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Abstract: Previous research has highlighted significant socio-environmental inequalities in the UK and elsewhere. A city's greatest polluters typically reside in affluent suburban communities located along the city's periphery, whilst those creating the least emissions reside in central locations, and most likely experience the largest associated health burdens. Using the culturally diverse city of Leicester as a study case, and building on Mitchell & Dorling's (2003) localised form of the Polluter Pays Principle, we investigate this environmental injustice. A pattern detection analysis of localised intra-urban interactions was undertaken using a 'Local Indicators of Spatial Association' (LISA) modelling approach of high resolution census data, Driver Vehicle Licensing Agency (DVLA) records, road transport emission maps and geocoded hospital admissions records provided by the NHS Leicester City Primary Care Trust.

Pearson's R statistics identified an inverse correlation between mobile polluters and communities characterised as either socially (-0.78) or environmentally burdened (-0.34), confirming the existence of environmental inequalities. Whilst some inner-city communities moderately contribute towards their environmental burden, these contributions were substantially outweighed by those made by external communities, whom appear to avoid the social, environment and physical cost of their actions. In contrast to their more affluent counterparts, residents of less affluent areas tend to use 'greener' and more active transport options, although any associated health benefits appear largely offset by increased periods of environmental exposure. Strong signs of spatial structuring within the modelling framework, suggest there may be a need to tailor travel schemes to local populaces. For example, in affluent areas where less environmentally friendly transport options tend to be adopted, options based on local carpool schemes may be more amenable than those based on enhanced public services.

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IMPLEMENTATION OF THE POLLUTER PAYS PRINCIPLE IN LOCAL TRANSPORT POLICY

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HIGHLIGHTS

- LISA analysis shows socio-environmental inequalities between communities in UK city [85 characters]
- Poorer inner-city residents are subject to a disproportionate environmental burden [84 characters]
- More effective future transport schemes may need to be community-specific [76 characters]

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ABSTRACT

Previous research has highlighted significant socio-environmental inequalities in the UK and elsewhere. A city's greatest polluters typically reside in affluent suburban communities located along the city's periphery, whilst those creating the least emissions reside in central locations, and most likely experience the largest associated health burdens. Using the culturally diverse city of Leicester as a study case, and building on Mitchell & Dorling's (2003) localised form of the Polluter Pays Principle, we investigate this environmental injustice. A pattern detection analysis of localised intra-urban interactions was undertaken using a 'Local Indicators of Spatial Association' (LISA) modelling approach of high resolution census data, Driver Vehicle Licensing Agency (DVLA) records, road transport emission maps and geocoded hospital admissions records provided by the NHS Leicester City Primary Care Trust.

Pearson's R statistics identified an inverse correlation between mobile polluters and communities characterised as either socially (-0.78) or environmentally burdened (-0.34), confirming the existence of environmental inequalities. Whilst some inner-city communities moderately contribute towards their environmental burden, these contributions were substantially outweighed by those made by external communities, whom appear to avoid the social, environment and physical cost of their actions. In contrast to their more affluent counterparts, residents of less affluent areas tend to use 'greener' and more active transport options, although any associated health benefits appear largely offset by increased periods of environmental exposure. Strong signs of spatial structuring within the modelling framework, suggest there may be a need to tailor travel schemes to local populaces. For example, in affluent areas where less environmentally friendly transport options tend to be adopted, options based on local carpool schemes may be more amenable than those based on enhanced public services.

1. INTRODUCTION

Road-transport accounts for a substantial proportion of air quality objective pollutants present in the Post-industrial cityscape, attributed to the movement of labour forces and physical merchandise often within close proximity to residential districts. Furthermore, the confined nature of European intra-urban environments often determine spatial variations in traffic pollutant levels, which tend to be associated with a plethora of social disparities. Spatial modelling, object identification and gradient association techniques previously identified underlying structures in the archetypal UK multicultural city of Leicester, whereby persons of minority and lower socioeconomic status habitually reside within intra-urban areas experiencing elevated environmental burdens (Jephcote & Chen 2012, Jephcote & Chen 2013, Jephcote et al 2014).

