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Urban energy, carbon management (low carbon cities) and co-benefits for human health

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In the past decade, there has been growing evidence that activities to mitigate climate change can have beneficial impacts on public health as a result of changes to environmental pollutants and health-related behaviours. Urban settlements provide particular opportunities to help achieve reductions in greenhouse gas emissions and thus associated health benefits. Energy efficiency improvements in housing can help protect against the adverse health effects of low and high temperatures and outdoor air pollution; transport interventions, especially ones that entail increased walking and cycling, can help improve physical activity and the urban environment; and switching to low carbon fuels to generate electricity can reduce air pollution-related health burdens. However, interventions need to be carefully designed and implemented to maximize health benefits and minimize potential adverse health risks.

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Introduction

This paper considers the issue of energy consumption by urban populations, the need and opportunities for decarbonization, and the likely implications for health of strategies aimed at reducing carbon dioxide and other greenhouse gas (GHG) emissions. The focus on urban settings is motivated by the projected growth of urban populations both in absolute terms and as a proportion of total world population, especially in low and middle income countries, coupled with the potentially large contribution of urban populations to energy consumption and GHG emissions to the atmosphere. Although definitions vary of what constitutes urban populations, estimates by the Population Division of the United Nations Department of Economic and Social Affairs suggest that by 2008 half of the world's population lived in urban areas, and that this proportion may rise to 67% by 2050 [1]. The scale and pace of urbanization are especially remarkable in Asia [2].

The context of climate change is now widely appreciated. The necessary trajectory of abatement is extremely challenging [3]: a rapid reversal of the current upward trend in GHG emissions, and an eventual halving of *global* GHG emissions by midcentury, with (under the principle of convergence to an equitable global *per capita* average) much larger reduction of 80–90% in high-income countries [4]. This can only be achieved by major changes in all sectors of the economy.

Until recent years, arguments for climate change mitigation were largely based on the need to avoid adverse environmental, social and economic consequences. However, there is now growing realization that there may be impacts on health, and that these impacts may not only lie in the avoidance of the largely deferred and uncertain climate change-related impacts, but also in more immediate, local impacts relating to changes in environmental pollutants and health behaviours that many decarbonizing measures would entail. It is these ancillary impacts on health of GHG mitigation, sometimes referred to as the 'health co-benefits', that are the focus of this review. While the term co-benefit is widely used, it should be noted that the consequences of decarbonization, though generally beneficial to health, are not always so. A more accurate but less attractive term would be simply 'health impact'.

The literature in this area is inchoate and largely confined to publications of the last 10 years, but growing rapidly. This paper presents a summary of the co-benefit debate, and some of the emerging issues for policy.

Urban energy and carbon management

Consideration of the large environmental footprint of cities might suggest a disproportionate impact in terms of energy use and GHG emissions. Indeed previously reported figures [5] suggest that as much as 80% of global energy use may be linked to cities. However, it is impossible to make precise statements about the contribution of cities to global GHG emissions because, as the UN Habitat report notes, "There is no globally accepted definition of an *urban area* or *city*, and there are no globally accepted standards for recording emissions from sub-national areas.''[6] Moreover, the calculation depends on framing with respect to responsibility for the production or consumption of energy. Accounting for where emissions are produced would suggest that cities account for 30–40% of global anthropogenic GHG emissions [2], considerably less than a proportionate contribution would suggest, while a consumption-based calculation indicates a figure of 40–70% [7]. Dodman suggests that urban *per capita* emissions are substantially *lower* than the average *per capita* emissions for the countries in which they are located [8•]. However, he also notes that there are particular reasons to address GHG abatement at the urban scale, including benefits to health [8•,9].

The opportunities for decarbonization in any urban environment are multiple and complex. Substantial reductions will require the combination of technological development, infrastructure investments and behavioural change. The mechanisms for achieving such change will require the full panoply of economic, legislative and educational initiatives. Though often cited as a key route to reducing energy use, it should be noted that energy efficiency often leads to *more* not less energy consumption [10] largely because of the rebound effect that operates both at the macro-economic level [11] and in terms of the decisions made by individual bodies and households [12,13]. Countless examples might be cited: the efficiency of the car engine, air travel, street lighting, all of which have grown exponentially as efficiency (and hence affordability) has improved [10]. It is true that richer economies, on the whole, achieve greater economic output per unit of greenhouse gas emissions (lower carbon intensity) [14], but despite this the single most important determinant of CO_2 emissions is wealth [15]. This is true among individuals and at country-level (see for example country-level plots of CO_2 emissions vs *per capita* Gross Domestic Product available from Gapminder world: www.bit.ly/tAXAv0). This relationship emphasises the essential need to decarbonize energy sources.

