Implementing Green Infrastructure for Air Pollution Abatement: General Reccomendations for Management and Plant Species Selection

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3 authors:

Prashant Kumar
University of Surrey

Abhijith k v
University of Surrey

Yendle Barwise
University of Surrey

Implementing Green Infrastructure for Air Pollution Abatement:

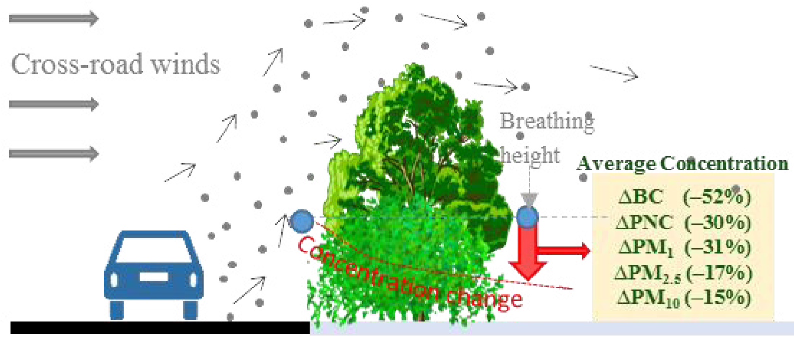
GENERAL RECOMMENDATIONS FOR MANAGEMENT AND PLANT SPECIES SELECTION

Prashant Kumar, KV Abhijith, and Yendle Barwise | 2019

GLOBAL CENTRE FOR CLEAN AIR RESEARCH
UNIVERSITY OF SURREY

Introduction

Green infrastructure (GI) includes trees, hedges, individual shrubs, green walls, and green roofs. GI offers many different benefits or services, including flood risk mitigation, microclimate regulation, carbon sequestration, improved health and wellbeing and – the focus of this document – air pollution abatement. Air pollution comprises variable quantities of many different types of pollutants, including gaseous pollutants, such as nitrous oxides (NOx) and particulate matter (PM), which is composed of particles such as black carbon (BC). Road traffic is a dominant source of air pollution in urban areas globally. In near-road environments, vegetation can act as a barrier between traffic emissions and pedestrians (figure below), by collecting pollutants and/or redirecting the flow of polluted air.



The above figure was extracted from Abhijith and Kumar (20191), who found pollutant concentration reductions downwind of hedge-tree combination barriers for BC (black carbon), PNC (particle number concentrations), PM1 (particulate matter with aerodynamic diameter <1 µm), PM2·5 (particulate matter with aerodynamic diameter <2.5 µm), and PM10 (particulate matter with aerodynamic diameter <10 µm).

This document summarises best practice regarding GI implementation for improved urban air quality and reduced pedestrian exposure to air pollution. Generic (i.e. not site-specific) recommendations are offered for typical urban environments. These recommendations are based upon contemporary scientific evidence and knowledge, and may therefore be subject to modification as the evidence base develops.

This guidance document consolidates major findings from relevant publications, including a detailed report on the relationship between vegetation and urban air quality[1], review articles[2,3] and other guidance documents[4].

Furthermore, this document complements a recent report[5] commissioned by the mayor of London, which included inputs from the Global

1 Air Quality Expert Group, 2018. Impacts of Vegetation on Urban Air Pollution. https://uk-air.defra.gov.uk/
2 Abhijith, KV., Kumar, P., Gallagher, J., McNabola, A., Baldauf, RW., Pilla, F., Broderick, B., Sabatino. S.D., Pulvirenti, B., 2017. Air pollution abatement performances of green infrastructure in open road and built-up street canyon environments – A Review. *Atmospheric Environment* 162, 71-86.
3 Barwise, Y., & Kumar, P., 2019. Designing vegetation barriers for urban air pollution abatement: a practical review for appropriate species selection. In preparation.
4 Ferranti, E., MacKenzie, A., Levine, J., Ashworth, K., Hewitt, C., 2019. First Steps in Urban Air Quality. Second Edition. A Trees and Design Action Group (TDAG) Guidance Document.
5 Greater London Authority, 2019. Using Green Infrastructure to Protect People from Air Pollution. https://www.london.gov.uk/WHAT-WE-DO/environment/environment-publications/using-green-infrastructure-protect-people-air-pollution

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Centre for Clean Air Research, and extends beyond its scope by offering recommendations on plant selection and vegetation management.