1.1. JUST TRANSPORTATION

Transportation is a conduit for opportunities of economic mobility, sustainability and human interaction, which in a 'Just' scenario may serve to address social imbalance. In the real world, costs and benefits associated with transportation developments are not randomly distributed, with the lion's share spent on roads, while urban transit systems serving ethnic and lower social groups are often left in disrepair: In the United States, public transit has received roughly $50 billion since 1964, while roadway projects have received over $205 billion since 1956 (Bullard et al. 2004). To a lesser extent disparities in transport related public expenditure are observed in Great Britain, with £7.52 billion spent on roads and £3.33 billion was spent on local public transport in 2012 (RAC Foundation 2014).

Bullard (2003) considers disparate transportation outcomes to fall under three broad categories of inequality:

> *"**Procedural Inequity:** Attention is directed to the process by which transportation decisions may or may not be carried out in a uniform, fair, and consistent manner with involvement of diverse public stakeholders. Do the rules apply equally to everyone?*
>
> ***Geographic Inequity:** Transportation decisions may have distributive impacts (positive and negative) that are geographic and spatial […]. Some communities are physically located on the 'wrong side of the tracks' and often receive substandard transportation services.*
>
> ***Social Inequity:** Transportation benefits and burdens are not randomly distributed across population groups. Generally, transportation amenities (benefits) accrue to the wealthier and more educated segment of society, while transportation disamenities (burdens) fall*

disproportionately on people of colour and individuals at the lower end of the socioeconomic spectrum."

(Bullard 2003, pp.1188)

Across England, 78.0% of households in the highest income group own one or more cars, compared to only 53.0% in the lowest income group (Dft 2015). Car ownership would appear directly related with mobility, and thus access to opportunity, with 22.0% fewer trips made by the lowest income group (Dft 2015). Public and active modes of transportation are favoured by lower socio-economic groups, perhaps out of necessity rather than choice. *"In general, most transit systems have taken their low-income and people of colour "captive riders" for granted and concentrated their fare and service policies on attracting middle-class and affluent riders out of their cars"* (Bullard et al. 2003, pp.1189). A lack of car ownership, inadequate public services and a high proportion of 'captive' transit dependents are likely to exacerbate issues of social, economic, and racial isolation.

In the Western World, sprawl-fuelled growth has exacerbated the economic, social and racial polarisation of communities, with the suburban flight of jobs and white middle-income families leaving behind: A concentration of urban core poverty, closed opportunity, limited public mobility to non-centric locales, economic disinvestment, social isolation, and urban-suburban disparities (Bullard 2000). In the UK it is emerging that after decades of suburban flight, young, affluent and educated workers are returning to congregate in regenerated urban neighbourhoods, fuelled by demographic trends and lifestyle preference favouring the close proximity of amenity hubs to attractive 'green' spaces (Moir & Clark 2014). The redesign and appropriate pricing of city central workspaces have also played a crucial role in this redistribution of the population, with urban locations accounting for 53-70% of the annual office space take-up in the UK over the period 2002-2012 (JLL 2013).

McLeod et al's (2000) incorporation of hierarchical spatial elements, while investigating national trends in UK air pollution and increasingly complex social structures, identified an association between reduced air quality and regional deprivation, the effect of which was locally magnified in ethnic minority communities. Successive modelling accounting for levels of urbanisation and ethnic diversity, found persons of higher social status to be more likely exposed to higher pollutant concentrations. McLeod et al (2000) concluded that wealthier inhabitants consider a range of property characteristics prior to purchase, however a limited quantity of housing stock display the required environmental and cultural amenities, with the latter characteristic ultimately of preference in the decision making process. Thus, sweeping measures to address mobility, transportation choice and air quality across urban locations, may under certain circumstances increase the equity gap.

Within the transportation literature, the term ‘Social exclusion’ is often employed to refocus the debate not just based on income-related deprivation, but across the wider political and cultural systems determining social integration (Hodgson & Turner 2003, Kenyon et al 2002, Preston & Raje 2007). Transport plays a crucial role in the discussion of social justice, through its creation and indirect distributions of socio-economic benefits and burdens, that are not exclusively defined by welfare economics (Beyazit 2011, Martens 2012, Mullen et al 2014).

