Fifty shades of green, or why and how we should live in a luxuriant urban oasis

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Abstract

Many people believe that increasing the amount of foliage, trees and soft landscaping in our cities would prove useful environmentally, economically and socially. A whole host of specific benefits of green urban environments have been proposed, including urban heat island mitigation, stormwater management, air pollution reduction, enriched biodiversity, improved ecosystem services, and food production. It has been argued that using natural infrastructure is a less complex route to these ends than the standard approaches.

This paper outlines a critical appraisal of the science and reasoning behind these cited benefits of greening cities. It is an initial skirmish with the issues, to begin the process of understanding which of them really work, to what extent, and how they might be applied in urban environments.

Keywords cities, health, green infrastructure, plants, energy

1 Introduction

Most buildings rely on infrastructure networks to provide them and their occupants with essential services such as energy, water and food. Incorporating more foliage, trees and soft landscaping within these networks (including their buildings) could reduce the complexity of overall urban systems whilst maintaining or improving their functions, now and in the future. This would be positive in terms of both quality of the urban environment and efficiency of resource use.

This paper describes a critical overview of the science and reasoning behind a number of benefits of deploying green infrastructure. The list of issues appraised is by no means exhaustive, and the paper only considers the potential positive impacts of green infrastructure. Some interventions may be double sided: for example, the urban heat island we seek to mitigate may in fact be beneficial in the cold winter months, reducing heat loads and lessening risk of icy roads. This was not analysed as part of this research.

Firstly, existing literature was reviewed; and where mechanisms seemed viable, further analyses were carried out to examine these at differing scales. In places the approaches taken are necessarily crude: the idea was to attempt to give a quantified, unbiased overview of green infrastructure's usefulness.

The particular mechanisms examined are urban heat island mitigation, stormwater management, air pollution reduction, biofuel production, acoustic attenuation, and food production. These could prove very useful: cooler cities would have a reduced requirement for mechanical cooling systems; air scrubbed clean by vegetation would improve air quality; and city scale deployment of water retaining green infrastructure would reduce requirement for expensive sewer systems.

We have approached the issues from a designer's point of view; attempting to answer the question "what are the green city designs that produce meaningful city scale benefits?". As previously stated, due to the brevity of this paper the analyses carried out and the conclusions reached are necessarily crude. One might view the work as a back-of-envelope type analyses for a collection of green infrastructure aspects. Nevertheless, it is felt that the work is certainly valuable. The authors have not found other comparable works.

2 Context

Many organisations have been pushing for increased, integrated greenery in the built environment: the London Plan[1] includes policy to 'promote, expand and manage the extent and quality of, and access to, London's network of green infrastructure' to secure benefits including biodiversity, food production, mitigation of/adaptation to climate change, water management, and health and well-being. The Environment Agency wants 'green roofs to be a mainstream technology within new developments in London'[2], and The Borough of Camden planning guidance states that they 'encourage food to be grown wherever possible and suitable'[3].

But what is the design of a really green city? The topic is vast, and spans multiple fields. There are many studies discussing the scope of benefits of enhanced urban greenery[4,5], as well as much research into specific areas such as PM10 air pollutant capture by coniferous trees[6]. However, from a designer's point of view, information relating to useful applications of urban greenery to yield meaningful, city scale environmental benefits is arguably less available.

In a report for the City of London Corporation, BOP undertook a meta-analysis of the benefits of green cities[5]. This looked at existing literature, and examined which green benefits are likely to be occurring, and to whom. Their conclusions are shown in Table 1. Note: 'City of London Portfolio' refers to the densely urbanised London borough "The City" and some large green spaces, not the whole of London.

	Evidence		**Impact**			
	Large spaces	**Small spaces**	**CoL R&W**	**CoL Bus.**	**London R&W**	**London Bus.**
Air cooling	✓✓✓				✓✓✓	
Reducing rainwater runoff	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
Pollutant absorption	✓✓	✓✓	✓✓		✓✓	
Carbon capture	✓	✓	✓		✓	
Supporting biodiversity	✓				✓	

Table 1 - Environmental benefits and mechanisms linked to the City of London portfolio, from BOP report into the benefits of green cities[5]
Key: CoL = City of London, R&W = residents and workers, Bus. = business

So, in order to yield the reported benefits, how much green is required, in which locations, and of what types? The aim of this paper is to attempt (however crudely) to pull together the analysis of several potential benefits, and state, in a quantified way, that doing 'X' results in meaningful benefit 'Y'.
London, UK has generally been used in the research and analysis. This was mainly because the authors of this paper live there, and there is a reasonable amount of relevant writing and data available.

Greater London is already a very green city: about 40-50% of its land by surface area is green open space of some kind, in the form of parks, private gardens, or railway line sidings[7]. Figure 1 shows how this compares to some other major world cities.

Estimates for the total (public and private) green space have been made using UK government Generalised Land Use Database data[8] and the assumptions that 60% of private garden area is green and 20% of “other” spaces are green. The analysis, described graphically in Figure 2, showed that the least green borough is the City of London with about 7% green coverage. A typical inner London borough (for example Islington or Lambeth) has about 30% green cover.

The extent of green space reported within a city can vary, depending on where one draws the urban boundary and which part of a city one looks at: when zoomed right in the cover could be anything from 0-100%. Fuller et al.[9] report that the average green space coverage of a sample of 386 European cities was 19%. Figure 1 gives an indication of green space cover in different cities of the world. However, this does not include private gardens, which in London for example provide approximately an additional 10%[5].

London’s climate is temperate; it has a summer (July) average peak temperature of 23°C and a winter (February) average low temperature of 3°C. The 0.4% percentile coldest hourly temperature is -0.4°C and the 99.6% percentile hottest hourly temperature is 27°C (not including urban heat island effect). Winter building heating loads are generally much higher than summer cooling loads. London experiences an average of 4 sunshine hours per day and 600mm of rainfall per year[10].

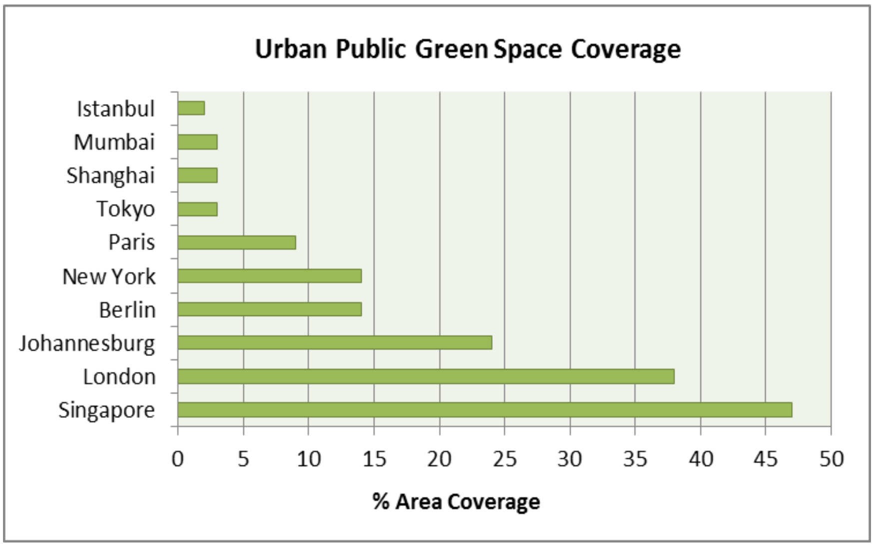


Figure 1 - Urban public green space coverage. Not including private gardens. Data from the World Cities Culture Forum.