General design recommendations

The recommendations given in Table 1 are relevant to both street canyon and open-road environments (described in subsequent sections).

Table 1. General recommendations

Seasonal effects	Evergreen species are generally recommended for continuous impact over the course of the year and because air pollution concentrations can be worse in wintertime.
Leaf surface	The chosen vegetation should have complex, waxy (e.g. *Juniperus chinensis*) and/or hairy (e.g. *Sorbus intermedia*) leaf surfaces, with a high surface area (i.e. small and/or complex leaves). These features assist in the deposition and removal of particulate pollutants.
Non-invasive	It is important to select non-invasive species.
Non-poisonous	When planting near sensitive populations (such as school children), it is important to avoid species that are poisonous (e.g. *Taxus baccata*) or that that may cause allergic reactions.
Road safety	Vegetation barrier design should be managed to meet applicable safety regulations for the visibility of drivers, cyclists or pedestrians. Similarly, barriers should not impede accessibility where relevant

General management considerations

Appropriate GI can be used to mitigate air pollution. However, the management of vegetation can itself be a source of emissions, not only through the equipment used but through biogenic volatile organic compound (bVOC) emissions from the vegetation, which increase when a tree is 'wounded' (e.g. by pruning).' In order to minimise any potential trade-offs between the air quality benefits offered by urban vegetation and the potential costs (both monetary and environmental) associated with establishment and maintenance, it is important to consider the long-term suitability of a species to the planting site. Working with nature, or understanding and playing to the natural tendencies of individual species, will optimise success rates in establishment and performance. This, in turn, will minimise costs associated with management (e.g. re-planting and aftercare, including weeding and pruning). Unfortunately, it would not be possible to create a thorough list of low-maintenance species, for two primary reasons. Firstly, the incalculable range of potential environmental conditions means that different species will be suitable (and therefore require less maintenance) for different sites. Secondly, different objectives necessarily entail different ideal growth forms (it would, for example, be inefficient to maintain a fast-growing species as a low hedge, or to maintain a slow-growing species until it becomes an effective shelterbelt). With this in mind, Table 2 provides a summary of key points to consider.

Table 2. Considerations for effective green infrastructure management regarding species selection.

Management consideration	Description
Air pollution tolerance	Species should be tolerant of air pollution in order to remain healthy and effective in mitigating it. Observed tolerance (rather than proven via experimentation) may be sufficient. However, air pollution tolerance should be considered alongside any trade-offs (for example, a species may be highly tolerant of air pollution but a high emitter of bVOCs, as is the case with London plane (*Platanus x hispanica*)).
Tolerance of other typical urban stresses	The chosen species should be suitable for the specific conditions of the site, which may include, for example: salt spray (for winter road conditioning), drought, root compaction, flooding, waterlogging, or shade.
Growth shape (morphology)	Species should be selected on a site-by-site basis and with their projected growth form in mind. In a shallow street canyon, for example, a medium-sized and low density - highly porous canopy species may be suitable, whereas in a deep street canyon, a naturally compact tree or shrub may be more appropriate (Table 4).
Succession*	Consideration of a species' successional stage under open forest conditions can help to indicate the type of environment in which it may thrive. As a simplified example: early successional (or 'pioneer') species, such as birch, tend to cope well under exposed and windy conditions, whereas late successional (or 'climax canopy') species, such as oaks, tend to be shade-tolerant.

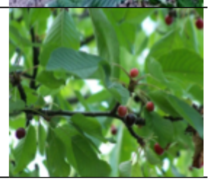
*Succession describes the process or system of natural change in the species structure of an ecological community (e.g. an area of woodland) over time. This process is generally predictable for a given community, and includes the order in which certain species tend to become established.

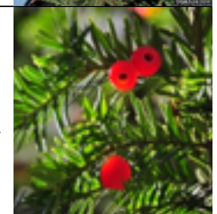
In urban areas that may often be subject to temperatures above 20°C, species that are high-emitters of bVOCs should be avoided, particularly for large-scale planting schemes. Such species include oaks, poplars, willows, and spruces. Similarly, the assumed air quality benefits of introduced vegetation may be nullified if the chosen species releases high amounts of allergenic pollen during the flowering period. Where sensitive human populations coincide (for example, near schools and nursing homes), insect-pollinated species or female varieties of dioecious species are recommended .