Moving beyond a simplistic monetary debate, Martens (2012) considers the inclusion of the transport sector in Walzer’s ‘Spheres of Justice’. According to Walzer (1983), dominance and much of the policy debate is typically claimed by ‘regular goods’ (money and power) distributed through the principle of free exchange, while the creation of ‘distributive spheres’ for goods with distinct social meaning (education and health services) operate to limit their domination; Injustice occurs when ‘distribution spheres’ are not autonomous, otherwise a situation of ‘complex equality’ prevents the accumulation of inequalities across different goods or spheres. Building upon this concept, Martens (2012) views transport as an overarching social good rather than a distribution of individual objects, with the commodity defined not by the perceived freedoms of increased potential mobility (which ignores distributions of choice), but through the accessibility of fulfilling ones underlying social need. From this a ‘maximax’ distribution criterion is theorised, which seeks to combine an outcome of maximum average accessibility with a limit on the maximal gap allowed between societies worst and best-off. Beneficially the uniformity of the ‘equality’ principle is not required, allowing for inevitable differences in accessibility created by space, and unlike the ‘need’ criterion it does not require a paternalistic approach to differentiate trip necessity. Under this approach, policy can increase accessibility levels for some at the expense of those best served, with positive outcomes also obtained from non-mobility related solutions (i.e. land-use intervention).

More equitable implementations often elude existing systems, where distribution focuses on revenue over universal accessibility, demand forecast is based on past travel behaviour reflective of free market distributive mechanisms that ignore latent demand, and when policy success is measured through its performance of parts rather than societal benefit (Martens 2012). This is highlighted by the spatial mismatch literature, which identifies concentrations of low income groups in central cities, a decentralisation of low wage jobs, and a lack of investment in new public transport facilities leading to a sharp decline in job access among the urban poor (Ihlanfeldt 1993, Ong & Miller 2005). Thus, space is divided into centre and periphery, with inequality in accessibility being inevitable, and while policy is unlikely to correct this difference it is capable of redefining it. Another widely defended justice criterion is the 'principle of need', which advocates greater levels of accessibility for certain individuals or groups, to avoid exclusion from social needs or the use of essential public services (Murray & Davis 2001, Hodgson & Turner 2003, Geurs & van Wee 2004, Apparicio & Seguin 2006, Currie 2010). Yet, the challenge in the field of transport is to distinguish needs from wants, and how to translate the basic needs of access to essential services into travel.

The interpretation of such needs is perhaps most viable at the neighbourhood level, for three reasons: (a) optimal integration with the existing transport infrastructure plans which focus on the collective rather than individuals; (b) census based neighbourhood units are considered to provide stable demographic information which best meet the current demand of long-term forecasts; and (c) participant confidentiality is maintained. The following sections seek to evaluate the equity of existing transport infrastructure via Pearce et al's (2010) previously unconsidered 'triple jeopardy' of social, environmental and health inequalities at the neighbourhood level for the aforementioned reasons. This approach is considered to comprehensively capture the imposed effect of transportation through an environmental accountability framework. Still, the authors recognised its limitation of considering the 'principle of need' where complex social situations call for greater levels of accessibility. This raises the question, at what cost should one group's accessibility socially, environmentally, impede the social, environmental and well-being of others? On the other hand a penalisation of excessive mobility via polluting modes is perhaps required in order to seriously address socio-environmental inequality, considering that accessibility can and should also be rebalanced by better land use policy. This is not the place to define these open and unresolved questions, with the authors advising policy makers to consider the 'principle of need' prior to imposing actions on local communities identified from an environmental perspective.

1.2. TRANSPORT CHOICE: GREAT BRITAIN

The use and quality of public transport in British cities outside of London and Greater Manchester has declined in recent decades, with urban transport services becoming increasingly fragmented following the (a) deregulation of buses in the Transport Act 1985, and (b) privatisation measures in the Railways Act 1993 (Preston et al 2008). In part, this is due to greater prosperity and increased car ownership, but a lack of coordination in local public transport services to provide a low cost, quality and integrated service has also played a role (RAC Foundation, DfT 2013a).

Since bus deregulation, patronage in the English metropolitan counties has decreased by 48% over the 19 years from 1985-2004, with a 23% real term increase in fares and a 20% decrease in service levels (in terms of vehicle-km operated) occurring in the period 1994-2004 (Dodgson et al 2006). Passenger focus surveys cite cost (43%), trip quality (37%), and the stress of making connections on time (32%) as barriers to the use of bus services in England, with 60% of the public only travelling via bus if they had no other choice and 52% perceiving users to be of a lower social status (DfT 2011).