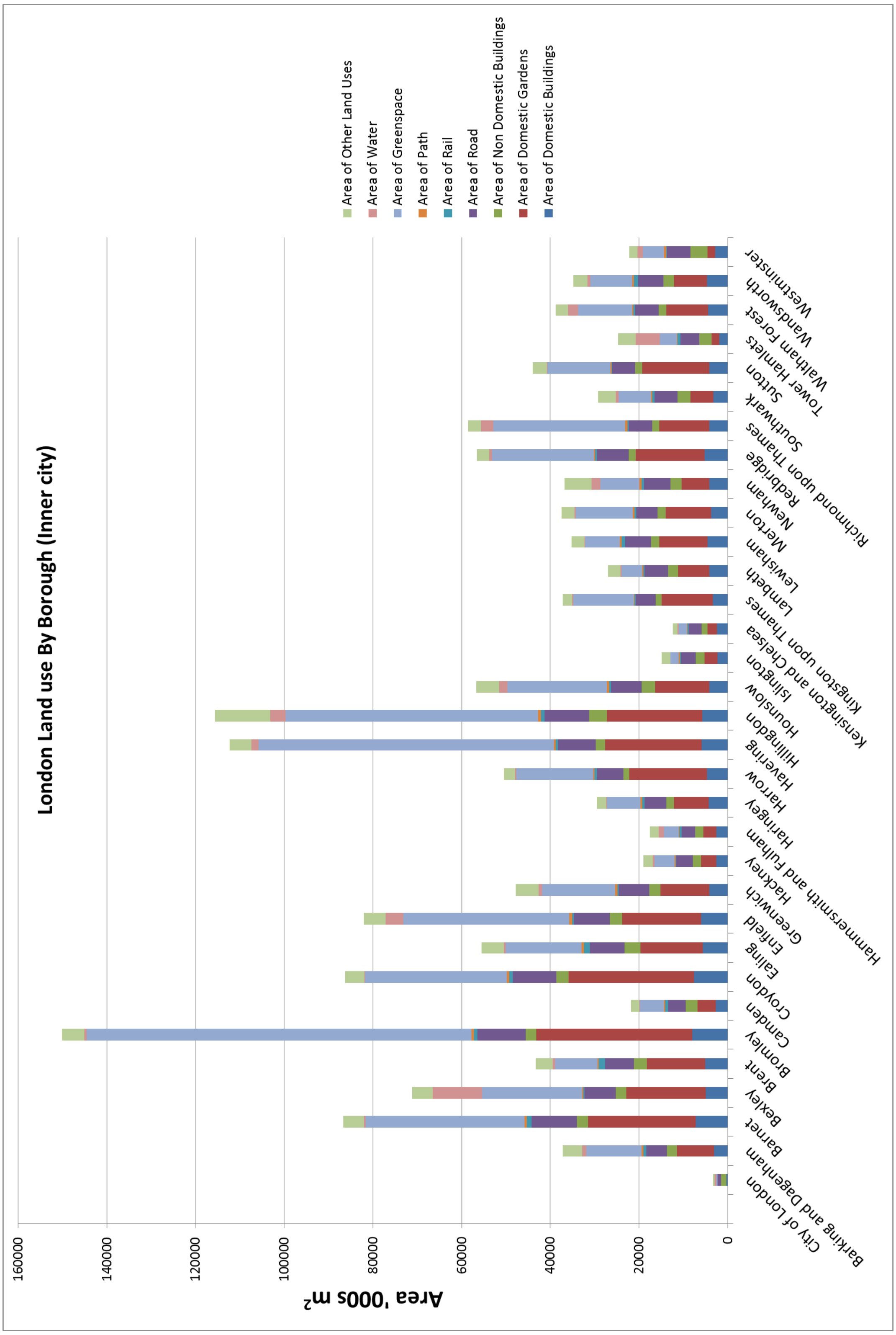


Figure 2 - London borough land uses. Data from the Generalised Land Use Database. Published by Office for National Statistics.

3 Findings

In this section of the report, the findings of the research and analysis are described. A concluding section follows, in which all the different strands are brought together.

3.1 Urban heat island mitigation

The concrete, tile and asphalt materials that comprise urban fabric, along with the concentration of domestic and industrial heat use within cities, can cause urban temperatures to be several degrees hotter than adjacent countryside. This is known as the urban heat island (UHI). Figure 3 shows an illustration of a number of the mechanisms which cause the phenomenon, as described by Oke in 1982[11].

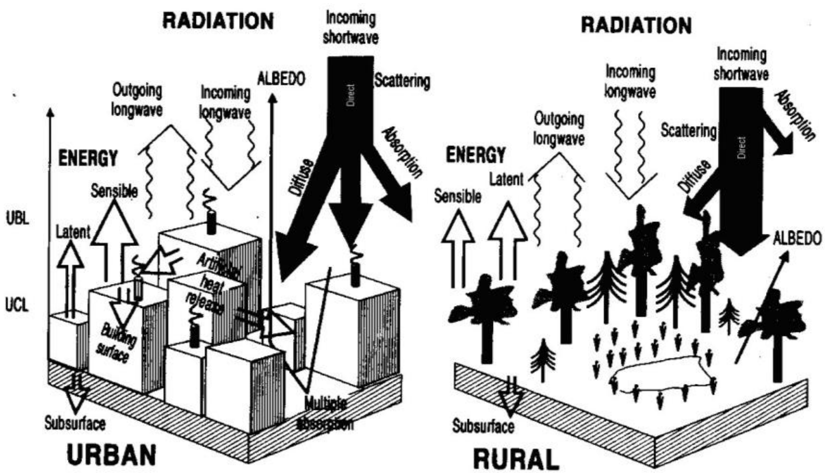


Figure 3 – Physical mechanisms of the UHI, from Oke[11]

A number of studies have been undertaken into the UHI in the London area, including work by Watkins et al[13] and Mavrogianni et al[14]. Figure 4 shows some work by the GLA showing the temperature difference between central London and its surrounding countryside to be around 6°C.