Beyond meeting the targets of climate change mitigation, there are additional motivations to seek decarbonization and the diversification of energy sources away from dependence on fossil fuels, including concerns relating to the consequences of 'peak oil' [16–19], and the need to ensure energy security both at country level and for individual households. Recognition of the potential gains to health and of improved quality of life is, for many, a compelling argument that adds powerful weight to the case for carbon reduction.

Decarbonization and impact on public health

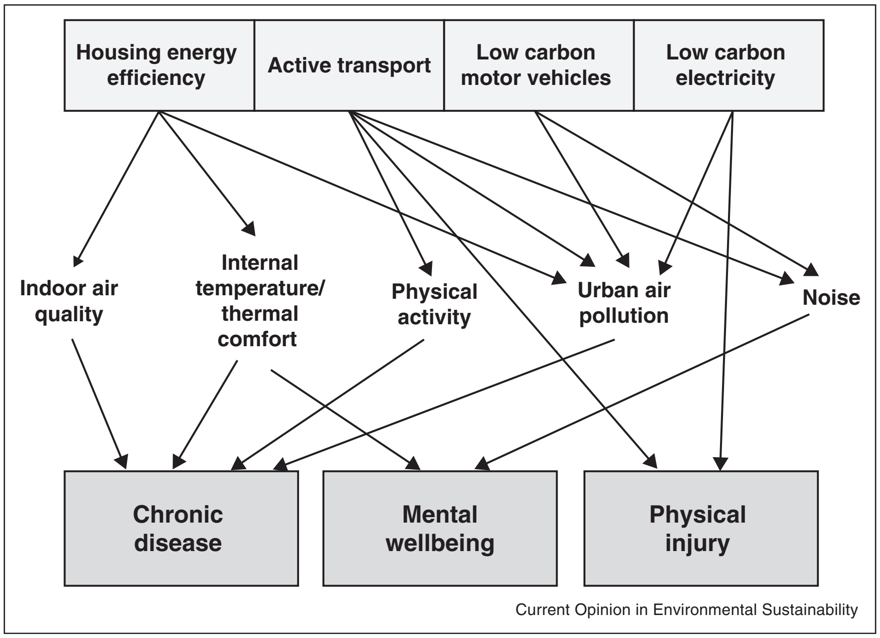
Many decarbonization measures are not specific to urban environments but could apply in any setting. Cities do, however, offer particular opportunities for decarbonization in such areas as mass transit, waste-to-energy generation and systems for co-generation of power and use of 'waste' heat. Although primarily used for climate change adaptation purposes, there are also opportunities for mitigation and health benefits in the continued development of biophylic cities (for instance, via reduced indoor summer temperatures without the need for air conditioning [20]). It is impossible to provide a comprehensive account of all options for GHG reduction strategies, and the multiple pathways by which they may influence health. Further, opportunities for decarbonization exist in sectors that are not specific to urban areas, for example within food production and agriculture. The sections below outline some key points of principle in relation to three important urban sectors (Figure 1). Current evidence is strongest and most consistent for physical rather than mental health impacts and the majority of research to date has focused on high income settings. As such, this summary will focus largely on these areas.

Built environment, housing

In the built environment, urban planning and the performance and use of buildings are both relevant to GHG reduction. Urban structure and land-use also influence the urban heat island (UHI) effect – the phenomenon by which metropolitan areas experience higher outdoor temperatures than surrounding rural areas because of heat retention and anthropogenic heat emissions associated with urban development [21]. During periods of summer heat, the UHI may both increase energy demand for cooling, and exacerbate heat risks to health [22–25]. In theory, land use changes designed to reduce the UHI effect, such as increasing green space, could therefore have beneficial effects on both, but there are obvious practical constraints on the degree of achievable land use change in most cities. In addition, the potential winter benefits of the UHI for reduced heating demand and exposure to cold may be diminished. From a health perspective it may be more cost-effective to concentrate on the adaptation of buildings to reduce exposure to heat in the *indoor* environment [26] even if this conflicts with energy goals (for example through provision of air conditioning).