Although rail use in Great Britain has doubled since 1994, to 1.6 billion passenger journeys, such trends are driven principally by London commuters (Rail Executive 2014). Like other public modes, rail has seen a real term fare increases of 24% and poor customer experiences are frequent, with South East operators recording 8.6-9.5% of passengers in excess of capacity during morning commutes (DfT 2013b, Action for Rail 2013). Furthermore, Britain is currently reported to have Europe's highest commuter fares, with season tickets priced at 0.14 £/km, compared to the respectively low values of 0.08 £/km in the Netherlands or Germany, and 0.04 £/km in Switzerland (Action for Rail 2013).

In England, the mix between modes of travel has marginally changed over the period 1994-2014, with the share of trips made via active (walking and cycling) modes decreasing from 28% to 24%, and public transport increasing from 9% to 11% (DfT 2015). Transport choice surveys cite the danger of road cycling (60%), the limited number of dedicated cycle paths (37%), and secure storage (41%) as key barriers to the uptake cycling in England (DfT 2011).

1.3. POLLUTER-PAYS PRINCIPLE (PPP)

At its core 'Environmental Justice' seeks to provide equal access to a clean environment and equal protection from possible environmental harm irrespective of socioeconomic factors (Cutter 1995). Of significant importance is the 'The *Polluter-Pays Principle'* (PPP), the notion that environmental actions embody mechanisms for assigning culpability, shifting the burden of mitigation to the polluters rather the polluted. "Thus EJ research seeks to determine whether marginal and/or minority groups bear a disproportionate burden of environmental problems, and whether planning policy and practice affecting the environment are equitable and fair" (Mitchell & Dorling 2003).

Under the OECD councils preliminary 1972 and ensuing 1974 recommendations, “the Polluter-Pays Principle means that the polluter should bear the costs of pollution prevention and control measures, the latter being measures decided by public authorities to ensure that the environment is in an acceptable state" (OECD 1992). Yet, fundamentally the PPP is not a concept of equity, but rather a measure for ensuring economic efficiency and minimising distortions in international trade, by incorporating environmental costs in the decision-making process; thus optimising the use of natural resources and ending the cost-free use of the environment as a receptacle for pollution (Vicha 2012). At an international level, such concepts exist in the trading of greenhouse gas emission allowances, in that pollution costs are internalised (efficiency), but also that producers buy their allowances before they pass on those costs to consumers (equity) (Woerdman et al 2007). The principle’s precise legal definition has not been rigorously defined and, as a result, where PPP has been applied, it is often in an *ad hoc* manner by enforcement agencies acting responsively to situations on a case-by-case basis, most often focusing on the selective use of establish rules rather than seeking to refine a framework or unifying theory (Mann 2009). In this regard, corporate accountability in international environmental law has been traditionally dealt with by taxation charges on toxic substances and dangerous goods or more commonly through the retrospective compensation of the victims of environmental harm typically from developing nations (Luken 2009, Luppi et al 2012). Both, approaches can be considered crude implementations of the PPP. The prior adds an extra financial burden on those seeking to use potential harmful materials that could be used to fund monitoring and mitigation activities in ‘at risk’ areas, while the latter is perhaps the bluntest implementation, seeking, after the event, to make the polluter pay direct financial and legal penalties for damage done.

According to the traditional PPP definition, ‘Pigovian taxation’ addresses the negative externalities and societal consequences arising from the actions of commercial enterprise, through levying additional sector specific taxation (internalisation of cost). Alternatively, the government can follow a command-and-control approach, with activity restriction through abatement devices, speed control and allocated zonal access emerging as measures to control mobile pollution sources. Idealistically, internalisation restores the Pareto optimality of competitive equilibria, where no actor can be made better off without making someone worse off, resource waste is minimised, and the welfare of society is at its maximum (Schmidtchen et al 2009).