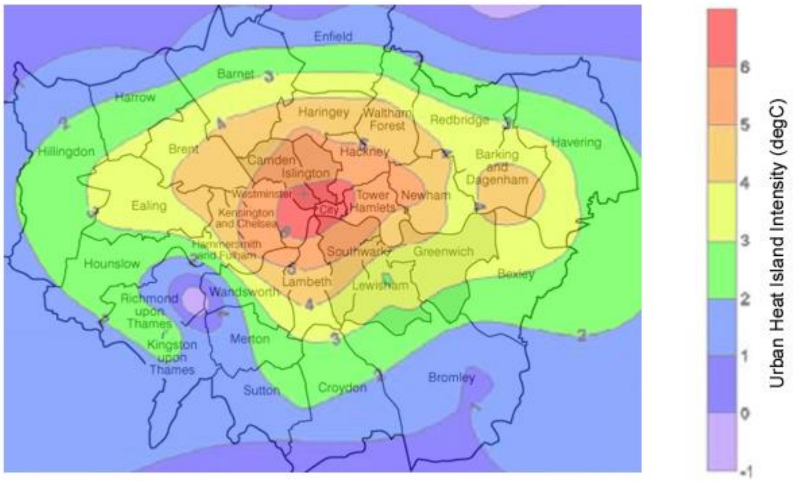


Figure 4 - London Urban heat island intensity map generated from measurements at 6 sites during the summer of 2000. Data and graphic adapted from GLA report [b]

Potential problems of the UHI include a higher risk of discomfort both inside and outdoors, and associated adverse effects on health; an increase in the prevalence of and energy use for cooling systems[15]. If urban temperatures rise further due to the UHI effect and/or climate change, these problems would be exacerbated.

Enhanced urban greenery can contribute to reducing UHI effects by a) shading surfaces and b) evapotranspiration from vegetation and soils to keep surfaces and media cool relative to their non-green counterparts. These effects are well documented: surface temperatures within a green space may be 20°C lower than that of the surrounding urban area, giving rise to 2–8°C cooler air temperatures and a cooling effect that extends out to the surrounding areas[16].

For many cities, London included, it would be beneficial to use this effect so that future city temperatures are no hotter than they are now. As a result, it would be likely that natural ventilation, the simplest form of ventilation and cooling (which most London buildings currently use) would remain adequate, subject to other constraints such as air quality, noise, and security.

STAR (surface temperature and runoff) tool by The Mersey Forest and The University of Manchester[17,18], a computer modelling technique, was used to examine the potential for urban cooling by enhanced green space under future climate scenarios.

This model outputs a single figure peak (in time), average (in space) surface temperature of the area analysed, which was used as an indicator of the “hotness” of the city. The model is based on an energy balance of incoming solar radiation, convection, evaporation, conduction into soil and thermal storage in building mass. It does not take into account warm or cool winds that may be blowing, shading of surfaces by vegetation, rainfall or variable wind speeds, and it assumes that water is available for evaporation from soils. It is most suitable for areas 4Ha to 500Ha.

The model uses the UK Climate Projections[19] (UKCP09) to generate future climate data – in this case for 2020s, 2050s, and 2080s, all for the high (SRES A1FI) emissions scenario. Figure 5 shows the results for a generic city centre area of specified building and green area coverage for a hot summer day.

A typical inner London borough has about 30% green cover: for this, the modelling has predicted a maximum surface temperature of 27°C. To maintain this temperature by 2080 would require increasing green cover to 55%. However, there are large areas within London that have only 20% green space. In these areas the modelling predicted current maximum temperatures of 28°C. To maintain this condition by 2080, green cover would need to increase to 40%.

There are many subtleties that this analysis does not consider. One of the most important is the fact that whilst the total amount of rain is represented in the model, it does not account for the fact that sometimes there is no rain and during these times the ground may be dry. In that respect the model probably over estimates the cooling potential.

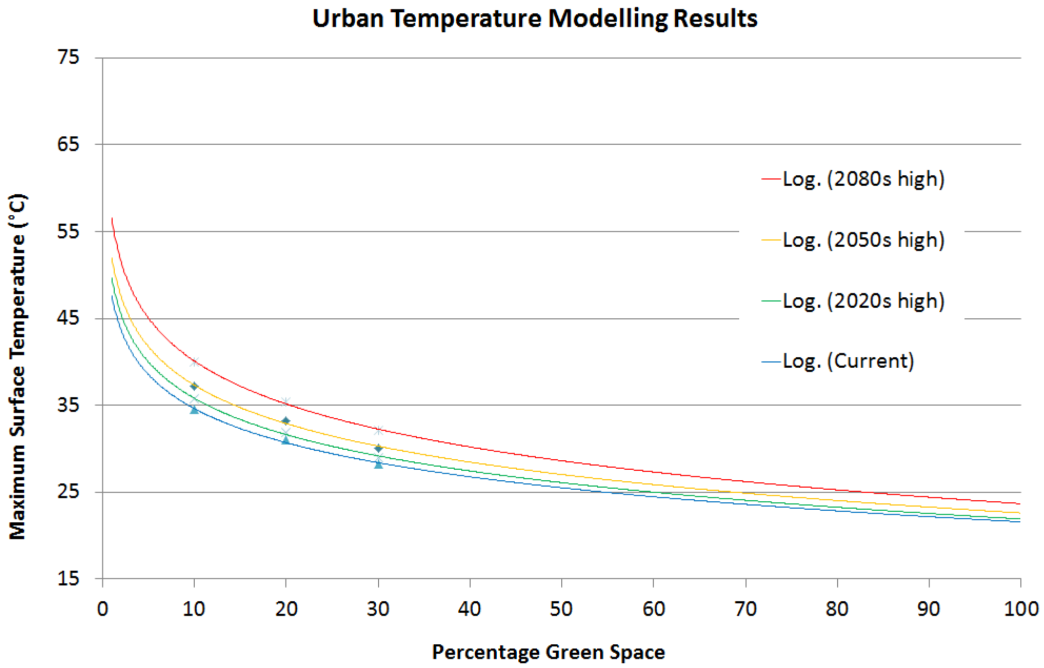


Figure 5 - Urban temperature modelling results for different amount of green space coverage for a generic UK large city centre location.

3.2 Insulation

Much literature about green roofs cites enhanced insulation as a benefit, for example the City of London Green Roof Case Studies[20]. In some respects this is misleading. Compared to insulating materials, green roofs (soil and plants) are not good insulators. A 100mm thick green roof provides about the same amount of insulation as 10mm of mineral wool, as shown in Figure 6b.

However, calculating the actual heat transfer through a green roof is more complicated than using a crude U value approximation. The conductive loss or gain from the building interior is driven by the sum of all contributing external heat transfers, as illustrated in Figure 6a.In certain circumstances dynamic effects (rain, water storage, evaporation and drying out) can yield heating and cooling energy savings compared to non-green roofs. A New York experimental study[21] found that on average winter conductive heat loss through the roof was reduced by 20% and summer heat gains through the roof reduced by 60% when compared to a non-green (black, insulated) roof. Although these effects might benefit the rooms with roofs, the energy benefit to a whole individual building is likely to be small. This is because, even for a single storey building the conductive heat gains or heat loss through an insulated roof are small fractions of the total building heating or cooling loads. At a city scale, the heating and cooling reductions that might be brought about by green insulation would be an even smaller fraction since most buildings are multi storey, therefore roof areas are a small fraction of total building envelope areas.

