (2004), in 2001 Oxford had a 30-year tradition of promoting the use of public transport and among the youngest buses in European cities. Public transport took second priority after pedestrianisation at a time when there was a consensus to limit road expansion. People were encouraged to take public transport and use the park-and-ride system for parking outside the city centre. The closure of High Street to private vehicles discouraged them from entering the city centre and encouraged the use of public transport, taxis, and cycles, effectively aiming to reduce private vehicle (car) traffic. According to

Parkhurst (2004), the problem was that increased use of buses augmented the greatest polluting vehicles (large diesel engines) at the expense of a less polluting mode of transport, namely cycling. However, this current study contends that this may not be deleterious after all due to improvements in the bus fleet to electric hybrid technology in place by 2010 (which tackled both NO_X and carbon emissions) and due to a growth in cycling that has been evident since 2002, especially in weekday traffic. The main disadvantages to battery EVs is their high capital cost, which is generally 50–100 % greater and their performance is not equal to conventional vehicles; however, they do have urban applications, such as regular, predictable drive cycles less than 100 km/day, that make them suitable to delivery cycles and possibly public transport on short urban routes (Lane and Warren 2007, Box 2.12, p. 73). Most importantly, it is essentially a zero-emission vehicle at the point of use, and has potential to be fully zero-emission if supplied by renewable sources of energy. Their contribution to the urban environment, in addition to zero-emissions, is reduced noise pollution; although, they may increase heavy metals, such as lead and cadmium) as battery-powered vehicles. Research has observed reductions in traffic emissions of 9 % associated with traffic-reduction schemes, with greater reductions anticipated for CO (e.g. Tate and Bell 2000). The only concern conveyed for central Oxford is that NO_2 levels have remained higher than imposed thresholds, but this may be remedied with the introduction of electric hybrid buses (although this continued to increase in 2011 and 2012 after fleet renewal).

Sustainability should consider three systems: biological and resource; economic; and social, comprising biological resilience as well as growth and development (Newson 1992). This chapter has focussed on sustainability defined primarily from an environmental approach to urban resilience, as taken previously by Thornbush et al. (2013, Fig. 1, p. 3), where economy, society, and the environment are included in the sustainable development of cities (after Golubchikov 2011). Other researchers are encouraged to assess the OTS from other perspectives, including the economic and social, in an integrated approach (as in the integrated multidisciplinary approach appearing later in this brief).

The OTS succeeded to reduce overall traffic congestion in central Oxford (although not at all streets/routes due to traffic redirection). There seems to be an increasing trend in cycling in the city centre, showing that the scheme achieved another one of its objectives (to increase cycling in the city centre, in addition to reducing car traffic in the city centre). Drastic reductions of cars and taxis are especially evident on High Street. Air quality has improved for most of the measured pollutants, except O_3 in particular. Also, NO_2 concentrations at kerbside sites remain above the set threshold, even though this is not the case for PM_{10}, but its concentration remains stable. Further research is needed to assess other impacts, such as the economy and human health in addition to other environmental indicators, such as impacts on building soiling and decay.

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Chapter 4
Implications for Urban Sustainability

Abstract Recent developments are considered here in terms of the built environment and ways to ensure steps towards urban resilience through the mitigation of human-derived greenhouse gases (GHGs). Oxford building stone (and its buildings), in the aftermath of the OTS, are considered within a contextual framework of planning, urban design, and transport. Drawing from the broader literature, these topics are discussed from different parts of the world, with an emphasis on developed nations as leaders in climate-change mitigation through low-carbon urbanism.

Keywords Built environment · Urban resilience · Climate-change mitigation · Greenhouse gases/GHGs · Urban planning and design · Low-carbon urbanism

The longitudinal assessment of environmental health based on buildings in central Oxford has revealed an improvement, at least in the inner cordon, in traffic congestion and air quality. The aims of the OTS for buildings were certainly met. For instance, it was anticipated that there would be reduced traffic-induced damage to the building façades (cf. Thornbush and Viles 2005). The OTS, however, did not cut bus and lorry traffic in the city centre, and bussing actually increased (as along High Street). This means that associated air pollution (as from diesel HGVs) will continue to be a problem. It is noteworthy, however, that a fleet of (26) energy-efficient (electric hybrid) buses was launched in 2009; these double-decker buses emit 30 % less carbon and have reduced NO_X emissions (BBC 2010). This effort will ensure that increased bussing will not produce more pollution due to this technological fix.

In the absence of improved technology, other cities have experienced more pollution. Kingston upon Hull, for instance, saw an increase in the average daily mean concentrations of SO_2 (+26 %) and NO_2 (+5 %) as well as particulates (PM_{10}: +39 %) with the implementation of bus lanes (Crabbe and Elsom 1997). Motor traffic can also affect dust, as in Italy (when, in 1989, 50 % of dust was attributable to high motor traffic), and the deposition of PM, which blacken marble surfaces and contribute to stone decay associated with material loss and the formation of gypsum crusts (Realini et al. 1995). Indeed, even with hybrid EVs, there are still some emissions that could lead to further decay of environmental health in the city centre.

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Even though the OTS did reduce traffic levels to approximately 1957 levels (Thornbush and Viles 2005: 46, Fig. 1), there was no clear post-OTS decline in NO_2, and continued vigilance is needed. Hybrid vehicles still rely partly on combustion processes (for electricity production), with coal-burning and motor engines responsible for much of soiling and decay of Oxford stone.

In some cases, however, technology has not been a panacea. Indian cities, for instance Mumbai, which have a higher share of public bus transport and use of suburban rail, experienced a reduction of 60 % in energy and emissions when compared with cities such as Delhi (Das and Parikh 2004). The use of mass transit systems over private passenger vehicles can lead to reduced energy demand and energy savings as well as improved local air pollution, including carbon emissions (Phdungsilp 2010). Public transport, therefore, reduces vehicular congestion and associated emissions, but greater demand leads to the deployment of more fleets, which could offset any gains in air quality from transport restrictions. It is crucial to bring in hybrid and fully electric buses in cities to curb pollution from increased use. Where this is not possible, the use of alternative fuel, as in China (Ou et al. 2010), may be beneficial for the environment and human health.

Rather than a continued dependency on combustion (of fossil fuels), it has been suggested that renewable sources of energy be employed in energy production (e.g., Hart 2003). Hydrogen could reduce GHG emissions to zero, improve air quality, and even diminish noise pollution from engines. However, hydrogen-energy infrastructure is in technological immaturity, as is evident in Norway between Oslo and Stavanger, where socio-technical networks failed (Kårstein 2010). Electric vehicles represent a step forward in cities, but would similarly be limited initially by the availability of charging stations (e.g., Electric Recharge Grid Operator preceding the deployment of EVs) that would ideally rely on an intelligent rechargeable network based on renewable energy (Andersen et al. 2009) in order to reduce pollution problems associated with conventional combustion energy production (based on any fossil fuel and combustion process). Some countries have already introduced such an approach (e.g., Israel, Denmark, Australia, and the US) for reduced reliance on hydrocarbon fuel (Sveum et al. 2007). There are roads that are sufficiently wide (for instance, Broad and High Streets in central Oxford), where recharging stations could be enplaced.

Alternative forms of transportation are another possible consideration towards accommodating more urbanites and reducing reliance on private vehicles. Aerial ropeways, for instance, have been implemented as a mode of urban transport, and some cities have adopted metrocables, as in Medellin and Caracas as well as Algeria's aerial ropeway serving the cities of Skikda and Tlecern (with transit-system connections) and a new gondola system in Koblenz (UN-Habitat 2010). In London, the Emirates Air Line was introduced in June 2012 to transport passengers at an elevation of 90 m between Greenwich and the Royal Docklands. These aerial ropeways utilise less material and energy and are non-polluting; hence, they have lower ecological footprints and are safe modes of sustainable transport. Trams have been deployed typically in European cities, but their potential is still unrealised in places like China and have been considered for use in Chinese cities

(Tang and Ma 2011). The notion of the AutoTram has also been deliberated to provide transportation with hybrid propulsion using electrical power trains that have the potential to be long vehicles (Wiel et al. 2007).

Google has also been working on a navigation system that enables automated cars 'self-driving vehicles' to rely on video cameras, radar sensors, and lasers in conjunction with road-maps to transport passengers without the driving necessity. This could reduce accidents on the road (due to human error) and also establish optimal routes for single road trips, effectively reducing journey time. Nevertheless, technology does not offer all of the solutions to achieving sustainable transport systems (Banister 2011), and a combination of strategies may work best to meet emissions reduction goals (Mashayekh et al. 2011). For instance, Denver, Colorado may benefit most from a mix of regulatory and voluntary actions (e.g., voluntary behaviour change in energy use and consumerism in combination with technology shifts) to mitigate 1 % of GHGs each year in the transportation and buildings sectors (Ramaswami et al. 2012).

In addition to technical approaches, it is important to consider urban planning and the optimisation of traffic flows. Road infrastructure improvements should include improvements of connectivity and continuance possible through intelligent transportation systems, for instance to reduce traffic bottlenecks and provide suitable traffic diversions. In this way, it is possible to alleviate traffic congestion and air pollution, and even eliminate or at least deter the need for traffic-reduction schemes. Additional options include road pricing and car-parking policies, congestion-pricing tolls (e.g., London's Congestion Charge zone), park-and-ride facilities, ride-sharing and car clubs, and travel planning. It is also possible to reduce car dependency by work-from-home or live-near-work schemes that should be supported by governments.