A largely unexplored issue within the EJ literature is the question of whether a Localised Polluter-Pays Principle (L-PPP) exists, whereby the community responsible for producing pollutants experiences proportional environmental and social burdens. This is somewhat of a surprise, when considering that private vehicles (individually owned mobile sources), rather than large industrial facilities (corporate owned point sources) typically account for the larger proportion of detrimental pollution in urban areas. To-date the focus of EJ research has commonly been upon describing or quantifying how the socio-physical structures of the urban environment shapes health, with limited attention paid on the origins of the albeit complex environmental contributions imposed by personal sources. Recently, either as a conscious move towards a more comprehensive application of the PPP or simply a fortuitous offshoot from generalised policy, the introduction of policies based on urban zoning charges has brought aspects of local environmental responsibility into the remit of the ordinary citizen. However, the direct redistribution of collected wealth from such schemes to effected communities is not, at this stage, a required element of these policies nor, if it were, is it clear if conventional transport-sector mitigations would be the most effective mechanism for minimising environmental impacts in the most affected areas.

In 2003, the London Congestion Charging Scheme (CCS) became operational, as a means to alleviate traffic congestion throughout the cities central districts. Modelling indicated that wards located within the Congestion Charging Zone (CCZ) could experience a 1.3% reduction in NO_2 concentrations, an improvement that the modellers equated to 183 Years-of-life-gained per 100,000 persons over a 10-year period (YLG_{10}) (Tonne et al 2008). However, London's least (38.15μg/m^3) and most (47.01 μg/m^3) deprived ward quantiles, respectively, experienced 0.05% and 0.5% reductions on their pre-CCS NO_2 concentrations (corresponding to 5 and 60 YLG_{10}), suggesting this scheme, although of some benefit, has done little to address the social gap in environmental exposure.

Similarly, Cesaroni et al's (2012) evaluation of two low-emission zones established in Rome across the period of 2001-2005, revealed well-off residents to experience the greatest health gains from zoning implementation. Here, residential reductions in NO_2 concentrations were observed to conservatively provide 687 YLG_{10} for communities of high socioeconomic position, compared to benefits of only 163 YLG_{10} experienced by residents of the most deprived quintile (Cesaroni et al 2012). In a certain respect, the Rome LEZ fails as an environmental scheme as it should be the attention of policy workers to minimise existing societal gradients. This concept has become a priority of the UK government, following the independently commissioned 'Marmot Review' of evidence-based strategies for reducing health inequalities, which called for policy objectives to (Marmot et al 2010):

[1] Give every child the best start in life

[2] Enable all children, young people and adults to maximise their capabilities and have control over their lives
[3] Create fair employment and good work for all
[4] Ensure healthy standard of living for all
[5] Create and develop healthy and sustainable places and communities
[6] Strengthen the role and impact of ill-health prevention.

Still, one should not rule out a scenario where deprived communities emit the most and thus the polluter is paying. If this is the case then perhaps an ethical approach beyond that of the Polluter-Pays Principle is required. Yet both zoning studies fail to address such issues because they take no account of the origins of residentially experienced road-transport pollutants. Thus it is recommend that focus be placed on locating and defining communities of interest (in terms of pollutant creation and exposures), in order to improve the ethical efficiency of future traffic management schemes.

Likewise, local scales of influence has begun to take precedence in the historically framed international climate justice debate, as the distribution of climate change responsibilities and vulnerabilities have been found to parallel existing patterns of urban inequality (Satterthwaite et al 2008). Broto & Bulkeley's (2013) survey of 627 urban climate change experiments in 100 important urban nodes of the global economic system, positions EJ concerns (24.6%) above those of urban form (6.7%), built environment (24.7%) and adaptation (12.1%) concerns; only urban infrastructure (32.1%) was deemed to be of greater priority. While both private actors and civil society organisations explicitly considered justice measures, public actors were shown to have a poor uptake fuelled by the belief that existing mandates of governance adequately consider social justice (Broto & Bulkeley 2013).

1.4 FRAMEWORK FOR ANALYSIS

Mitchell & Dorling's (2003) environmental justice analysis of British air quality across 10,444 electoral districts, uniquely explores the role of locally generated vehicle emissions in the air-quality poverty relationship. Levels of NOx contributed by each community were derived from 'static' modelling techniques combining: [a] 1991 UK Census recordings of car ownership (ward level) categorised into vehicle type by DVLA fleet information (postal district), with [b] European Commission emission factors and typical travel distances respective of vehicle age. While following a comprehensive method for calculating community contributions, such models are still restricted by their 'static' nature, in that they fail to account for actual population movements in favour of a uniform vehicle-age distance function.