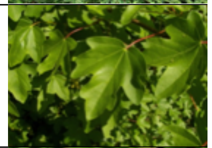
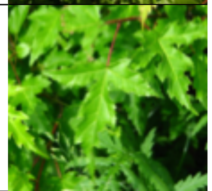
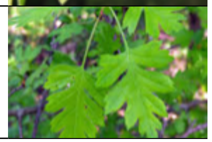
Potentially effective species

The woody plant species in Table 3 are identified as potentially advantageous for air pollution abatement. To encourage plant diversity, this list includes native as well as other suitable non-native species found in the literature. Similarly, it should be noted that this list is not exhaustive, and is offered instead as a starting point in species selection and an outline of points to consider with respect to the context of the planting site (see **Street canyons** and **Open road environments**). For brevity, the table explicitly and solely reflects aspects of species that relate to air quality. The suitability of each species to the environmental conditions of the planting site is paramount (see **General management considerations**)

Table 3. Woody plant species that are considered to be effective for air pollution abatement, based either upon experimental findings, an exhibition of beneficial traits, or a combination of both.

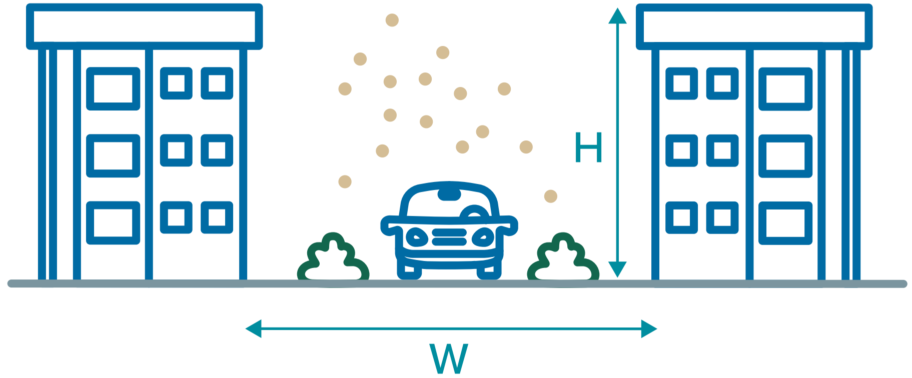
Tree species	Type	Air pollution tolerance	bVOCs	Pollen	Canopy density	Comments	Image
Scots pine (*Pinus sylvestris*)	Evergreen conifer	Observed/ proven	Low	Low	Moderate	Early successional; native; good drought tolerance	
Stone pine (*Pinus pinea*)	Evergreen conifer	Observed/ proven	Low	Low	Dense	Non-native; a more compact option than *P. sylvestris*; good drought tolerance	
Himalayan cedar (*Cedrus deodara*)	Evergreen conifer	Unknown/ unproven	Low	Low	Dense	Non-native; potentially a massive, broad tree; very good drought tolerance	
Swedish whitebeam (*Sorbus intermedia*)	Deciduous broadleaf	Observed/ proven	Low	Low	Moderate	Naturalised in UK; known salt tolerance; some tolerance to drought; leaf undersides are hairy	
Ulmus 'Rebella'	Deciduous broadleaf	Observed/ proven	Unknown	Low	Moderate	Non-native; medium-sized tree; resistant to Dutch elm disease; good drought and salt tolerance	
Wild cherry (*Prunus avium*)	Deciduous broadleaf	Observed/ proven	Low	Low	Moderate	Early successional; native; good drought and salt tolerance	
Callery pear (*Pyrus calleryana*)	Deciduous broadleaf	Observed/ proven	Low	Low	Dense	Non-native; proven viability for paved environments; good drought and salt tolerance	
Staghorn sumac (*Rhus typhina*)	Deciduous broaflead	Observed/ proven	Low	Low	Moderate	Early successional; non-native; small- to medium-sized tree; good drought and salt tolerance	
False acacia (*Robinia pseudoacacia*)	Deciduous broadleaf	Observed/ proven	Low	Low	Open	Early successional; non-native; potentially a large tree; good drought and salt tolerance; can be invasive	
Common hackberry (*Celtis occidentalis*)	Deciduous broadleaf	Observed/ proven	Low	Low	Moderate	Early successional; non-native; massive tree; some observed drought and salt tolerance	