Indeed, because a technological fix does not present all solutions, an ecological paradigm can be most suited to improve urban sustainability in transport. Taking a sociotechnical approach is advantageous here because of opportunities afforded by developing countries that do not have easy access to up-to-date technology. For this reason, and others, new technologies cannot be a panacea for sustainable development in urban transport. Social initiatives affecting consumerism may work to reduce resource use and waste, as for instance lower material standards for the wealthy (Satterthwaite 2011). In Australia, for instance, there has been support for a socio-technical understanding of domestic consumption behaviour (e.g., Moloney et al. 2010). Behavioural change through a non-consumerist approach could reduce consumption (and waste production), and also remedy the problem of affordability associated with technological fixes. Changing attitudes from convenience-oriented to low-carbon-oriented, for instance, would stimulate energy conservation based on such a behaviour-change approach (Zhao and Chu 2009). This can be endorsed through policy, as with the provision of sustainable transport to reduce petroleum dependency (Chapman 2007).

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Chapter 5
Further Pollution Reduction

Abstract Urban planning has defined urban space as separate from rural land use and the countryside. Cities are covered in cement (concrete) and tarmac up to the urban-rural fringe. Greenery is typically associated with the surrounding countryside or greenbelt area, where vegetation cover encapsulates the extent of the built environment. This notion of urban land use that excludes greenery needs to change in order to promote (and achieve) a fully integrated mitigation-adaptation approach to global warming. By introducing urban greening, it is possible to employ vegetation as a soft-engineering strategy that can be naturally and cheaply deployed as a CSS. This green movement is already being stimulated in cities by recent architectural requirements and designs that include, for instance, grass roofs and rooftop gardens. In this chapter, recent findings addressing urban agriculture are presented and specifically discussed. The literature conveys a growing interest in this mitigation-adaptation approach, and recommendations are made (as possible solutions) for its adoption in developed cities. This contributes to an understanding of the contemporary role of urban vegetation and its function (as a carbon sink, and more) within urban contexts, and this is relevant for any deliberation of Oxford's history of green walls and impacts on pollution abatement through urban greening.

Keywords Urban space · Urban land use · Mitigation-adaptation · Soft engineering · Carbon capture and storage/CSS · Carbon sink · Green architecture · Urban agriculture

Other efforts are possible in the ambition to reduce GHG, mitigate global warming, and adapt to climate change in cities. Urban agriculture is one of the venues offering CSS, in addition to green envelopes on buildings in an urban setting. This is part of a soft-engineering approach that also advocates urban greening to promote improved environmental quality in cities through pollutant absorption and better environmental health. What is more, urban agriculture offers integrated ecological-economic benefits by contributing to job creation, income, and food security. So, it represents one of the integrated strategies to achieve urban sustainability by way of ecological, economic, and social means.

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Urban agriculture is seen as a mode of integration for rural-urban landscapes. Much of it is located in periurban areas (towards the fringe), although there is some evidence of urban agriculture occurring in the built environment (cities), as with integration with the building envelope (Torreggiani et al. 2012), which will be developed in the next chapter. According to these authors, this integration can be conceptualised as part of the relationship between consumption, food production, and the environment. Indeed, it is difficult to maintain agriculture solely in the countryside (and bidirectional trends should be evident), as cities continue to expand and cover agricultural land. The expansion of cities (urbanisation) is a prominent landscape modifier that is currently irreversible, as half of the population resided in cities in 2007 (when for the first time in history more than half of the world's population occupied urban environments, cf. Izquierdo 2007), and urbanisation continues to grow with population expansion (with some two-thirds of the world's population living in cities by 2030, and an estimated total population of 9 billion by 2050) especially in developing countries, as in Africa (Thornton and Rogerson 2013). There are several ramifications of this growth, including urban sprawl, which is altering landscapes like never before, and will be subject in Chap. 7 in association with the UHI effect.

With the encroachment of agriculture into the urban environment, linked environmental issues associated with, for example, fertilisers (and eutrophication), pesticides (and bioaccumulation), and impacts on natural biodiversity (cf. Kerr 2012) will become more prominent globally as urbanisation continues to expand. Nevertheless, there are other pressing issues that stem from socioeconomics that compound these problems and necessitate for the distribution of food resources, as for instance with rural-urban migration of poor farmers in the developing world. So, the picture is not solely one of ecological integrity and environmental health, but also one of human health and well-being.

In poor African countries, such as the Democratic Republic of the Congo, Senegal, Gabon, Mozambique, Botswana, Mali (and even in less impoverished countries like South Africa, Egypt, and Namibia), allotment gardens are a source of food and extra income as well as green spaces in urban areas (Izquierdo 2007). These initiatives are backed by the UN Food and Agriculture Organization. Urban farmers have set up kiosks in their neighbourhoods in order to market surplus produce, earning at least an extra dollar a day. Food is grown wherever possible in cities, where there is enough space and light (e.g. windowsills, courtyards, stairs, etc.), including as microgardens. Hydroponics are deployed as a growth substrate (instead of soil) grown in a variety of containers (recycled water bottles, old tyres, trays, etc.). In this fashion, some 25 kg of produce (lettuce, beans, tomatoes, onions, etc.) are grown and sold for cash.

Social adjustments, however, are required for urban greening through agriculture in cities. The urban demand for locally produced foods, for instance, is needed to stimulate the development of local foodstuffs in farms, including those located in an urban setting. This demand for 'close to home' seasonal and organic produce (Jarosz 2008) could also spur rural restructuring and an emphasis on small-scale (family-based) farming, which could support local farmers and sustainable livelihoods. It is vital for urban agriculture to grow beyond farm-to-city schemes (as of organic produce delivery), and that it is actually produced locally within cities in order to reduce food miles associated with transportation costs and energy consumption for food delivery.

The initiation of the global economic crisis led to food-price increases (a food crisis) in 2007–2008, which affected poor urban-dwellers in particular (Cohen and Garrett 2010). The policy responses to this problem were predominantly rural-based, however, even though the impacts greatly affected the urban population, leading to urban food insecurity. In the developed world, there has been a relatively recent push to develop urban agriculture, potentially turning cities to agricultural powerhouses, as for instance in Detroit, Michigan, USA (Colasanti et al. 2012). World views were gauged in voting exercises to ascertain priorities concerning specific UK research needs, and it was determined that participants thought that food affordability should top the agenda (Ingram et al. 2013); food safety and security as well as climate change impacts on food production were conceived as important. However, trade, transport, etc. did not feature highly by participants to achieve food security.

Governance can pose an obstacle to achieving food security, as experienced in subSaharan Africa, where responsibility is shifting from government to households and individuals, which is restrictive to political action (Maxwell 1999). There is also the problem of increasingly landlessness that can be especially pervasive at the periurban fringe (Maxwell 1996). By scaling up community and home gardens as production networks (particularly the latter, which in Chicago, USA represent three-fold the former and make-up 13 % of land that is used for food production, Taylor and Lovell 2012), there could be some economic opportunities in the making of urban gardening. McClintock et al. (2013), for instance, demonstrated how even a conservative scenario of urban vegetable production can contribute 2.9–7.3 % of Oakland's (California) consumption. Nevertheless, in the West African lowlands, for instance, it is thought that even integrated rice-vegetable production is not an important part of pro-poor development, as it is constrained by water control limiting temporal integration (Erenstein et al. 2006).

Regardless of such social and physical constraints, in Berlin, Germany, for instance, urban gardening appears in allotments and gated communities; public-access community gardens are encouraged because they have greater (social, political, and economic) ramifications, and generate learning about social-ecological conditions as well as promote the development of 'sense-of-place' even in degraded neighbourhoods (Bendt et al. 2013). In addition to the benefits associated with 'environmental learning' (Bendt et al. 2013), the rural-urban transfer of food production would assist urban households that are vulnerable to hunger due to the lack of social connections to rural areas, as in Windhoek, Namibia (Frayne 2004). Home gardening also represents a way to diversity production, which is a common response (in addition to effecting reproductive activities) to constrained incomes in Gweru, Zimbabwe (Rakodi 1995a).

There has also been some concern over growing food in highly polluted environments, such as cities. Nevertheless, research has shown the city-grown washed fruits produced in the Berlin (Germany) inner-city area did not pose a health risk (von Hoffen and Säumel 2014) even though these authors found high levels of cadmium and lead in nuts, berries, and fruits harvested from shrubs and trees located in the inner-city. Even gardens located on rooftops, which help with energy conservation through the provision of attic insulation as well as reduced life-cycle costs of extensive green roofs in Singapore (Wong et al. 2003), can be affected by dispersed pollutants in cities; although contamination should occur closer to ground-level. So, food production as a type of urban greening has this caveat of potential contamination due to the environmental setting where food is grown, and this needs to be further assessed at individual sites before planting programmes are initiated. More research is needed to test for contamination of urban crops as part of the cost-benefit analysis in planning for urban agriculture.

Studies already exist, however, that test for optimal growth conditions, such as species diversity. It has been found that planting a diverse plant mix (as in extensive green roofs) should be preferred over planting a monoculture in order to ensure greater survivability, as in dry conditions (affecting drought tolerance), because plants of the same taxonomy compete for resources (Nagase and Dunnett 2010). This criticism can be applied to agriculture more generally, however, and not just to urban agriculture, which has other constraints. One of the greatest challenges for developing urban (and periurban) agriculture is the availability of land as cities continue to expand. At present, for instance, vegetable production is economically viable in Asian cities; however, the problem of land scarcity questions its long-term feasibility (Midmore and Jansen 2003). This issue affects all cities where land prices are increasing, and there are pressures on greenfield sites (including allotments) used for gardening.