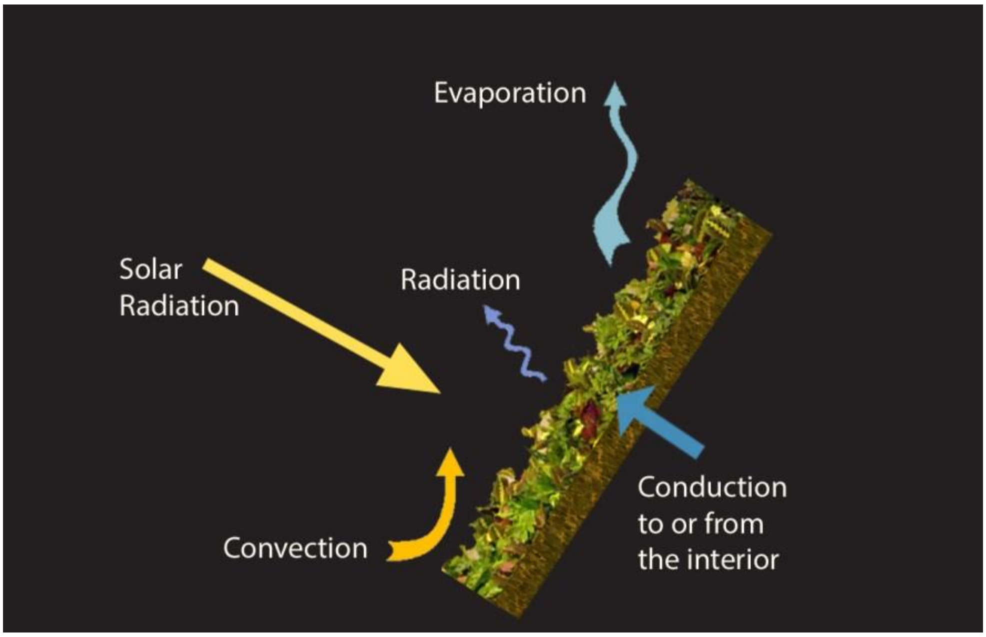


Figure 6a – Heat transfer in a lump of green

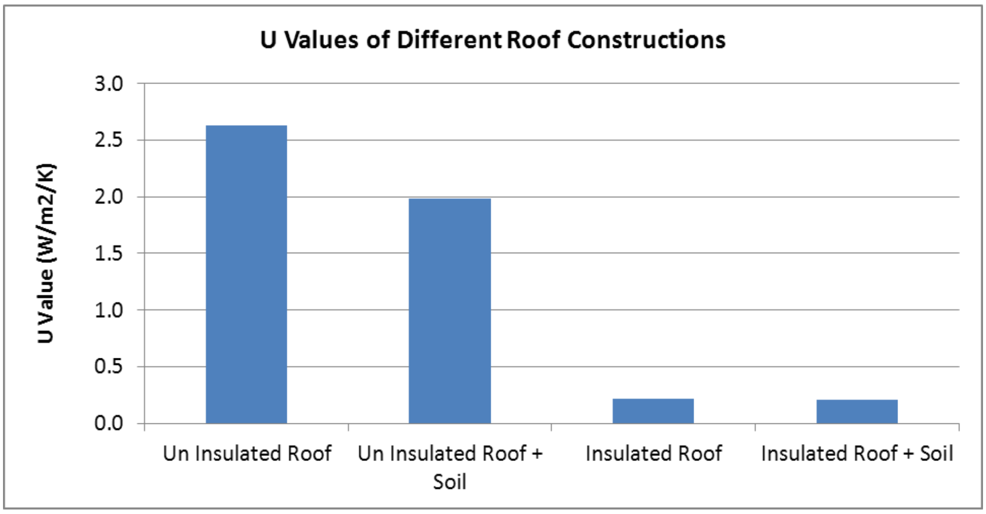


Figure 6b - Crude U values for different roof types. (Assuming 30% soil moisture content).

3.3 Stormwater management

Within cities, rainfall is often disposed of directly from impervious surfaces into surrounding waterways, via drainage networks. This makes the cities themselves, as well as areas downstream, vulnerable to flooding, erosion, and sewer surcharging.

Green infrastructure could help mitigate this by coping with water in a more natural, less complex way: this is called ‘sustainable urban drainage’, or SuDS. These work via infiltration, whereby water infiltrates into the ground, and therefore does not need to be conveyed any further, and by attenuation, whereby water is held back and released more slowly into the water system. Examples of SuDS systems include swales (grassy ditches), which work via both infiltration and attenuation, or green roofs, which provide attenuation only.

The soil in SuDS can also act as a filter, reducing the pollution entering the watercourses from urban run-off[22]. A given amount of soil (on a green roof, for example) can only hold a certain amount of water before becoming saturated, at which point any further rainfall will run off as from an impervious surface. The water held in the soil may drain away at a slower rate, be used by plants, or evapotranspire to atmosphere.

Very positive results have been reported on the viability of green roofs for urban stormwater attenuation – Palla et al at the University of Genoa demonstrated that widespread installation of green roofs could reduce peak run off rates by as much as 85%, depending on various parameters such as storm duration and intensity[23].

The sewers in London are designed to cope with a 1 in 30 year storm event: any more severe storm will result in some level of flooding. This paper investigates the green roof storage necessary to limit run off from non-permeable surfaces in the city to the current sewer design flow rate, during a more severe storm. This would mitigate the need for extension of the sewers.

London’s land area is roughly composed of 30% green space, 30% buildings, and 40% other, non-permeable surfaces. Assuming green spaces require no additional attenuation in storm events, the storage required on roof tops to limit the run-off from the buildings and non-permeable surfaces was calculated as the difference between the 1 in 30 year rainfall rate and the 1 in 100 year flow rate with a 30% increase for climate change. This resulted in a rainfall rate of 50mm/hr, meaning a storage depth of 50mm across all roof tops would be required to limit run off as described. Assuming a soil fraction of 70%, and ignoring the potential inconvenience of unsuitable roofs, this could be met using 350mm deep green roofs across 50% of buildings in London.

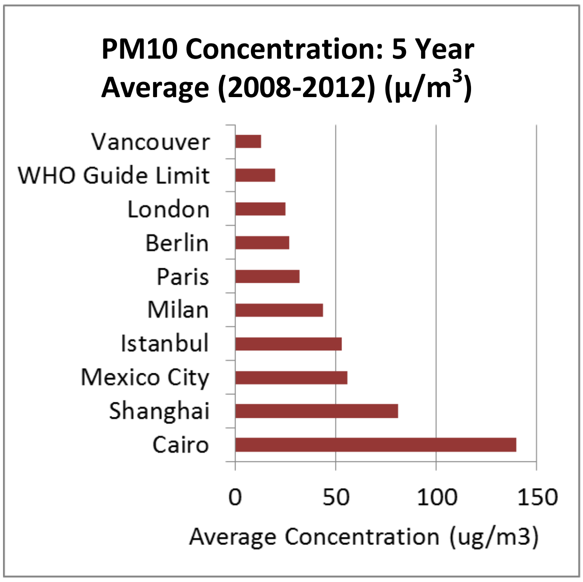
Figure 7 show an impression of the impact of moving from the current situation to one in which dispersed green roofs are used as stormwater attenuation. Dispersal is important: generally the sewer network runs beneath the streets, and so the attenuating green roofs need to be spread out along the routes of the streets rather than all clustered together.