Suitable for hedging	Type	Air pollution tolerance	bVOCs	Pollen	Canopy density	Comments	
Leyland cypress (*x Cuprocyparis leylandii*)	Evergreen conifer	Unknown/ unproven	Low	Low	Dense	Non-native; very fast-growing, and potentially very large; good drought and salt tolerance	
Common yew (*Taxus baccata*)	Evergreen conifer	Observed/ proven	Low	High, but dioecious	Dense	Late successional; native; versatile hedging plant, can be trained to form a barrier of any shape; good drought tolerance	
Box (*Buxus sempervirens*)	Evergreen broadleaf	Unknown/ unproven	Low	Low	Dense	Native to southern England; low-branching; good drought tolerance	
Western red cedar (*Thuja plicata*)	Evergreen conifer	Observed/ proven	Low	High	Dense	Late successional; non-native; good, dense hedging plant for a tall barrier; good drought tolerance	

Chinese juniper (*Juniperus chinensis*)	Evergreen conifer	Observed/ proven	Low	High, but can be dioecious	Dense	Early-successional; non-native; good drought tolerance	
Field maple (*Acer campestre*)	Deciduous broadleaf	Observed/ proven	Low	Low	Dense	Early successional; native; some observed drought and salt tolerance	
Amur maple (*Acer tataricum subsp. ginnala*)	Deciduous broadleaf	Observed/ proven	Low	Low	Dense	Late successional; non-native; good drought and salt tolerance; ornamental autumn colour	
Downey serviceberry (*Amelanchier arborea*)	Deciduous broadleaf	Observed/ proven	Low	Low	Moderate	Non-native; some observed salt tolerance; moderately sensitive to drought; ornamental autumn colour	
Common hawthorn (*Crataegus monogyna*)	Deciduous broadleaf	Observed/ proven	Low	Low	Dense	Early successional; native; good drought and salt tolerance	

Street canyons

When considering air quality and pollutant dispersion, street canyons are a complex urban feature.



H is the height of the buildings and *W* is the horizontal distance between the buildings. The ratio of *H* to *W* is called the aspect ratio, which significantly affects pollutant dispersion patterns. For simplicity, street canyons can be broadly defined according to their aspect ratio.

$H/W \geq 2$ = deep or narrow street canyons

$0.5 < H/W < 2$ = moderately deep street canyons

$H/W \leq 0.5$ = shallow or wide street canyons

Deep street canyons can experience increased pollutant concentrations regardless of the presence of vegetation, due to limited air exchange between polluted air within the canyon and fresh air outside it. The presence of large trees in street canyons can result in a deterioration of overall air quality, by trapping pollution at ground-level. This does not mean that existing trees should be cut down, because they offer ecosystem services beyond air quality support, but that due caution should be undertaken in considering appropriate species for new planting.