Despite urban challenges, agriculture has great potential to establish itself in urban areas. It is already viewed as a vital part of attaining food security for households in some places, such as in post-conflict Freetown, Sierra Leone (Lynch et al. 2013). In addition to contributing to urban greening and sustainable urbanisation, urban agriculture can be instrumental as part of 'food liberalisation', hence functioning to effectively connect people with the environment. There is potential, for instance, of engaging local authorities as well as communities to develop a proactive and integrated planning process (Martin and Marsden 1999). Urban planners need to work closely with agricultural scientists and health specialists (Binns et al. 2003), however, in order to ascertain holistically the impacts on health. For instance, in Kano, Nigeria contamination by industrial and domestic toxins poses a concern (Binns et al. 2003); nevertheless, health should be approached holistically, so that economics are also taken into consideration in overall human health and well-being. Perhaps as urban agriculture is practised more widely in cities, and as it becomes more commonplace and an accepted form of agriculture, policies can change to safeguard this resource, so that it can influence pollution and regulations governing it in urban areas. Change takes time and adjustment, and there are bound to be some barriers at first, but these obstacles need to be overcome for the greater greening of cities through such a human-serving ecological service. This could also act to integrate the rural-urban spheres, contributing to their continuum (e.g., Lynch et al. 2013).

Urban agriculture ultimately provides opportunities to re-establish and develop interactions between people and the environment (Roehr and Kunigk 2009). Such a connection could promote psychological well-being through proximity to nature as well as improve physical health through improved sanitation, for instance moving from treatment plants to urban farms for waste-water management, as is evident in Accra, Ghana (Lydecker and Drechsel 2010; low-quality water, such as reclaimed water and surface water, can be used to irrigate vegetable crops as part of periurban agriculture, Plauborg et al. 2010). It is noteworthy, however, that the form of urban and periurban agriculture deployed in cities will vary across cities and countries because of differences in urbanisation patterns as well as socioeconomic conditions (Dossa et al. 2011), and this shall have an impact on the type of agricultural system (e.g. small-scale subsistence or semi-commercial or larger scale commercial gardening; field crops; livestock; etc.) adopted and its environmental effects. Much research examines field-cropping, so that urban farming with livestock has been largely overlooked and is currently understudied. The work by Dossa et al. (2011), for instance, represents one attempt to consider agricultural systems in Sudano-Sahelian West Africa; however, more studies are needed to examine typologies of urban agriculture elsewhere in the world in order to inform environmental impacts and health.

More research is also needed to examine urban agriculture as a type of casual employment that is particularly prominent in developing countries. Subsistence urban agriculture can provide poor households with income (over what is used for household food consumption), and this affects their ability to access food and they, in turn, impound food affordability through the informal urban food sector as small-scale retailers in markets, as has been evident in the Bandim District of Bissau (Lourenco-Lindell 1995). Such informal food economies are incremental to achieving urban resilience. This has been seen at times of energy scarcity (Barthel and Isendahl 2013), for example, when it has become apparent that urban food production can be an integrated urban activity that contributes to urban resilience. Its contribution to long-term food security also enhances urban sustainability from a socioeconomic and environmental standpoint.

Scale needs to be considered in the urban food production sector in a free-market economy, as variations between small- and large-scale production can lead to different outcomes, which can be exemplified by the experience of small-scale producers in Johannesburg, South Africa (Bbun and Thornton 2013). More specifically, the scale of production can affect competition and the ability of (small-scale) urban producers to access markets. As such, urban and periurban agriculture has the ability to resurge community-based cooperation, as at a time of post-war recovery in Freetown, Sierra Leone by helping to safeguard livelihoods through food security (Maconachie et al. 2012). This is an example of how urban agriculture has grown in response to difficult economic times, and other (African) case studies exist, such as for Harare, Zimbabwe (Drakakis-Smith et al. 1995). Such cases support the link between poverty and deprivation (e.g., as in Kenya, Memon and Lee-Smith 1993; Rakodi 1995b) and the need for urban agriculture. In South Africa, there was development of urban agriculture evident as part of post-apartheid reconstruction, with difficulties experienced due to accessing land, financing and machinery, transport, crop security, and support services (May and Rogerson 1995).

Even though there is a connection between poverty and urban agriculture, there is reason to believe that better-off households benefit more than poor households (e.g., Lee-Smith 2010). This research conveys that in equatorial Africa at least small mixed crop-livestock farming is typically part of the urban farming system. Most urban farmers in East Africa, for instance, are established migrants whose production goes to support household consumption (Sumberg 1995). According to the author, this labour does not replace formal employment (either part- or full-time), so that few of these urban farmers are very impoverished. Much public lands are used, as in Kampala, where half of all urban land is farmed (Sumberg 1995). Relatively better off individuals are involved in commercial production (especially of livestock) because they can gain formal credit, so that this is a limitation for poor urban farmers (e.g., Cabannes 2012). It has been found that among low-income households are those with women (Floro et al. 2013), who are likely to engage in food production. This finding has been supported by other studies that have discovered, for instance, that female-headed households in Nairobi, Kenya holding low-income occupations or are unemployed are among the poor who depend on urban agriculture to be procure food (Lado 1990). In Malawi, two types of households engage in urban farming, those often headed by women that are uneducated, have a low-income, and employ agriculture to supplement income versus middle- to high-income households that are often male-headed and farm for personal consumption (Mkwambisi et al. 2011).

This connection with urban poverty lends itself well to gender studies in the developing world as well as urban political ecology, where marginalised inhabitants, not just in Africa but in other developing countries, such as Managua, Nicaragua mainly through the cultivation of fruit trees (Shillington 2013), fend for their rights to urban metabolism. Indeed, urban agriculture in the developing world has been justified from the standpoint of: ability, necessity, and opportunity (Choguill 1995). The former (ability) stems from origins in rural activities; necessity is normally bound with poverty and employment in the informal sector, including for migrants using unused/public lands for food security, and where opportunity exists in the absence of urban planning and regulations. Indeed, necessity, in particular, as a prerequisite for the development of agriculture in cities indicates that it is a type of survival strategy, as is evident for the Lubumbashi in the Democratic Republic of Congo (Tambwe 2006).

This does not mean that urban agriculture satisfies the needs of the urban poor in all cities. Even though urban agriculture is practised, there may be a reliance still on supermarkets and even the informal sector for food (Crush et al. 2011). Moreover, according to the authors, there is likely to be much variance from city to city in southern Africa, with some communities not participating in any notable urban food production, so that their households do not gain income from the selling of produce. For this reason, it is important to continue research into urban agriculture. Past research has tended to focus on traditional farming and rural agriculture, so that cities were bypassed in this area, as in the UK cities of Leeds and Bradford (Howe 2002).

Nevertheless, in developing countries, such as in Kano, Nigeria for instance (Lynch et al. 2001), urban agriculture does provide various benefits, including employment (and income), food provision, and flood control. According to the authors, urban agriculture is being threatened here (in northern Nigeria) because of tenure security and land development.

In addition to socioeconomic constraints on the development of urban agriculture, as evident for developing countries, are also environmental constraints, such climate (solar radiation, temperature, moisture/water availability, etc.) and pollution-related restrictions (air quality, soil pollution, etc.) as well as other factors posing growth restrictions, including nutrient supply, soil degradation, and pests (Eriksen-Hamel and Danso 2010). Soil quality is particularly known to vary according to local conditions (both physical and socioeconomic), as is evident in Oakland, California, where lead (Pb) contamination of soil occurs (generally below the 400 ppm levels of federal screening acceptability) especially in low-income (African-American) neighbourhoods located in West Oakland in comparison to the affluent (white) parts in Oakland hills (McClintock 2012). The relevance and importance of flood protection in cities is increasingly recognised in association with climate change, as with the case study of Antananarivo, Madagascar (e.g., Aubry et al. 2012). According to these authors, its multifunctionality is also being recognised along with the contribution of urban agriculture to sustainability. One of its functions, that has been largely overlooked, is the ability to reverse degradation, in addition to increased urban production (as of unused land) and improving the overall urban landscape, as in Tanzania and other African cities (Howorth et al. 2001), even where practised as an illegal urban activity. Importantly, according to these authors, within the context of informal (squatter) settlements, such as in Dar es Salaam, is, again, flood protection as part of hazard reduction in cities.

The legality of urban agriculture obviously varies between countries, and for instance Howorth et al. (2001) noted that it is actually illegal in most African towns and cities. Regardless, it has recently gained in popularity even in developed American cities (Bartling 2012), where much of it is allowed by local governments and even where local zoning codes and land-use ordinances disallow it. One of the reasons for this leniency in developed cities, such as Buffalo, NY and other American 'Rust Belt' cities (Metcalf and Widener 2011), has included food security in urban areas where abandoned property and vacant lots are abundant, as in derelict inner-city areas. According to these authors, from a systems framework, urban agriculture is becoming a part of sustainable agriculture. Regardless of current reactions to urban agriculture at various levels of governance and in different countries, it is not a new phenomenon, as in Africa for instance (Rakodi 1988), where it was part of non-Islamic pre-colonial cities. It has been stipulated that there exists an ancient relationship between farming and cities (Nelson 1996), where agriculture was founded for trade. There are current efforts, such as in Dar es Salaam (McLees 2011), to make urban agriculture an acceptable urban activity that is recognised by city-zoning plans. According to this author, some landowners are even willing to admit farmers onto their properties to work their land.