Such an approach would be roughly equivalent to meeting the requirement that the surface water run off rate be limited to the hypothetical green field run off rate for a given area of the city (a requirement for most planning applications for new developments in London).

Figure 7 - London pre- and post- green roof intervention

3.4 Air quality

Many cities suffer from poor external air quality, causing increased mortality. Air pollutants include particulate matter, nitrogen and sulphur oxides, soot and ozone. Two of the most prevalent pollution types are particles less than 10µm in diameter (PM10s) and nitrogen dioxide (NO_2), both predominantly from road traffic[24]. The World Health Organisation (WHO) gives guidelines on key air pollutants that pose health risks: for PM10s, exposure should be limited to an annual mean concentration of 20 µg/m^3 and for NO_2, 40 µg/m^3 [25]. They state that reducing PM10 levels from 70 to 20 µg/m^3 would reduce air pollution-related deaths by 15%[25].



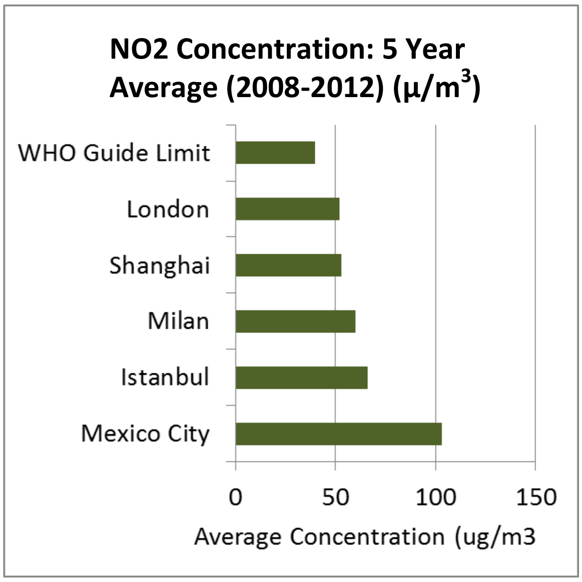


Figure 8 - Air pollutant concentrations for different cities measured at a mixture of roadside and non-roadside locations.

Figure 8 shows measured annual averages for several cities[26]: all exceed WHO recommendations. Pollutant concentrations peak along busy roads: Figure 9 illustrates this for PM10s in part of central London. London average PM10 levels are about 25 µg/m^3 with main roadsides around 40µg/m^3, and NO2 levels around 55 µg/m^3 with main roadsides of around 80µg/m^3 [27]. These exceed WHO guidelines by about 20% for non-roadside areas and 50% for roadsides.

Plants and trees have the potential to reduce air pollution by deposition as pollutants, such as PM10s, stick to them. An experimental study found that vegetated surfaces could trap about 30 times more particulate pollution than smooth concrete surfaces[28].

Several large scale computer modelling studies of this mechanism have been carried out[29,30,31]. These showed current tree PM10 removal rates of about 1% or 0.3 µg/m^3 (of total urban PM10 production), and that increasing tree cover further reduced average PM10 concentrations. Tallis et al.[30] predicted a further reduction of average PM10 concentration of about 1%, or 0.3µg/m^3, when urban tree cover in the GLA area is increased from 20% to 30%. The % change is small, but arguably the total PM10 removal, around 1000 tonnes/yr, is valuable.

This doesn't really capture the resulting PM10 microclimate distributions: if planting was increased near to pollution sources, local areas may see much greater benefits. Tallis et al. suggest that roadside conifers have the potential to enhance PM10 removal: conifers trap the most pollutants, and the roads are the source of pollution. However, under certain conditions adding trees to polluted street canyons can exacerbate the situation, as dilution by fresh ambient air mixing is reduced[32].

Vegetated walls may offer better air pollutant removal rates: they provide a large pollutant trapping area without unduly reducing ambient air mixing. Pugh et al. used street scale CFD modelling to simulate the PM10 and NO2 pollutant removal rates from generic street canyons[33,34]. They found that at low (1m/s) wind speeds, with 50% green wall coverage, the reduction in both pollutant types within the street was typically 20%, see Figure 10. However, this effect was strongly influenced by wind speed.

Urban wind speeds near to buildings are difficult to predict: microclimate wind patterns and turbulence can be highly variable. A study on wind turbine performance in central London[35,36] found that measured wind speeds at 10m above roofs were approximately 30% lower than reported Heathrow data. To provide a first order estimation of the frequency of central London above-roof wind speeds the CIBSE Heathrow TRY[37] wind speed data set was reduced by 30%. Figure 11 shows that the above roof wind speed is rarely less than 1m/s, and also shows the predicted annual frequency of PM10 concentrations for a street canyon with 50% green walls. The predicted frequency weighted average PM10 concentrations was reduced by 3% to 34µg/m³ for roadside locations.

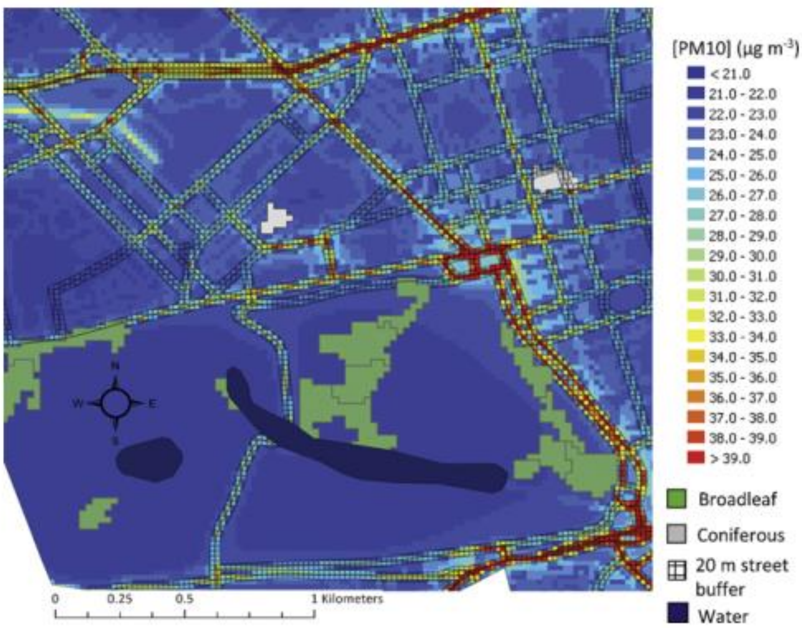


Figure 9 - PM10 concentrations (annual mean) for a part of central London (2010 data). Picture from Tallis et al.[30]