Although, Mitchell & Dorling (2003) identified residents from the areas of poorest air quality to contribute the most emissions per car, a clear pattern emerged in which wards experience the greatest NO_2 concentrations collectively emitted the least NOx, and experienced higher levels of deprivation. These findings would suggest that strong socio-environmental inequalities prevail throughout modern Britain, igniting the previously highlighted need for ethical groundwork prior to the implementation of future traffic management schemes. Whilst Mitchell & Dorling (2003) establish this tangent of EJ research, further research is required, as L-PPP issues have yet to be explored within the context of health outcomes, or across smaller intra-urban communities which have highly variable demographics.

This article seeks to develop upon Mitchell & Dorling's (2003) L-PPP concept, by exploring the interactions between intra-urban community generated vehicle emissions and Pearce et al's (2010) 'triple jeopardy' of social, environmental and health inequalities. Crucially, methodological enhancements are to be achieved by (a) analysing actual intra-urban workforce travel patterns, rather than assigning each community with a universal travel function; (b) assessing the L-PPP at a higher resolution census unit; and (c) through incorporating previously unexplored health outcomes into the creation-exposure evaluation.

Under this framework, this study aims to define intra-urban relationships between the creation and exposure of air pollution in a post-industrial setting, to best inform the internal actions of local policy makers. While the influence of commercial and longer distance commuters will disproportionally contribute to overall air pollution, external contributors to the city's ecosystem are not considered as preventative measures for such groups are best served by national policy. The later discussion of future cities offers some advice on how the influence of external groups may be mitigated.

2. METHODOLOGY

2.1. DATA COLLECTION

Leicester is a culturally diverse British city. In 2001, the city housed 279,924 inhabitants across 73.32 km^2, 22.3% of which were children aged 0-15 years (ONS 2003). The city is considered to be relatively deprived, ranked as the 31st poorest out of 354 Local Authorities in England for the revised-2004 and 2007 Indices of Multiple Deprivation (ONS 2007, ONS 2008). Leicester is currently ranked as the 21st small (population <800,000) and 98th overall most congested city in the world, with trips across the city's highways, arterial and local roads taking on average 23% longer than expected, rising to 53% during peak flow periods (TomTom International 2015).

Underlying demographic information was obtained from the 2001 UK Census, as part of the ESRC Census Programme (ONS 2003). Intra-city deprivation rates for Leicester were calculated using unweighted z-scores of four census variables (Carstairs & Morris 1991); outputs range from -7.19 (affluent) to 9.14 (considerably deprived), with 0 identifying communities with the city's expected social standing. Census Flow Data, providing information on the movement of people across LSOA's (Origin-Destination) as part of their daily commute to work in 2001 was obtained through the UK Data Service Census Support Service (ONS 2014).

Leicester City Primary Care Trust provided a geocoded respiratory subset of NHS hospital admissions (ICD-10: J00-99) for children residing within Leicester Unitary Authority's (UA) 187 Lower Level Super Output Areas (LSOA's) from 2001-2005. Admissions were weighted against the number of persons aged 0-15 years residing within each census area LSOA, in order to obtain a 1-year standardised hospitalisation rate.

Residential exposure to particulate matter up to 10µm in diameter generated by road-transport (TPM_{10}) was obtained at the LSOA level by kriging the '2008 1x1km Road Transport PM_{10} Emission' map of Leicestershire (R-AEA 2010), as outlined in Jephcote et al (2014).