There are also examples of civic engagement in urban farming as part of socioecological practice in developed countries, as for instance in southwestern Ontario, Canada (Sumner et al. 2010). According to the authors, urban agriculture here is community-supported (known as community-supported agriculture), and has emphasised local food production as part of sustainable-farming systems. Such schemes can foster gardening as a development strategy and even support entrepreneurship (Karaan and Mohamed 1998). In Britain, gardening has emerged from being a traditionally male activity (for both active and retired males) to a socially diverse engagement also involving women (Buckingham 2005). According to the author, women in low-income households here are also using gardens to produce food for their families. This reiterates the function of urban home gardens as survival strategies that enable self-provisioning to meet household needs evident in various countries, regardless of their level of development it seems, including Santarém, Pará located in the Brazilian Amazon (WinklerPrins and de Souza 2005).

Urban transformations, such as that of urban agriculture within the context of a resilient low-carbon future, build upon what is permissible, desirable, and possible (Ryan 2013), and social standards affect their development. Some are considering ecolocalisation as a neoliberal approach to peak oil and climate change (North 2010). This author contends that localised economies are possible that occur closer to markets as they are less carbon-dependent and less resource-intensive. Alternative food networks have been formulated that emphasise proximity and the local, as apparent in Barcelona, Spain (Paül et al. 2013), which look to the rural-urban fringe as the city's link with the countryside. Pressures abound, however, limiting the urban-rural continuum (that connect cities and the countryside through periurban farmlands), and this includes urban pressures (as from expansion) and sprawl, and the latter will be considered later in this brief.

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Chapter 6
Energy Conservation

Abstract This chapter reviews the literature mainly of recent developments in urban greening. By incorporating more greening in cities, it is possible to capture and store carbon. In this way, vegetation acts as a soft-engineering strategy that can be cheaply deployed to achieve low-carbon cities. This can be performed in different ways, as through façade greening (as with the use of climbing plants), grassed roofs (including extensive green roofs), and roof gardens. Here, all of these methods of urban greening are considered with respect to their ecological functions and benefits. Thermoregulation is one of the many impacts of vegetated surfaces (through the provision of shade and insulation), including green walls. In addition to urban microclimatic control, there are also recognised (environmental) benefits of air filtration and purification, storm-water retention, and more. The research conveys urban greening as an effective mitigation-adaptation tool for climate change, acting also to improve urban climate, including the UHI effect and wind tunnelling in cities, as well as urban pollution more generally. The benefits of green roofs and façade greening are especially considered for urban greening before presenting a critical evaluation of the literature.

Keywords Urban greening · Façade greening/Green walls · Climbing plants · Thermoregulation · Cooling effect · Microclimate · Urban climate · Urban heat island (UHI) effect

This chapter presents, from a critical perspective, the contribution (benefits) that urban greening, particularly green roofs and façades, can make towards achieving low-carbon cities. In the current (international) effort to make cities more climate-neutral, the mitigation of climate change through the reduction of GHG emissions has been targeted in the built environment. For some time now, for example, industry has moved towards the fringe of cities or outside of them in the developed world. More recently, land-use patterns are under consideration. Planning is implicated here through urban design and the allocation of green space in urban areas as well as the conservation of existing urban parks and forests. In addition, architects have developed what is known as 'green architecture' to

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introduce urban greening directly through green-building. In this way, cities are undergoing a transition to low-carbon through various changes that improve air quality (by reducing GHGs in some way). Indeed, Davoudi et al. (2009) espoused setting urban tree-planting (as well as open space and habitat protection) as a priority action (A1) to counteract the effects of climate change through the degradation of urban air quality. As Priority 1, A1 involves action, whereby 'mitigation is directly and immediately synonymous with adaptation', as with urban tree-planting. Many European cities, for example, are currently transitioning through transport strategies and urban greening; for instance, Oxford and London, Paris, and Berlin.

It can be argued that the consideration of urban vegetation has been overlooked in comparison to hard-engineering strategies, such as creating global carbon pools (Lal 2008), and is deserving of further attention. This is particularly relevant in light of a recent UN-Habitat (2011) publication *Cities and Climate Change: Policy Directions* that relays global GHG emissions associated with agriculture and forestry at 31 % (p. 14). The report conveys how urban areas directly change land use (claiming agricultural land into the built environment) and through suburban encroachment and urban sprawl onto land previously with a vegetation cover, reducing the potential to absorb CO_2. It is extremely important to consider land use in climate change, as evident by recent studies showing the impacts of demographics as well as urbanisation on future climate change (O'Neill et al. 2010). Indeed, Seto et al. (2012) have suggested that under current trends of urban expansion, it is expected that urban land cover will increase by 1.2 million km^2 by 2030. They have considered this a global issue requiring policy changes in order to curb biodiversity and vegetation carbon losses.

Some researchers, for instance Donovan (2003), have estimated the potential for urban forests (in the West Midlands conurbation) to store 489 kt of carbon (roughly 6 % of the conurbation's annual CO_2 output). Moreover, she discovered that about half (51 %) of the conurbation is still available for tree-planting, so that the potential for using this carbon sink in urban areas could be effectively doubled. In addition to the absorption of CO_2 and an overall improvement of air quality, trees provide many urban services, such as contributing to the condition of soils, operating as part of the hydrological cycle, and moderating fluctuations in microclimate (Enis 1984). Although, admittedly, no substitute for good planning and architectural design, an urban design that integrates greenery is bond to improve ecological services within cities. Furthermore, research has shown that building-integrated vegetation (houses with an ivy façade or meadow roof) are rated highest and preferred (White and Gatersleben 2011). Indeed, this approach in green architecture has been encouraged recently, encouraging architects to employ green building and design (e.g., Li 2011).

Buildings present a considerable opportunity to achieve low-carbon cities. This could be established through new technologies, but also through the use of more established (natural) techniques like greening approaches. There is a long history, for example, of turf walls and sod roofs, as in Icelandic turf architecture used since the late 9th century (van Hoof and van Dijken 2008). Most recently, green roofs have been recognised for their potential as a climate-change adaptation and mitigation tool (Williams et al. 2010). Vegetated roofs can comprise grass (in the case of grass or grassed roofs), but also other vegetation, as plants absorb CO_2 in the daytime for photosynthesis, and can, thereby, reduce atmospheric levels of CO_2 in the nearby area by as much as 2 % on a sunny day (Li et al. 2010). The use of *Sedum* sp., especially *Sedum album*, in extensive green-roof systems (with substrate depths of 2.5–12.7 cm) has been found to be an effective approach to carbon sequestration in just 2 years, with capture concentrated in root spaces (Getter et al. 2009).

One of the benefits of using urban greenery is reduced atmospheric pollution. In addition to CO_2 absorption, other air pollutants are also reduced with the implementation of green roofs, including NO_X as well as O_3, (PM_{10}, SO_2, and CO (Niu et al. 2010). Taha et al. (1997) suggested urban reforestation as an energy saving measure that also reduces O_3 concentrations when low emitters of biogenic hydrocarbons (tree species, such as pine (*Pinus nigra*), larch (*Larix decidua*), and silver birch (*Betula pendula*) rather than oaks (*Quercus* sp.), willows (*Salix* sp.), and poplars (*Populus* sp., Donovan 2003) are used. Street canyons have been investigated, where pollutants tend to concentrate from sheltering by buildings located along roadsides, as in many European cities that have narrow streets flanked on either side by tall buildings. According to Pugh et al. (2012), street canyons reduce the dispersion of air pollutants due to recirculation and low wind speeds. They recently discovered that urban vegetation can increase particle deposition in street canyons, effectively reducing street-level concentrations of NO_2 by 40 % and PM by 60 %. This is illustrative of the ecological function of vegetation in cities, acting as an effective pollution filter even in dense urban areas. In Chicago over a 1-year study period, 19.8 ha of green roofs removed an estimated 52 % of O_3 as well as 27 % of NO_2, 14 % of PM_{10}, and 7 % of SO_2, with the highest amount of reduction in May and the lowest in February (Yang et al. 2008). Nutrient and heavy-metal retention has been observed in Berlin, where green roofs act as ‘urban sponges’ that can reduce algal problems from nutrient-loading of urban water bodies (Köhler et al. 2002). Another benefit of green-roofing is that it mitigates stormwater runoff generation in the urban environment, reducing the risk of flooding (Fioretti et al. 2010).

Green roofs have also been found to reduce noise pollution, especially emitted by fast-moving light vehicles, with flat roofs as particularly effective shields (van Renterghem and Botteldooren 2009). Van Renterghem and Botteldooren (2008) observed the best efficiency at 15–20 cm of substrate thickness in green roofs for optimal sound-proofing, but benefits are not really improved beyond 20 cm. Although, Wong et al. (2010b) discovered that the sound absorption coefficient increases with a greater greenery coverage. Sound absorption was also tested by Ardila et al. (2009) for vegetation-integrated wall construction.