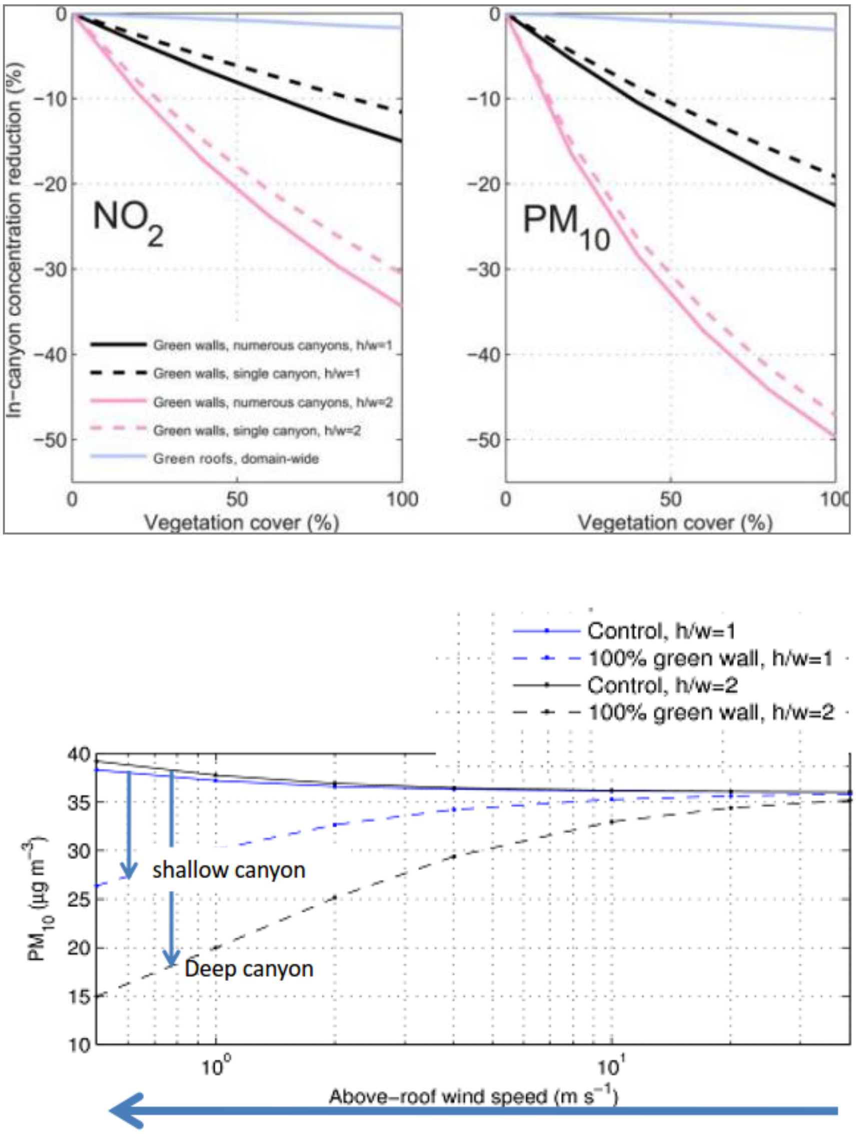


Figure 10 - Air pollution reduction from green walls. Pictures and data from Pugh et al.[33]

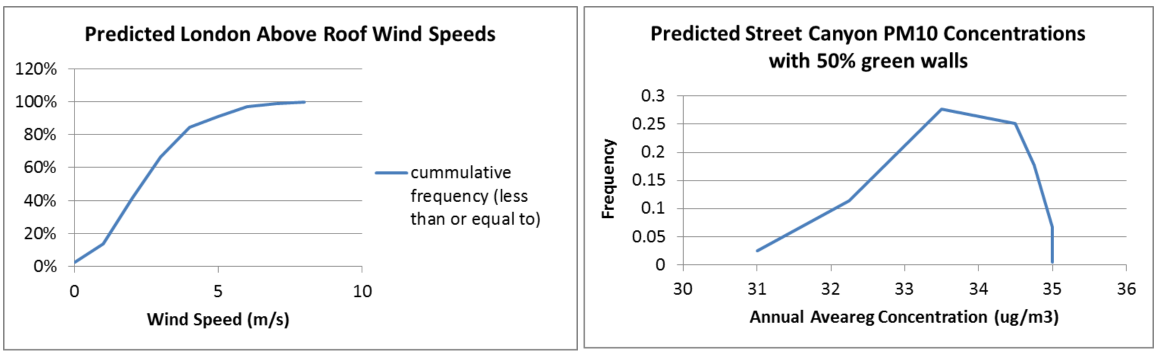


Figure 11 - a) Predicted central London wind speeds and b) green walled street canyon air pollution concentration

3.5 Biofuel production

Space and hot water heating in the UK accounts for around a third of energy use, and 40% of CO2 emissions[38]. At present the majority of buildings produce this heat by combustion of fossil fuels such as gas, which is a one way street for carbon to be pumped into the atmosphere.

One option is to burn biofuels in place of gas. The argument for this is that the carbon released into the atmosphere can very quickly be re-captured by growing: biofuels replenish themselves much more rapidly than the fossil fuel alternatives[39]. The Clean Air Act[40] places restrictions on burning biomass within cities due to the impact on air quality, but for the sake of this research the authors assumed this can be overcome by filtration of flue gases.

One of the most common energy crops grown is miscanthus, which is both fast growing and high energy[41]. Using benchmarks for average annual heating requirements (in kWh/m^2/yr) for some common building types, and the energy content and yield of miscanthus, the authors calculated the growing areas required to replace gas combustion with miscanthus combustion as a heat source.

Figure 12 shows a typical UK house[42] with the minimum area of miscanthus[43] growth required in order to heat the building each year: this was in the region of 10-30 times. For a 2 storey PassivHaus dwelling[44], this would be 2.5-5 times the building footprint, and for a 5 storey good practice office block it would be 60-100 times the building footprint. This makes the point that this is not a viable solution for an urban setting: there is simply not enough space in cities to grow sufficient crops.

In fact, the Forestry Commission thinks there is potential for approximately 300,000 tonnes of timber production per year from London's existing woodlands[45]. This would heat approximately 30,000 of the capital's homes[46]: this is just 0.5% of London's housing stock and therefore does not meet the authors' self-made definition of "significant".

Further study could be carried out into the potential contribution from any additional biomass waste, however it guessed that the heat value of this would be also be small.