Table 4. General recommendations for different aspect ratios

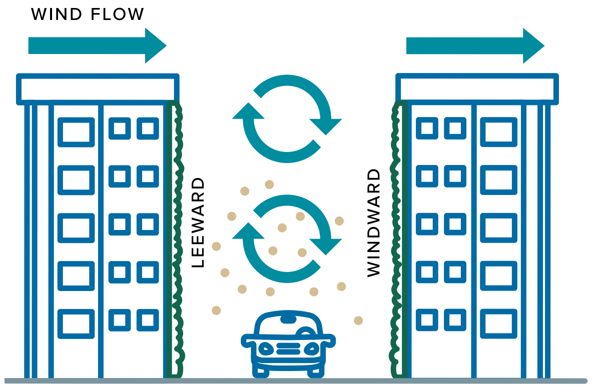
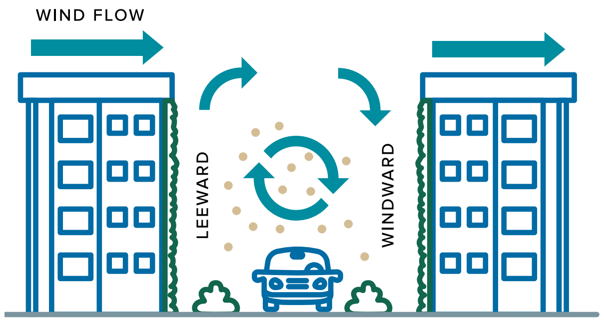
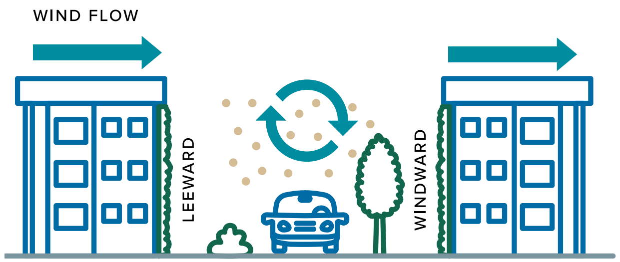
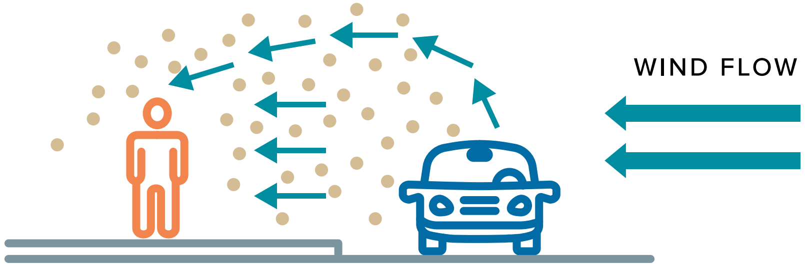
Street canyon aspect ratio	Sketch (wind direction roughly perpendicular to the street)
H/W ≥2 (deep or narrow street canyons) Recommended: Trees - No Hedges - No Green walls - Yes	
0.5< ***H/W*** **<2** moderately deep (nearly regular; i.e. w~=h) street canyon Recommended: Trees - No Hedges - Yes Green walls - Yes	
H/W ≤0.5 (shallow or wide street canyons) Recommended: Trees - Conditionally (small, lighter-crowned species, preferably planted only on the windward side) Hedges - Yes Green walls - Yes	

Table 5. Generic features for street canyons

Design parameter	Considerations
Location	If the prime objective is to reduce exposure for pedestrians or cyclists, hedges should be planted close to the road, between the road and footpath/bike path. Green walls can be constructed on the pillars of flyovers, retaining walls and other boundary walls.
Selection of vegetation	In deep street canyons, no forms of vegetation except green walls are recommended. In mid-depth street canyons (Table 4), shrubs or hedges and green walls can be planted, but trees are not recommended. Large, dense trees should be avoided in all street canyons, but smaller or lighter-crowned trees may be planted in shallow street canyons.
Spacing	Continuous hedges (with no gaps or spacing) provide a better reduction in exposure for pedestrians and cyclists. If trees are to be planted (shallow canyons only), they should be spaced generously apart from one another.
Height	For hedges, a height of around 2m is recommended.
Thickness	For hedges, a thickness of 1.5m or more is recommended.
Density (leaf area)	In street canyons, a higher density for hedges and lower density for trees is recommended (see Table 3).