In addition to absorbing pollutant gases and particulates, urban greening can have microclimatic effects. Green roofs, in particular, have been found to buffer daily temperature fluctuations (He and Jim 2010). This is performed by green roofs as insulation devices (rather than as cooling devices) that reduce the heat flux through roofs (del Barrio 1998). This author assessed relevant parameters of green roof design, including leaf properties and coverage (leaf area index) as well as soil density, thickness, and moisture content. Others, such as Fang (2008), have focussed on coverage ratio and leaf thickness. Lower temperatures have been measured under a covering of thick dark green vegetation, which can be higher under sparse red vegetation or on exposed soil (Niachou et al. 2001). Kumar and Kaushik (2005) tested for the thermal protection of a green roof due to shading, and found that for a green rooftop garden in Yamuna Nagar the cooling potential with solar shading was 3.02 kWh per day, maintaining an average room air temperature of 25.7 °C. In Sacramento, California, shade trees provided up to 42 % of peak demand savings and average daily savings of 3.6 and 4.8 kWh/d, with seasonal (cooling) energy savings of 30 % (Akbari et al. 1997). Bowler et al. (2010) performed a meta-analysis of urban cooling by vegetation located in green sites, and discovered a reducing temperature of 0.94 °C on average for parks.

There is an obvious benefit of the use of vegetation on old constructions with moderate or no insulation. For an ivy-covered roof, Takakura et al. (2000) found that temperatures were very steady throughout the day, with lower daytime temperatures and higher night-time temperatures (around 24–25 °C) compared with bare concrete surfaces. Castleton et al. (2010), for instance, encouraged the use of green roofs on older buildings that have poor insulation and could be retrofitted in the UK. Ascione et al. (2011) tested the performance of Palazzo dell'Aquila Bosco-Lucarelli, a historical building located in Benevento, southern Italy, examining energy retrofit technology that could lead to a primary energy saving of 22 %. These authors found a significant energy (and economic) optimisation of building energy, including reduced air draught and thermal insulation of the external wall. Another example in the large urban area of Legnano near Milan in Italy, which constitutes an 'architectural rehabilitation' of a couple of historical industrial buildings, where solar passive heating/cooling techniques were employed, including green roofs (Ferrante and Mihalakakou 2001). The authors have demonstrated how planting just *one tree per house* (in typical one-storey buildings in American cities) can produce a cooling energy savings between 12 and 24 %. As conveyed by Akbari et al. (1997), planting three trees per house is capable of reducing the cooling load between 17 and 57 %.

Façade greening is not a new concept or innovation, but one that has in gained popularity in the last decade as an energy saving method (Sheweka and Mohamed 2012). Experiments have been executed at the Universiti Sains Malaysia, Penang by Rahman et al. (2011), where legume species (*Psophocarpus tetrogonobulus*) were employed (for a month) for insulation on a biofaçade wall testing for its potential for energy efficiency. A further example (case study) of a green façade undertaken at the Liwa International School for the hot climate of Al Ain city in the Emirate of Abu Dhabi since the end of 2010, conveyed lower daytime temperatures on average of 5 °C in July compared with a bare wall (Haggag et al. 2012). Pérez et al. (2011) confirmed that the shading effect of green façades contributes to lowering temperatures and increasing relative humidity through evapotranspiration and by acting as a wind barrier. Heat flow losses indicative of energy saving are reduced on plant-covered wall sections of a building façade, as shown with an experimental approach, with heat loss reductions ranging from 15.5 up to 30 % (Onmura et al. 2001; Jim and He 2010; Teemusk and Mander 2010). Using an ivy-covered sunscreen (consisting of Japanese ivy that withers in winter), covering a west-facing wall in Japan, Hoyano (1988) revealed that exposed sections of wall exceeded the outdoor air temperature by nearly 10 °C at 15:00 on a clear day. With a transmittance of solar radiation across an ivy sunscreen of approximately 5 %, the equivalent shading coefficient was found to be approximately 12 %. Di and Wang (1999) experimented on a west-facing two-storey building wall covered with a thick cover of ivy and discovered a reduced radiation gain due to shading in the summer, with the peak-cooling load reduced by 28 % on a clear day.

Besides for retrofitted historical buildings and structures, a vertical plant canopy could be employed in modern building developments (Ip et al. 2010). This approach has been adopted in Greece, where a plant-covered wall improved energy conservation in a building envelope as well as improved and regulated microclimate in the built environment (Kontoleon and Eumorfopoulou 2010). A sky-rise greenery approach has been taken in Singapore as a Garden City (similar to Chicago, Toronto, Tokyo, and Germany, Wong et al. 2007). The objectives of this approach were: (1) to beautify the environment; (2) to improve air quality; (3) to create better thermal conditions; (4) to mitigate the UHI effect; (5) to provide amenity space; and (6) to enhance the aesthetics of a building. These researchers recognised different forms of building greenery, including rooftop and podium gardens, balcony planting, and façade greenery. Vertical greenery systems have also been used in Singapore, to cool ambient temperatures in building canyons (Wong et al. 2010a).

More research is needed to test for optimal types of vegetation cover used for urban greening. For example, researchers studying heat flux under shrubs found it always to be negative (Wong et al. 2003). Besides on roofs, turf (turf-based vertical planting modules) has also been employed on walls at a housing apartment (Cheng et al. 2010). Another consideration is the impact of biodiversity in the response of these green systems. Researchers, for example, have found that water loss and surface cooling by green roofs can be improved by planting multiple species (Wolf and Lundholm 2008). One advantage of using evergreen vegetation is perhaps its reduced seasonal decomposition of foliage, which could increase surface acidity where there is leaf decay, such as in the autumn for deciduous climbers, including Virginia creeper (*Parthenocissus quinquefolia*).

The potential for biodeterioration is a valid consideration, especially where historical buildings are concerned (e.g., Griffin et al. 1991). For this reason, it is necessary to continue to research (in the field and laboratory) biota-substrate interactions (e.g., Steinbrecher et al. 2010, who examined the attachment pads of Boston ivy (*Parthenocissus tricuspidata*), the attachment roots of ivy (*Hedera helix*), and the clustered attachment roots of trumpet creeper (*Campsis radicans*)). Indeed, it is important to address the colonisation by higher plants of historical buildings as well as heritage monuments, especially as regards the chemical and mechanical effects of plant colonisation (Mishra et al. 1995; Lisci et al. 2003).

Winkler (1966), for instance, already recognised the impact of plants on bare stone through the production of organic acids along the root system. Nanoparticles secreted by ivy tendrils have been found to play an important role in vertical plant adhesion (Wu et al. 2010). In addition to chemical weathering, plants also trigger physical (or mechanical) weathering, as in the case of some lichens (*Verrucaria baldensis*) that have been found to initiate the formation of mesoscale solution basins on limestone through microscale biopitting to form biotroughs (McIlroy de la Rosa et al. 2012). The bioprotective role of *Hedera helix* on old stonewalls has already been explored as a 'particle sink' (Sternberg et al. 2010) and for moderating microclimates across wall surfaces (Sternberg et al. 2011). Others have also observed the sink capacity of (climber) vegetation on the upper side of leaves in living walls, which is particularly evident at roadside locations (Ottelé et al. 2010). Thornbush (2013a) more recently considered the risks (as well as benefits) of using climbing plants specifically on the exterior of historical buildings. Table 6.1 likewise conveys the advantages and disadvantages of adopting urban greening. This allows for an assessment of sustainable cities that include street trees, for instance, which can help to resolve some issues and exacerbate others (e.g., reduce air pollution, increase particle deposition, and replenish oxygen, but also reduce ventilation; provide shade, but limit passive solar heating; mitigate light pollution, but can increase lighting requirements; store water, but require irrigation and have costs associated with repairing infrastructure; MacKenzie et al. 2010).

Even though it is not a perfect solution, urban greenery can nevertheless be seen as an integral part of urban ecological heritage (Jim and Chen 2010), which climbing plants can also be seen to encapsulate at Oxford colleges (Thornbush 2008, 2013b). Francis and Lorimer (2011) considered living roofs and walls to be habitat improvement techniques with potential for reconciliation ecology for urban areas. Their vision of its application at a landscape scale in urban areas is based on a bottom-up approach for improving biodiversity in cities that can be directed by urbanites. Jim (1998), for instance, conceived of Hong Kong's stone retaining walls as an ecological habitat, with some 505 walls containing 1275 trees over 1 m (and

Table 6.1 Some potential advantages and disadvantages associated with urban greening

Advantages	Disadvantages
Air purification	Added weight
Biodiversity	Bioweathering
Carbon capture and storage	Maintenance costs
Dust (particulate) capture	Required (ongoing) management
Reduced UHI effect	Root penetration
Sound reduction	Surface acidification
Stormwater retention	Surface moisture
Thermoregulation	Water use by vegetation
Wind barrier	Wind throw and break/snap

as much as 20 m) in height and many aged over 100 years, and an irreplaceable community asset. The need to preserve historical buildings as part of sustainable development is apparent in the perception of building professionals, as in Hong Kong and Shenyang (Lo et al. 2006), which should go some way in protecting them; although it is questionable whether stonewalls are considered to be a part of heritage conservation in China.