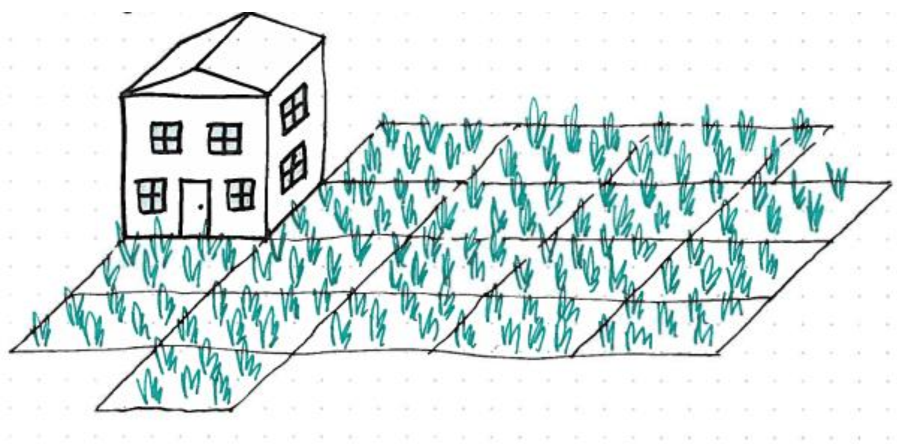


Figure 12 - Miscanthus crop land requirements for typical UK house

3.6 Acoustic attenuation

In London, ambient noise levels can be as high as 75-85 dBA[47]. The main source of this noise is road traffic, the sound from which is bounced between the hard, parallel surfaces of the street canyon. This means that increasingly, windows overlooking streets are closed, and energy intensive mechanical cooling and ventilation systems are installed.

Since vegetation is much softer and less reflective than glass or concrete, it seems intuitive that green facades may absorb sound, reducing noise levels. In fact, typically, the absorption coefficient of a green wall is about 0.7, compared to 0.02[48] for a brick wall: a green wall absorbs around 70% of an incoming sound wave's energy, while a brick wall only absorbs around 2%.

However, when the authors modelled this in more detail, looking at various configurations of green walls in a typical urban street canyon, the results were less promising than hoped. A ray-tracing computer simulation (CATT-Acoustic[49]) was used to predict the potential attenuation of traffic noise in a tall street canyon by absorption as described above.

Even with 100% green facades, there appears to be only around a 3dB reduction in street level noise, as Figure 13 shows. The effect increases a little higher up the façade, but is still barely perceptible. This suggests that direct noise is actually more significant in the urban setting than reflected, and therefore increased urban vegetation will not help: far more important is a reduction in source noise levels.

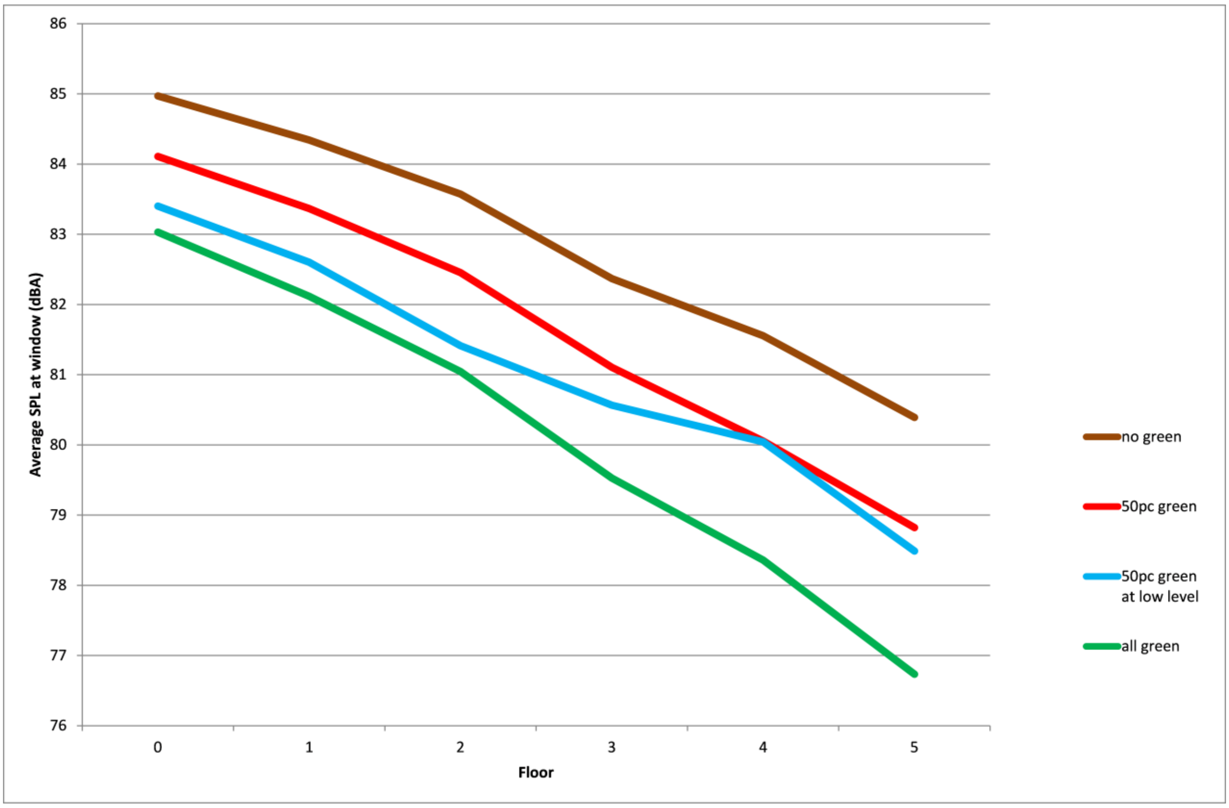


Figure 13 - Potential noise attenuation of different types of green façade

3.7 Food production

Today's food system is very much a global network: DEFRA estimates that food transport in the UK accounts for approximately 19 million tonnes CO_2e, or 1.9% of the country's total CO_2 emissions[51]. The UK produces around 50% of its own food, as shown in Figure 14, while around 75% of its fruit and vegetable consumption is grown overseas[51]. A third of the country's food related CO_2 emissions are produced by internal HGV transport, with air and sea together adding another quarter[51].