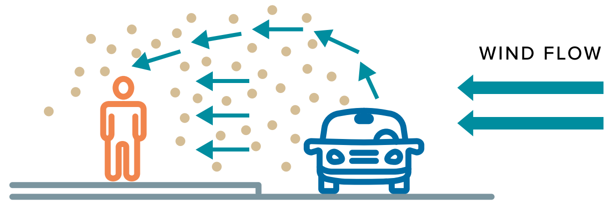
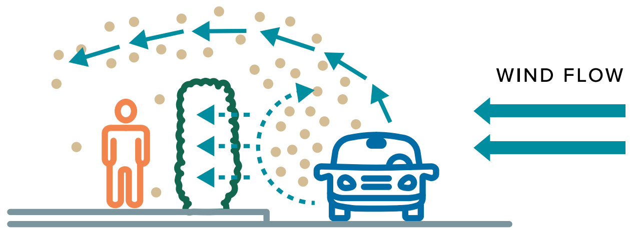
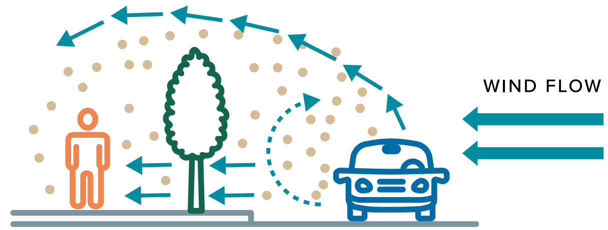
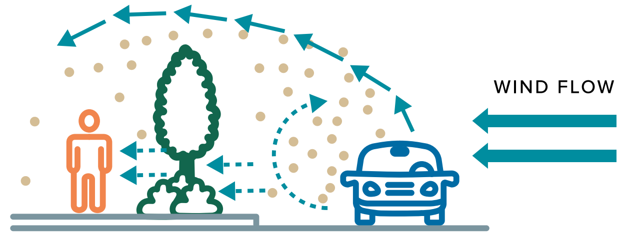
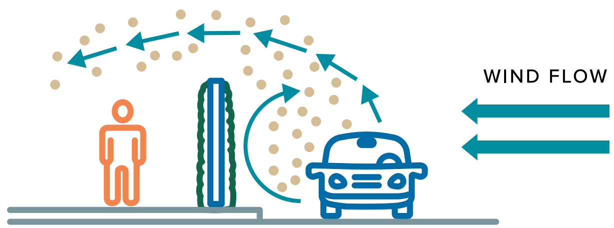
Open road environments

Open road conditions describe a road that is either away from buildings or where nearby buildings are generally detached. Here, wind flows are less hindered or influenced by buildings and other structures when compared with street canyon environments.



In open road environments, trees and other vegetation are often planted or occur naturally along one or both sides of the road. These forms of GI may be relatively broad areas of woodland or other vegetation, or may simply entail roadside hedges. They provide a natural barrier against emissions from the road, potentially reducing exposure levels for those travelling, working or residing adjacent to such roads.

Table 6. Simple description of open road conditions and pollution flow

Open road conditions	Simplified diagram
Open road with no vegetation barriers between traffic emissions and pedestrians.	
Open road with a hedge acting as a barrier between traffic emissions and pedestrians.	
Open road with trees acting as a filter between traffic emissions and pedestrians.*	
Open road with combined vegetation barriers between traffic emissions and pedestrians.	
Open road with a green wall acting as a barrier between traffic emissions and pedestrians.	

*Under some conditions, due to a windbreak effect, pollutants can stagnate behind a sparse row of trees, leading to deteriorated downwind air quality (Abhijith and Kumar, 2019).

Table 7. Considerations for open road green infrastructure

Design parameter	Considerations
Location	Hedgerows should be planted between the road and walkways or dwellings and in front of trees (if present); this configuration offers the maximum reduction of exposure.
Spacing	Barriers with no gaps provide better downwind exposure reduction.
Height	Where possible, it is recommended that the combined hedge-tree barrier or green wall has a height of 5m or more. Vegetation barriers with greater height result in increased pedestrian-side pollutant reductions. A minimum height of 1.5m is recommended.
Thickness	The vegetation should be as thick as possible; thicker vegetation barriers offer greater exposure reduction. If possible, a thickness of more than 5m is recommended.
Density	High-density vegetation barriers are generally better for reducing exposure levels downwind (see Table 3).

Acknowledgements

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Disclaimer

This document does not contend any general or comparative advantage of trees over hedges or vice versa; both are important interventions when implemented appropriately. Our intention is to instruct on the most appropriate GI solution for a given urban setting, including species selection and management recommendations. These are generic, best-practice recommendations based on the published scientific literature. Urban environments are complex and so are the dynamic systems of flow features and pollution dispersion. There is a dearth of published literature from which to draw evidence for specific circumstances, and our recommendations should therefore be treated as preliminary considerations. The growing evidence base will facilitate improvements to these preliminary considerations in the future.

Contact:

Professor Prashant Kumar
p.kumar@surrey.ac.uk
+44 (0)1483 682762

GLOBAL CENTRE FOR CLEAN AIR RESEARCH

UNIVERSITY OF SURREY

8593-0818

UNIVERSITY OF SURREY

Guildford, Surrey GU2 7XH, UK

GCARE@surrey.ac.uk

surrey.ac.uk/gcare