In the low-carbon-future approach to urban greening, it is sometimes questioned whether plants should be applied at all. Some authors, for instance Santamouris et al. (2011), assessed cool materials (with a high solar reflectance and infra-red emittance) to mitigate the UHI effect and to improve the overall environmental quality of cities. Greenery as a passive climate control and mitigation strategy for climate change, however, is effective in the form of energy conservation, since it is economical and an effective carbon sink. The capacity of vegetation to absorb CO_2 is advantageous, especially since levels of 2 % reductions have been discovered for extensive green roofs (e.g., Getter et al. 2009). The action of plants in thermo-regulation is both a relevant and important consideration in air-conditioner savings (cooling in summer and for hot climates) and heating (insulation in winter and for cold climates). Moreover, even though highly reflective white paint has been found to be effective in reducing sensible heat flux on surfaces, greenery was found to be more effective than highly reflective grey paint and concrete (Takebayashi and Moriyama 2007). In addition, vegetated walls lower surface temperatures of the air inside a canyon (due to evapotranspiration by plants), lowering air temperature and surface temperatures even not covered with vegetation (Alexandri and Jones 2008). This is especially relevant for historical buildings, where a solid wall (rather than cavity wall) design was employed before 1920 that can let more heat through, but could be insulated from the inside or outside (although more costly than cavity wall insulation). Based on insulating a semi-detached gas-heated three-bedroom home, (external) solid-wall insulation could save as much as 1.9 tonnes of CO_2 per year (Energy Saving Trust 2012). Using a leaf cover on external walls would thermally improve the indoor environment of buildings, especially in hot (arid) climates, particularly through an evergreen cover (Holm 1989).

It is important to apply field experiments to find solutions for environmental problems in the built environment, as in testing for low-carbon cities. For instance, by planting vine plants in a planting bed on the ground, it was possible to create an ultra-lightweight rooftop greening system to cover a factory for 2 years in an experimental trial application (Tachibana et al. 2010). Temperature has been a critical variable in studies of the UHI effect in cities and other climatic effects that are relevant to examine towards understanding and coping with the risks associated with climate change. This is especially important for already hot climates, such as Greece, where the plant foliage of climbers has provided cooling, particularly during hot periods. By adopting an experimental approach to urban greening and the use of climbers on walls to improve the thermal performance of building envelopes (Eumorfopoulou and Kontoleon 2009), it is possible to ascertain the benefits, such as towards energy saving, provided by façade greening. Before urban greenery is incorporated into new development planning, it is necessary to perform such field-based (as well as laboratory) testing of the impact of plants on their surroundings. In this way, it is possible to up-scale impacts in an urban setting and to determine possible advantages of such a soft-engineering approach to climatic mitigation. This would encourage further research into different climates and landscapes as well as a myriad of urban situations.

Urban greening has much to offer cities in terms of improved air quality, including reduced noise pollution and climatic regulation. Plants are a known carbon sink and should be included in the transition to low-carbon cities in climate-change mitigation. This chapter has reviewed much of the recent literature on greening in the built environment, concentrating mainly on building roofs (green roofs) and walls (façade greening). The contribution has been to accentuate the effectiveness of this soft-engineering strategy, which has much potential for cheaply and effectively (working with nature) control the emissions of GHGs, such as CO_2. Shrubs are effective for thermoregulation at ground-level and roots are known areas of (in-soil) sequestration. Studies have conveyed reduced daily CO_2 (on sunny days) and carbon storage noticeable within a couple of years. Furthermore, planting as much as only one tree per house can make a difference for cooling, which would impound on energy savings in summer.

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Chapter 7
Implications

Abstract In this chapter, the growing body of literature on the decarbonisation of cities is examined within the context of reducing UHIs and the mitigation of anthropogenic climatic warming. Relevant themes in the areas of governance and policy, urban energy infrastructure, and development and social justice are presented. These topics are addressed from the integrated (multidisciplinary) approach of cities undergoing a sociotechnical transformation to low-carbon.

Keywords Decarbonisation · Urban heat islands/UHIs · Climate mitigation · Urban governance and policy · Urban energy infrastructure · Development and social justice · Integrated approach · Sociotechnical transformation

Decarbonisation is subject to much discussion in contemporary discourse. This discourse has affected entire countries, such as the UK, that have committed to making reductions of up to 80 % in their GHG emissions (below 1990 levels) by 2050 (Committee on Climate Change 2008). Transport has received much consideration within this context, with London progressing to reduce its transport emissions (Hickman et al. 2010). Cities are affected as a past location for industry, which is currently still evident in developing countries, and carbon-neutral or zero-carbon cities have been targeted in attempts to mitigate anthropogenic climate change. More recently, integrated mitigation-adaptation approaches have been advocated (e.g. Thornbush et al. 2013), with urban greening having much potential to serve as a key integrating point (cf. Doudavi et al. 2009).

It is increasingly recognised that how land is being used is a major environmental issue in decarbonisation. Vegetation clearance to satisfy the needs of sedentary human occupation is drastically changing the appearance of landscapes and services provided by ecosystems at various scales. The urban-rural continuum in agriculture is one of the points addressed in this publication, and represents a linked human-environment opportunity to remedy landscape differentiation at a time when urbanisation continues to expand, impinging upon and threatening rural ecosystems

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and livelihoods. An analogy of the situation is a city that continues to grow, engulfing everything in its path (the way that London, for example, engulfed entire villages as it expanded in the past). It only makes sense that agricultural lands will ultimately also be taken up in the process of urbanisation.

With the spatial expansion of cities, mobility becomes a central issue. Transportation has been recognised (as by Kennedy et al. 2010) as an urban source of GHGs, as small cities undergo suburbanisation (currently apparent in Oxford) and the need for longer travel grows, increasing travel distances and times. A socialtechnical paradigm has been recognised in the literature as well as practically for Oxford, as hybrid buses were recently introduced to deal with associated vehicular emissions from public transport as the amount of commuters (who live on the fringe or in nearby villages, towns, and even other cities) continues to increase. A technological fix has been criticised, however, by some (e.g. Atkinson 1992) because technocentric solutions cannot solely remedy such an environmental crisis. Moreover, the author stipulated that societal changes affecting social structures, attitudes, and lifestyles is needed to supplement any technical measures. For one, consumerism figures greatly in the acceptance of new energy technologies (van der Sanden and van Dam 2010). For this reason, a sociological perspective has been advocated by some (e.g. Chen and Shi 2012) in the attainment of low-carbon cities. These authors have examined China, for instance, and identified a struggle between economic growth and low-carbon cities.

Urban greening (and agriculture) represent strategies to achieve traditional economic development, meanwhile also reducing carbon footprints in cities. This can be achieved through industrial structure adjustments and energy conservation technology (including that for transportation) as well as carbon sinks and low-carbon buildings and low-carbon lifestyles (Wu 2011). Harmonious development is required, especially for resource-dependent cities, in order to balance economic growth and reduced carbon emissions (Sun et al. 2011). Energy consumption can be augmented by industrialisation as well as through rapid urbanisation, particularly in developed countries due to domestic use (Liu 2011). It is, therefore, essential that social and technological factors affected by economic development and social progress, energy structure, usage efficiency, living consumption, and development surroundings be considered (cf. Su et al. 2012). Such holistic considerations (of society, economy, and environment) represent sustainable approaches, as for Jinhua City by Zhu and Su (2011), and for China at large from a social-science perspective of sustainable low-carbon cities by Opschoor (2011), who stresssed a regional socioeconomic approach to achieve a low-carbon economy. Such an integrated human-environment perspective should recognise environmental ethics while deliberating routes to low-carbon cities (Qin 2011). In considering the human element, it is necessary to address end-use energy consumption behaviour (Nguene et al. 2011).

Models of low-carbon development currently exist (e.g. Yusuhara, Japan is an ecomodel that was demanded due to a changing social situation, Kawakubo et al. 2010). In Japan, it is anticipated that 30–50 % of CO_2 emissions can be reduced from 1990 levels by 2030 whilst maintaining production growth of 1.6 % gross each year by the adoption of socioeconomic structural changes as well as technological measures, including land-planning; promotion of renewable energy; and lifestyle change (Shimada et al. 2007). Since Asian countries account for over half of global population and emissions, they are seeking to develop pathways towards achieving low-carbon emissions, while simultaneously reducing resource consumption and maintaining economic growth and the quality of life.

There is a greater online awareness of low-carbon cities in addition to a focus on global cities for sustainability, as for Arabic-Islamic cities as well as old cities, such as Jerusalem (Jarrar and Al-Zoabi (2008). Cities themselves have become hubs for development separate from the overall (national) level of a country's development. The city of Ardenal in Norway, for instance, which comprises some 40,000 people, has transformed itself from dependency on primary sectors (forestry, mining, and shipping) to the service industry of tourism and to information technology (Hirsh 2009). Here, an emissions inventory (performed in 2008) revealed that emissions predominated building-use and transport, and these are targeted to be reduced by 90 % by 2017 through the deployment of green certificates to electrical providers as well as an energy-efficiency programme. Biofuels are used for transport in addition to low-emitting small cars and an electrical car-pool system. Ardenal also participates in a Clean Development Mechanism with Mwanza, Tanzania. It represents an exemplary case study for the transformation of a city to low-carbon.

Other cities are also undergoing a low-carbon transformation. Liverpool, for instance, is seeking to generate employment through its low-carbon economy (North 2010). High-tech approaches are favoured in such cities in the developed world that are already building their quaternary sector. The 'Green New Deal' is an example of an urban sustainability strategy that is socially inclusive and focusses on investing in public transport and the local production of goods, including food and power generation, as well as retrofitting buildings. In this way, it is possible to maintain a high level of production (and associated consumption) at a low-carbon cost. Transport is key, and emphasis needs to be placed upon reducing travel time and dependence on private vehicles in order to reduce the use of petroleum and polluting GHGs (Dulal et al. 2011). Mobility is relevant for the ageing demographics of developed countries around the world (Han et al. 2012). Conversely, typically young cities (e.g. Hashtgerd New Town in Tehran province, Iran, where over half of the population is less than 26 years, Seelig 2011) is another demographic affecting some developing countries that could have implications for social trends in growing cities and thereby affect global patterns associated with urbanisation. Here, a climate-sensitive urban form has comprised reduced climate control (heating and cooling) and buildings that are culturally adapted and connected to public transport, with integrated energy and water systems, has demonstrated the effectiveness of planned approaches to reduce energy and resource consumption in the adaptability of design.