Potentially much greater impact on health is achievable through energy efficiency improvements to housing [27••]. Energy efficiency of dwellings (both new-build and refurbishments) depends on the thermal transmission characteristics of the building fabric (the insulation levels of its walls, floors and roof), the control of ventilation, and the efficiency of heating and other energy-consuming devices used within the home, possibly coupled with the on-site capture of energy (solar, wind, ground or air source heat). Improving energy efficiency can affect health directly by influencing indoor temperatures, indoor air quality, the use and cost of energy (with indirect effects on choices for low income families),

Figure 1



Key pathways to health of relevance to climate change mitigation in urban areas.

and the emission of toxic pollutants to the local environment. One of the major benefits in temperate climates is likely to be protection against cold-related morbidity and mortality in winter, although there is remarkably little direct empirical evidence about such impacts. However, there are good theoretical reasons and some indirect epidemiological evidence to suggest that well insulated homes are not only warmer [28], but carry a lower risk of adverse health effects [29–31] and improve mental and psycho-social well-being [32,33]. They may also help to reduce indoor temperatures during periods of outdoor heat, although there is potential to exacerbate the risk of overheating [34•].

Control of ventilation in an attempt to reduce energy demand generally reduces the flow of air from the outdoor environment to the inside, which has the advantage of protecting against exposure to outdoor pollutants, particularly fine particulate matter and ozone. However, reduced air exchange also has potential to increase the concentrations in the indoor air of pollutants derived from indoor sources (such as particles, nitrogen dioxide, carbon monoxide, radon, second-hand tobacco smoke, and volatile organic compounds), for which levels can already be greater indoors than outdoors in some circumstances [35,36]. Reduced ventilation may also have adverse effects on mould growth though warmer temperatures from improved energy efficiency will offset this to some extent [37]. Whether tighter control of ventilation leads to net health benefits depends on the nature of the ventilation system, the local outdoor environment, the relative toxicity of particles of indoor and outdoor origin, and occupant behaviour [38]. A 2009 analysis of the effect of energy efficiency improvements to the UK housing stock of the type and scale required to meet 2030 climate change mitigation targets suggested overall benefits to health [27••] – benefits which could be further maximized through judicious selection of intervention measures such as mechanical ventilation and heat recovery (MVHR) systems with particle filtering. If however, such systems are not installed, operated and maintained correctly then there is the potential for health *disbenefits*.

In low-income settings where occupants are often exposed to extremely high concentrations of combustion-related pollutants from the inefficient and poorly-ventilated burning of biomass, the potential for health gain is large given growing evidence on the adverse effects of such exposure on a range of health outcomes, including chronic obstructive pulmonary disease and ischaemic heart disease in adults and respiratory illness in children [27••,39,40•,41]. In such settings, widespread deployment of inexpensive improved cook stoves can reduce particle exposures substantially and help to achieve major public health gains while also partly reducing (mainly short-lived) GHG emissions [27••].

Improving energy efficiency can also help address fuel poverty [42], which may have (as yet largely un-quantified) effects on health not only because fuel poor households may not heat their homes adequately, but also because of impacts on the budgets of low income families.

What is more complex to evaluate is the effect of switching to more renewable sources where that also increases energy costs. The impact depends on the balance of household energy need (reduced by energy efficiency), the unit cost of energy, household income and behavioural factors.

Transportation

The main strategies for decarbonizing the transport sector are switching to renewable fuel sources (electric cars, hydrogen fuel cells) and/or reducing motor vehicle travel by reducing the need for journeys, increasing provision of public transportation or by encouraging active transport (walking and cycling) in substitution for car journeys. Both sets of strategies, but especially those that entail increased physical activity, would be expected to have appreciable and largely positive population health impacts [43,44]. The complex pathways by which transport strategies may affect health are broadly understood, and the World Health Organization has developed a useful assessment tool [45].