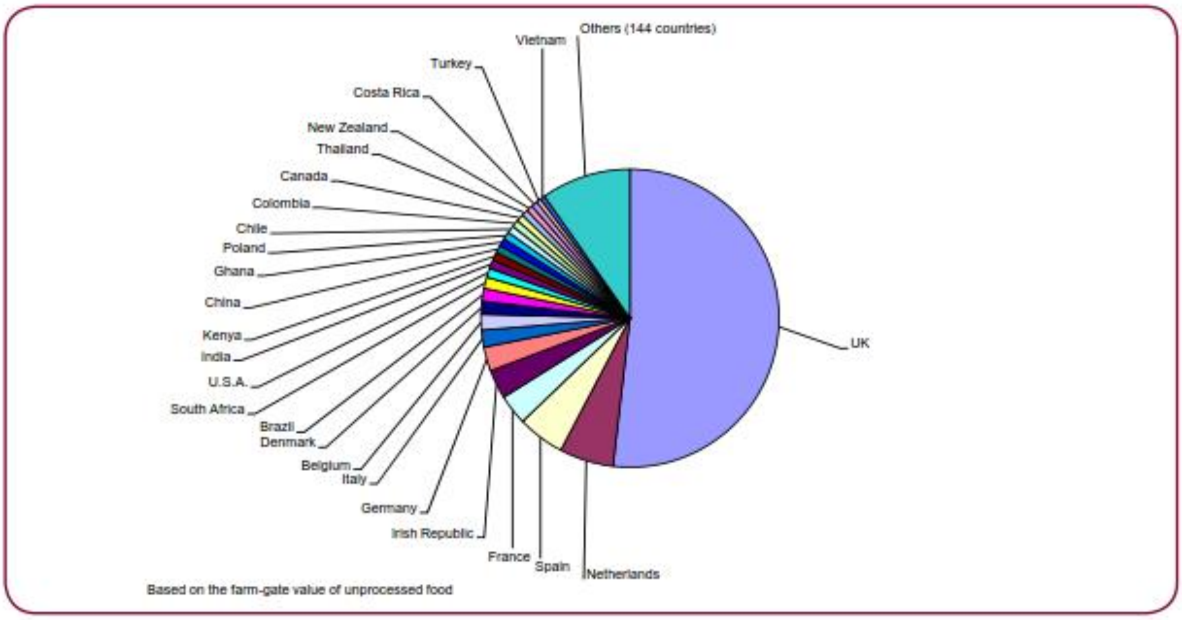


Figure 14 - UK Food Supply – from DEFRA[15]

Although some of these imports are as a result of cost or seasonality issues, which form the basis of a whole separate argument, there is certainly scope to reduce the amount of food imported, and therefore food-related CO2 emissions. But how much food could cities produce? Data on recommended fruit and vegetable intake from the WHO[52] was compared to the average UK crop yields according to DEFRA[53]. Applying this to cities involves assuming that crop yields in urban areas would match those achieved on agricultural land. The city considered was London – as already described, London is in fact already an unusually green city.

The calculations suggested that if 25% of London's existing green area was turned out to food production, this would yield approximately 20% of the city's fresh fruit and vegetable requirements. Assuming this resulted in a proportional reduction in imports, this could mean a reduction of around 5% in London's overall food related CO_2 emissions.

On the other hand, there are further benefits to urban agriculture than yield alone. During the research process, a whole host of other positives cropped up repeatedly in the literature: positive effects on community, mental health, physical health[54], and education were frequently noted. To give just one example, the National Housing Federation found its pilot community gardening schemes so successful and positive for their communities that they are rolling them out across the country, as part of the 'Neighbourhoods Green' initiative[55].

4 Conclusions

This work

A group of proposed environmental benefits of enhanced greenery in London have been examined. Some aspects look promising, with a suggestion that they could result in a city less prone to overheating, with a lower flood risk, slightly less polluted air, a lower food related carbon footprint and occupants with improved mental and physical health. Conversely, the potential benefits of enhanced building insulation, reduction in traffic noise and displacing fossil fuels by biofuel production look less realisable.

Due to the highly complex nature of the topic, the analysis has necessarily been quite crude. However, for each aspect an attempt has been made to quantify the benefit and state what would need to be done in order to realise a significant, meaningful city scale effects: Table 2 summarises the findings and describes some green design characteristics. These are rough estimates and can be viewed as one way, not the only way of achieving the desired outcomes.

In the cases of air pollution and acoustic attenuation, a far greater effect would be achieved by reducing the problems at source. In particular, reducing traffic and/or using cleaner/quieter engines would be more useful than introducing greenery.

An aspect not considered in detail is the fact that one design can realise multiple benefits. For example, adding green roofs to attenuate storm water also provides the requirements to mitigate the urban heat island effect.

In general city wide scale interventions have been considered. However, some aspects are relevant at smaller scales. Providing space for food growing can benefit individuals, greening the walls of a single street canyon has been shown to benefit that street's air quality, and green roof storm water attenuation can relive pressure on an individual branch of sewer. Urban heat island mitigation by enhanced green coverage is unlikely to be of much benefit at a single street scale but would probably work at a borough scale.

So, could greening cities provide a less complex way of achieving the desired outcomes than business as usual or alternative approaches? Well, one could define complexity as cost and ask for example "would greening 50% of London's roofs be more or less expensive than upgrading the sewers to produce the same storm water capacity?. The air quality analysis has raised an interested question. The predicted percentage reduction in PM10 concentration brought about by increasing urban tree cover by 10% is predicted to be small. However the total amount of PM10 removal is predicted to be 1500 tonnes per year. Perhaps increasing urban tree cover by 10% would be a less complex, cheaper method of removing this amount of PM10 than attempting to reduce traffic source emissions by the same amount? Unfortunately, answering these types of questions is way beyond the scope of this paper. However the analysis we have carried out has given an insight to which green city benefits might be most promising.

Cited benefit	Mechanisms/design features	Findings
Urban heat island mitigation	Increase greenery in areas away from large parks from 20% green cover to 30% green cover. Total inner London borough cover becomes around 50%.	UHI intensity reduced by about 2C. The warming effects of climate change are mitigated so that in 2080 London experiences urban temperatures similar to those today.
Insulation	Using green roofs to enhance insulation	Minimal benefit. Much simpler and more effective to use proper insulating materials.
Stormwater management	350mm Deep green roofs to 50% of roofs distributed evenly throughout the city attenuate stormwater	1 in 100 yr 1hr storm (including +30% climate change factor) is attenuated sufficiently so that the current sewer system is not overloaded.
Air pollution reduction	Increasing urban tree cover from 20% to 30%	Reduces average (background) PM10 pollution by about 1%, $0.3\mu g/m^3$. Total PM10 reduced by about 1500tonnes/yr. (Other air pollutants also reduced but not quantified)
	Adding green walls to facades at 50% area coverage along heavy trafficked street canyons	Reduces roadside PM10 an NO2 pollution by about 3%, $1\mu g/m^3$ within the street canyon. (Other air pollutants also reduced but not quantified)
Biofuel production	Growing heating fuels (e.g. miscanthus) within cities	Land requirement for significant growth would be unfeasibly large: 3-100 x building footprint area is required.
Acoustic attenuation	Applying green walls at 100% area coverage to the facades of trafficked street canyons.	Effect is barely perceptible to the human ear: around 3dB at street level.
Food production	Providing an area equivalent to 25% of London's existing green space for growing food.	20% of London's fruit and vegetable need could be met.
		Transport CO2 emissions reduced by around 5%
		Physical and mental health improved

Colour Key	Description
Green	Erring towards looking feasible and potential to realise a meaningful city scale benefit.
Amber	On the fence. Unclear if the mechanism/design could feasibly realise a meaningful city scale benefit.
Red	Unlikely to be able to produce a meaningful city scale benefit.

Table 2 – Summary of analysis of cited benefits of London urban greenery enhancement

Potential further work

Two important (and closely related) areas that have not been covered in this paper are access to green space and biodiversity. There are many proposed benefits that could be achieved by enhancing these including reduction in obesity[56], and improved pollination[57]. The authors would like to see these aspects analysed in a similar way: what are the specific benefits, what needs to be done to realise them in a meaningful way, how much green is required, in what locations and of what types?

Additionally, an underlying question that could usefully be considered throughout this work is that of land value, and the value of different types of land use. If we could substantially increase the quantity of green space as described in this paper, would we be better or worse off economically? And does this matter?

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