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Chapter 8
Conclusions

Abstract In this final chapter, the subtopical areas addressed in this brief are revisited, effectively connecting air pollution, urban greening, and energy conservation for low-carbon cities. The UHI effect is approached along with land use in the context of anthropogenic climate warming. As part of the transformation to low-carbon cities, Oxford is presented in the aftermath of the OTS, with an emphasis on transport, traffic pollution, (environmental) health, and urban sustainability.

Keywords Energy conservation · Anthropogenic climate warming · Low-carbon transformation · Post-OTS · Oxford · Transport · Urban sustainability

In this publication, various interrelated subtopical areas addressing air pollution, urban greening (including urban agriculture), and energy conservation have appeared with Oxford serving to integrate and place the discussion. Specifically, the OTS has been addressed throughout this volume, particularly in the first portion up to Chap. 5. Subsequently, these issues (such as urban agriculture, green buildings through the use of climbing plants, and land use, the UHI effect, and global warming were approached from a more general (non-case-study-specific) discussion. This conclusion to the brief revisits the OTS and a general assessment based on its contribution to urban sustainability for Oxford. It also delineates further concluding remarks on the overall subtopical areas, tying the volume together in conclusion.

Oxford is a small-medium-sized city, where traffic has always been a struggle. In part, this was due to its Medieval structure in addition to size. This aspect of Oxford can, however, be viewed positively because of its walkability potential. In its current compact size, it is still possible to navigate the city centre by walking, and many people reside close to work and walk to work on a daily basis. Others, as has been evident in Chap. 3, have been cycling into work, and we do get some serious cyclists in central Oxford. There is some discussion recently about potential in the UK for car-free development (e.g., Melia et al. 2014), and this sits well with Oxford. Some of the reasons for this, in addition to its size and compactness, is its well-established public transport system, including P&R system, and because of its

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historical town centre, which discourages the use of private vehicles in the aftermath of the OTS.

Indeed, the OTS has paved the way for transformation in Oxford. For instance, it was observed in the post-OTS phase that reduced exposure to traffic, in some parts of the city, provided benefits for those living near roadways that experienced reduced traffic after the implementation of the OTS, specifically leading to localised improvements in air quality that led to improved childhood respiratory health found in children who had pre-existing respiratory problems as well as those from less affluent backgrounds (MacNeill et al. 2009). The latter finding may be particularly linked with HGV traffic nearby their place of residence, most notably in the city centre. Nevertheless, according to these authors, it only took a small improvement in peak flow with the advent of the OTS to improve wheezing (respiratory health) at the population level.

In addition to the suggested improvement to respiratory health in humans evident with traffic abatement, it is also feasible to implement urban greening to improve human and environmental health in cities. For instance, in Hong Kong, extensive green roofing has reduced surface temperatures by 5.2 °C with greatest reductions close to the ground (less than 160 cm in height, Jim and Peng 2012). As a passive cooling approach, green roofs have the potential to provide savings in climate control (air conditioning in summer months) as well as represent energy conservation and associated CO_2 reductions. This volume has provided substantiated support for urban greening, including green roofs but also gardens, and more, to mitigate UHIs in cities (urban climate) as well as global climate (global warming), which is increasingly affected through the process of urbanisation. It is known that cities both drive climate change (as part of urban climate and the production of the UHI effect) and are affected by it (Simonis 2011).

A variety of greenery has been recognised to establish urban greening. One substantial form that is well worth maintaining are urban trees. These provide several benefits to the built environment, including socioeconomic as well as visual and aesthetic, ecosystem services, carbon sequestration and improved air quality, stormwater attenuation, and energy conservation (Roy et al. 2012). By comparison, according to the authors, there are few disservices, which include the cost of maintenance, light attenuation, the potential for infrastructure damage (as when strong winds blow or throw trees, causing them to come down), and some health concerns (allergies and possibly asthma). In Nanjing, China, for example, adult Indus trees hold both cooling capacities during the day and insulation properties at night (Zhao et al. 2011). The authors also conveyed that the adult Indus tree had a greater cooling capacity (a steeper temperature gradient) than grassland that was found to be particularly pronounced at 1.5 m above ground. These findings stress the thermal importance of mature trees over grass in regulating urban climate.

Gardens have also been justified in terms of their benefits to cities, where they are increasingly viewed as a luxury (Cameron et al. 2012) due to space constrictions augmented by urbanisation. Nevertheless, as qualified by the authors, they are instrumental in improving air quality in cities as well as for insulating houses (rooftops) and conserving energy; they are known to passively cool cities (counteracting the UHI effect) and mitigate flooding in addition to providing space for wildlife. Most important is their impact on human health and well-being, as observed with improvements to respiratory health nearby previously busy roads that experienced notably reduced traffic in central Oxford. In residential areas, for instance, green areas help to balance carbon-oxygen levels (Aydin and Çukur 2012). So, urban greening is an essential mitigation tool for emissions and also offer a way of improving health, both human and environmental.

As regards linked health, UHIs are known to be mitigated by vegetation (Zhou et al. 2012). As demonstrated by Onishi et al. (2010), for instance, the greening of an individual parking lot can reduce land surface temperature (LST) by as much as 7.26 °C in the summer. Such knowledge can be applied by planners to recommend tree-planting programmes (Sun and Lin 2007), and can be used as a basis to modify urban design as well as landscape policies. Tree protection measures, such as for instance The Woodlands' tree protection policy in Texas, USA (Sung 2013), have helped to lower LSTs between 1.5 and 3.9 °C than other (control) neighbourhoods. High-density urban areas lacking natural cooling, as provided by greening and (large) water bodies (Heusinkveld et al. 2014), are (increasingly) vulnerable to high night-time temperatures (as in Rotterdam, according to the authors) experienced during heat waves (e.g., Rotterdam in July 2006, Toparlar et al. 2015). Vertically built-up cities, such as Hong Kong, roof greening is ineffective for ground-level cooling (Ng et al. 2012), where trees are more effective for cooling at the pedestrian level. These authors also relayed that as much as 33 % of the urban area needs to be tree-planted in order to reduce ground-level temperature by approximately 1 °C. This implies that a maximum cooling effect of 3 °C at ground level is possible approaching a full coverage in Hong Kong, although lower LSTs have been reported elsewhere. In the UK, for instance, the UHI effect can be as high as 7 °C (Smith and Levermore 2008), and a substantial vegetation cover is needed to overcome this phenomenon (with a suggested increase in tree-planting of over 200 % required for the UK). These authors have recommended the use of urban greening as well as use of high-reflectivity materials and openness for wind-cooling in cities. In addition, buildings can be modified through façade greening, improved ventilation, and insulating (including glazing). The authors have also suggested behaviour change by the occupants of buildings, as this affects energy use and conservation.

In opposition to the UHI effect is what Vidrih and Medved (2013) termed the park cooling island (PCI) effect. This is determined by grass cover as well as the density and age of trees in parks. The authors ascertained that leaf area (measured by the coefficient of leaf area, leaf area index or LAI) can be used to normalise the PCI effect. Work by Hardin and Jensen (2007) similarly conveyed the ability of urban leaf area (measured by the LAI) to account for 62 % of the variation in surface temperature determined by simple linear regression, such that in urban/suburban Terre Haute, Indiana, USA every unit increase in the LAI corresponds with a surface temperature reduction of 1.2 °C. Other research has denoted the importance of green areas as well as vegetation type influencing the cooling effect of vegetation (Perini and Magliocco 2014). These authors attested to the effectiveness of vegetation at higher temperatures (as with heat waves) as well as in circumstances where there is a lower relative humidity. Cooling and humidifying effects due to plants (specifically for small-scale plant communities) have been observed to be the greatest in summertime, then autumn, spring, and the least in winter (Zhang et al. 2013). Temperatures reductions in this study for urban parks in Shenzhen City, China ranged between 2.14 and 5.15 °C, with relative humidity increasing between 6.21 and 8.30 %, and with the effects being most pronounced between 1400 and 1500 hours in this subtropical climate.

Leaf surface area is of course affected by attributes of the types of trees (and climatic zones) as well as their age and density-planting (as mentioned by Vidrih and Medved 2013 as regards the PCI effect). Road widening in Bangalore, India, for example, is removing older trees, which were planted using a greater diversity of species in the past compared with the less diverse species planted today (Nagendra and Gopal 2010). The authors have described the newer trees as small statured (since small-sized tree species are used) and as having narrower canopies than those felled. These replacement street trees are less capable of dealing with the environmental problems associated with pollution (including the absorption of GHGs, and carbon sequestration, and the mitigation of the UHI effects) and other urban issues associated with reduced vegetative effects, such as soil stability and runoff control. In addition to such considerations of the types of new trees planted in urban areas, attention is needed to address the effects of the growth medium (urban soils). Rahman et al. (2011), for instance, examined rooting conditions for trees in Amsterdam, where *Pyrus calleryana* are able to establish better in soil rather than pavements, causing them to grow twice as fast in the former medium. The reasons they provided for this are associated primarily with soil compaction affecting soil attributes, such as moisture content (reduced at 20 cm) impounded by soil structure and infiltration capacity. Consequently, trees grown in a soil substrate provided a peak evapotranspiration cooling of 5 times more than those grown in pavements.