Fuel switching reduces emissions of toxic pollutants to the urban environment and thus has an impact on air quality, with population wide benefits (to mainly cardiorespiratory health [46]). However, the source of the energy for the alternative fuels is critically important since little climate change mitigation will be achieved if these are based on combustion of fossil fuels. Measures that help to reduce methane (a precursor of tropospheric ozone formation) and black carbon emissions (notably emitted from diesel engines), may be especially effective in both climate change mitigation and public health impact [47•,48]. However, fuel switching has few impacts on other health outcomes except perhaps those related to noise pollution [49••]: electric vehicles are quieter, so their introduction would help reduce background levels of noise and related health impacts on, for example, cardiovascular disease [50] and sleep disturbance [51]. The overall level of health benefits from fuel switching may be substantial where there is a high level of substitution of conventional petroleum fuels, but modelling studies suggest they would be modest by comparison with strategies that promote active transport [49,52••].

Regular walking or cycling in place of motor transport, through their effect on physical activity and personal energy balance, have potential for comparatively large benefits to health with extensive epidemiological evidence on the link between physical activity and a range of chronic diseases (cardiovascular disease, cancer risks, dementia), mental well-being and weight-related conditions (especially diabetes mellitus) [45,49••]. Increased active travel and more walkable urban environments are also likely to result in large benefits to employment productivity, with additional associated health benefits [53]. Risk assessment models suggest substantial health gains if large population uptake of walking and cycling can be achieved [52••,54,55•]. However, as yet there is only limited empirical evidence that active transport is associated with overall greater levels of physical activity and weight reduction [56••], though there are favourable correlations at population level [57,58]. Moreover, the physical activity benefits may also depend on who switches to walking and cycling, and there is potential risk of increased road injury without additional protection measures such as the physical segregation of pedestrians and cyclists from vehicular traffic [52••,54]. Reassuringly, however, under reasonable assumptions, the benefits of increased physical activity from cycling appear to be substantially larger than the adverse effects associated with road injury or inhaled air pollution because of physical activity [59]. Reduced prioritization of motor transport can also have a role in improving community coherence.

Bringing about substantial shift in transport behaviour will often entail significant infrastructure investment and carry implications for land use planning [60]. There is, for example, evidence that high density cities have lower transportation-related energy consumption and CO_2e emissions, [61] and more compact cities may be important for achieving high levels of walking and cycling.

Electricity generation

Electricity generation is not specifically an urban issue but renewable generation is crucial for meeting GHG reduction targets. There have been multiple studies examining the potential health effects of switching from fossil fuels to low carbon alternatives [62–81]. Quantitatively the largest direct ancillary health effects of mitigation occur through reductions in ambient air pollution, and change in occupational injuries relating to the fuel cycle [82]. Studies reviewed in the IPCC Fourth Assessment report [64] show that moderate CO_2 reductions (10–20%) in the next 10–20 years also reduce sulphur dioxide (SO_2) emissions by 10–20%, and nitrogen oxides (NO_X) and particle emissions by 5–10%. Depending, among other things, on the population exposed in the targeted sectors and its vulnerability, this can lead to appreciable population reduction in years of life lost.

Distributed power generation through multiple microgeneration facilities is expected to play an increasingly important role in electricity generation in the future [83]. If low carbon/renewable methods are not implemented, an important debate for urban environments relates to the potential for additional local emissions of air pollutants. Whether this leads to an overall increase in exposure to air pollution depends on complex interactions involving the relative locations of facilities and local populations, atmospheric chemistry, meteorology and pollution transport [84]. However, there is the potential for adverse impacts if distributed systems are widely implemented in densely population urban areas [85]. Changing to more efficient systems (e.g. increased use of cogeneration systems instead of only electricity systems) has the potential for improved fuel efficiency and reduced GHG and pollutant emissions [86].

Conclusions

Urban environments are a vital focus for activities to help reduce GHG emissions. Major changes are required in all sectors of the economy but these changes offer the opportunity for interventions that benefit public health. There is growing recognition that climate change mitigation measures in the built environment, transport sector, power generation, and other areas can have appreciable, largely positive, current and near-future impacts on population health. As Haines and colleagues note, "these ancillary effects are important not only because they can provide an additional rationale to pursue mitigation strategies, but also because progress has been slow to address international health priorities… Mitigation measures can thus offer an opportunity not only to reduce the risks of climate change but also, if well chosen and implemented, to deliver [substantial] improvements in health."[87••].

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This paper provides an overview of a series of papers on the potential health benefits of tackling climate change.