The cooling effect of vegetation is reduced under drought conditions and this should be considered within the context of global warming for those places most likely to be affected by drought, such as some African countries and arid areas around the world. Gill et al. (2013), for instance, pointed out that summer droughts dry out soils and thereby reduce cooling. They suggested that this can be counteracted by planting grass that can be adequately irrigated by large rainfall events, as in Manchester, UK. Research by Armson et al. (2012) suggests that both a grass and tree cover is capable of surface cooling and are effective at regional cooling, with reductions of up to 5–7 °C in global surface temperatures provided by shading, which provides effective local cooling. Because of their shading, trees are favoured in protection plans, such as those encompassing the maintenance of large old trees and species diversity in urban forests within the American Midwest (Schmitt-Harsh et al. 2013), protecting species dominance as well as species-specific size distribution. Similarly, Canadian urban forests are an effective CO_2 sink, with an estimated tree canopy cover (based on remotely sensed data) of 27 % in urban areas that is capable of storing some 34,000 kt of carbon and sequestering 2500 kt of CO_2 each year (Pasher et al. 2014). By comparison, a study performed in Shenyang, China (based on field-survey data) showed that carbon stored in its urban forests was 3.02 % of annual carbon emissions from the combustion of fossil fuels (stored 337,000 t of carbon), so that carbon storage and sequestration could offset its annual emissions of carbon by 0.26 % (Liu and Li 2012). This rate of carbon storage and sequestration, however, depended on types and species composition as well as age structure of urban forests. Other authors (e.g., Ward and Johnson 2007), have incorporated spatial analysis methods (e.g., geographic information systems or GIS, global positioning systems or GPS, and remote sensing) as part of their geospatial toolkit used to investigate the attributes of urban forests, including land cover, structure, species composition, condition, carbon storage, and their contingent impacts, as UHI effects.

The reduction of pollutants, including GHGs, requires that human behaviour is modified in order to either produce fewer emissions (behavioural change, which is a social strategy addressed in this volume) or technological innovation (for technical solutions, which can be costly and, therefore, unrealistic for poor countries). To-date, work has focussed on technological fixes (improvements in transport technologies, Schwanen et al. 2011), as well as behavioural change, and so on. Technological improvements on their own cannot resolve all problems, such as the problem of congestion (Bannister 1997). For this reason, public transport offers an opportunity to affect massive change, while reaching people from various socioeconomic backgrounds. Its importance has been demonstrated in the case of the São Paulo subway, which closed due to striking and caused a subsequent (linked) increase in the concentrations of air pollution and increased mortality (da Silva et al. 2012). The socioeconomic and environmental function of public transport is obvious in this case study, with impacts on both human and environmental health.

Bus-based P&R schemes intercept cars on the urban fringe and have been found to avoid traffic in most cases (e.g., seven out of eight cases, Parkhurst 2000), but detouring may be required as well as switching services and making additional trips. This author found, for instance, that although traffic was avoided within urban areas using this transport system, the amount of traffic produced outside urban areas was greater, so that the main effect of such schemes was traffic redistribution. These findings suggest that bus-based P&R schemes do not reduce overall traffic congestion (as they only redistribute traffic), and so their effectiveness in traffic abatement schemes is questionable. Such research has found that P&R in Oxford and York (Parkhurst 1995), for instance, because they involved switching and additional trips, caused congestion to persist in these cities and perhaps even increased total travel. Travel behaviour is also changing, as portrayed through car-share programmes that are taken up by people who (for various reasons) have opted to give up their cars (Chatterjee et al. 2013). This strategy can effectively reduce the number of private vehicles on the road, which was a problem in central Oxford and one of the reasons for the implementation of the OTS. For Oxford, the county of Oxfordshire was also involved with the city of Oxford in the discussions and orchestration of the scheme, and such wider spatial planning (than the local) is needed in order to work towards more holistic management of vehicular emissions

(Olowoporoku et al. 2012). Local authorities, for instance, are known to prefer alternatives to P&R (Parkhurst and Richardson 2002).

Besides environmental impacts, there are also social consequences of mobility. For instance, the elderly living in villages and towns in the countryside in southwest England and Wales, and elsewhere in the UK and the world, can become excluded if unable to attend community events (even if only a short distance away) in a car-dependent system of mobility. Such mobility-related exclusion is particularly prevalent in rural areas (Shergold and Parkhurst 2012), where there is limited public transport and more reliance on private vehicles. Formalised lift-giving has been suggested by the authors. Such strategies reduce the number of (private) vehicles on the road, and can thereby reduce traffic congestion. However, they are not popular everywhere, as in Oxford, where the new car-pooling initiative is not utilised as frequently as public transport, probably due to reasons of safety. Parkhurst (2003a) cautioned about developing P&R schemes at the cost of investing in public transport. Initiatives, such as free bus passes for the elderly (Andrews et al. 2012) could provide an alternative solution for improving elderly mobility issues. Because they may not drive, the elderly tend to support road charging (Nikitas et al. 2011), and this has been attributed to prosocial attitudes. Other alternatives for mobility include cycling and rail use. In some cases these have gone hand-in-hand, with rail-users cycling into stations as part of bike-rail integration (relatively recent rate of 2 % in Britain contrasted with 40 % in the Netherlands, Sherwin et al. 2011) either storing their cycles at the rail station or using portable cycles to take with them on train coaches.

Encouraging pedestrianisation is also an effective traffic abatement strategy, and one that is often left for last and not really rigorously considered in the literature. An important part of the OTS was pedestrianisation, which, together with traffic restraint, managed to reduce 17 % of car trips to the city centre (Parkhurst 2003b). The author denoted also that bicycling was another highlight of the OTS, with 10 % of trips to the centre being made by cycle. Parkhurst (2003b) noted the lack of information about pedestrianisation since the implementation of the OTS in June 1999. He suspected that there was an increase in people walking to the city centre, but qualified this with there being insufficient annual data for a reliable quantification, and this is deserving of more attention. His conclusions regarding air pollution conveyed a small improvement in air quality and accidents; also, some redistribution of pollutants occurred associated with changes in bus routes and delivery vehicle traffic. The scheme has led to a reduced level of asthma among children, as indicated by 12 % lower numbers of emergency cardiovascular admissions to hospitals (Parkhurst 2003b). Finally, according to him, the local culture of public transport use that was already prevalent in Oxford before the advent of the OTS certainly lubricated the successes evident after its implementation. Moreover, the OTS acted to reinforce bus use, promoting bus use and the P&R system so that levels returned to those not seen since the 1960s–1970s (Parkhurst and Dudley 2004).

The proportions (in traffic reduction) that indicate success vary according to city. Los Angeles, for instance, which is highly dependent on motor-vehicle traffic, needs to shift automobile to transit riders by 20–30 % in order to reduce its transport-related GHGs sufficiently in order to achieve its urban sustainability goals (Chester et al. 2013). Shifting to public transport makes sense because this mode of transport is known to be (as in Toronto, Canada, Kennedy 2002) less energy intensive and releases less CO_2 (an order of magnitude lower). According to Kennedy (2002), for any transportation system to be sustainable, it needs to be flexible and adaptable, and suggests combining a mixture of modes, such as integrating bicycles and public transport or the construction of a light-rail system. Air pollution and GHGs remain among several environmental issues that affect cities around the world, including Chinese cities (Wang 2011).

In the UK, there has been a focus on sustainable transport policy, leading to innovations like P&R, which was arguably linked with increased regulatory measures following the 2008 European Commission directed to improve local air quality (Dijk et al. 2013). Restricting the use of private vehicles, in Oxford and elsewhere, including in many large cities, is an instrumental approach to achieving regional air quality targets (Goddard 1999). This author conveys that such a control policy could effectively impact this (air quality) and other environmental issues, such as traffic congestion and suburban development in cities, which is often limited by private vehicle ownership; so that there are larger ramifications of using a control policy to promote urban sustainability. Railway transport represents an effective mode of transport, as in some Italian cities, where such networks have improved accessibility while reducing traffic congestion and pollution (Conticelli 2011). The author additionally espoused how railway transport networks are capable of contributing towards urban regeneration, as is apparent in two Italian rail station redevelopments at Bologna and Reggio-Emilia HST stations. As denoted by Banister (1997), the road to urban sustainability via transport systems is to implement clean public transport while promoting behavioural change (walking and cycling) in order to reduce car-dependence.

Many environmental urban problems are linked and can be approached from a systems dynamics perspective (Armah et al. 2010). These authors examined, as for Accra, Ghana, how problems associated with urban planning include land-use planning in conjunction with traffic congestion and safety and pollution, posing health risks. The link between energy consumption, traffic emissions, land use, and traffic management have been explored by others from a green transport and urban sustainability integrative framework (e.g., Wei et al. 2012). Cities comprise interacting biophysical and socioeconomic components that exert environmental pressure on the system (Alberti and Susskind 1996). For this reason, it is necessary to approach the urban system from an integrated systems approach that considers both physical and social problems, which are often interlinked. This brief has shown how the OTS represented a complex problem in urban sustainability that was tackled from an environmental-human perspective. By impacting human behaviour (promoting bussing, cycling, and walking over the use of the private vehicle), it was possible to stimulate social change in order to clean up the local environment. This approach can be applied at a regional to national, and even perhaps international level, to make cities less car-dependent and more environmentally friendly places.

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