Annual LSOA estimates of private TPM_{10} emissions created from individual communities were derived by combining vehicle fleet compositions with workforce trips, which were assumed to represent a significant proportion of population movements. Vehicle compositions (%) within each LSOA were derived from a summary of privately owned vehicles registered with the Driver Vehicle Licensing Agency (DVLA) in 2010, provided by the Callcredit Information Group. Vehicle counts were disaggregated into their corresponding LSOA's, from 4 postal sectors for vehicles older than Euro III, and 22 postal districts for vehicles Euro III and above. This disaggregation procedure was achieved through the use of the online Postcode Best Fit (PBF) Methodology facilities, developed by the ONS to produce consistent demographic estimates over a range of geographic outputs regardless of whether nesting exists in the target structures (ONS 2011). The DVLA data was subsequently split into 25 vehicle groups defined by vehicle age (Pre-Euro, Euro I, Euro II, Euro III, Euro IV, Euro V), category (car, commercial vehicle, motorcycle) and fuel type (petrol, diesel). Motorcycles were uniformly classified due to low levels of ownership. The 25 designated vehicle groups were taken to account for a proportion of 2001 UK Census recorded LSOA trips to work, by mode of transport for persons aged 16-74 in employment. Each vehicle group was assigned a distance based PM_{10} emission factor (g/km) for urban driving conditions, recorded in the latest Department for Transport Emission Factors toolkit (DfT 2009). These emission rates were then combined with a commissioned Office for National Statistics (ONS) 2001 UK Census dataset, detailing the daily method of travel to work by the average Euclidean distance (km) travelled within each LSOA.

TPM_{10} contributions from public modes were estimated by combining a nationally-weighted emission factor with a national passenger split, applied to bus trips made by the local workforce, as recorded in the 2001 census. Parliamentarian records indicate that in 2005 a bus carried on average 9 passengers per vehicle (UK House of Commons 2005), with 2008 fleet-weighted emission factors for a bus operating in urban conditions (0.138 g/km) calculated by applying a Euro standard split (R-AEA 2014) to vehicle emission factors (DfT 2009). While full capacity may occur on some services at peak times, this mode of travel exists as a commuter subsidised community service emitting pollutants throughout the day.

2.2. STATISTICAL APPROACH

2.2.1. RESPONSE SURFACE MODELLING

The aforementioned datasets were analysed using the response surface capabilities of the statistical package, MINITAB 16. The resulting probability surfaces depict the relative likelihood of an outcome (z-Axis) occurring in a community as a function of two socio-environmental characteristics. For improved data visualisation, the procedure constructs a series of probability surface coordinates (**u**) from standardised x-Axis and y-Axis socio-environmental variables. Inverse-distance weighted (IDW) interpolation creates a continuous surface area for the z-Axis. IDW interpolation explicitly implements the assumption that things that are close to one another are more alike than those that are farther apart, written in the form (Shepard 1968):

$$\mathbf{u(X)} = \begin{cases} \sum_{i=1}^{N} \mathbf{w_i(X)\, u_i} \Big/ \sum_{i=1}^{N} \mathbf{w_i(X)} & \textbf{if } \mathbf{d(X, X_i) \neq 0} \textbf{ for all i} \\ \mathbf{u_i} & \textbf{if } \mathbf{d(X, X_i) = 0} \textbf{ for some i} \end{cases}$$

Where the interpolated value at a given point **u(X)** is based on the weight of influence of recorded observations:

$$\mathbf{w_i(X) = \ 1 \ / \ d(X, X_i)}^{\boldsymbol{p}}$$

X denotes an arbitrary interpolated point, and $\mathbf{X_i}$ is an observation (interpolating) point separated by a given distance d. Each of the regular 100 by 100 mesh surface points were obtained through interpolating all **N=187** datum points, with a high power parameter $\boldsymbol{p}$**=10** assigning predominant influence to observations of immediate proximity. The practice is conservative by nature, restricting z-Axis values to the current observation range. This is favourable if sampling errors are large and where isolated values or sudden transitions occur.

2.2.2. LOCAL MORAN'S I

Local Moran I statistics, were applied to each LSOA for the detection of spatial patterns that substantially compare or deviate from neighbouring elements (Anselin 1995):

$$\mathbf{I_i = Z_i \ . \sum_{j}^{n} W_{ij}\, Z_j} \qquad\qquad \mathbf{j \neq i}$$

Where, $\mathbf{Z_i}$ is the z-score value for the attributed of interest at the ego location **i**, and $\mathbf{Z_j}$ is the z-score value for the attributed of interest at neighbouring observations **j**. Spatial weights indicating the strength of connection between the paired LSOA features of **i** and **j** are represented by $\mathbf{W_{ij}}$. Only immediate adjacent geographic features were defined to have spatial weighting which were standardised by neighbour count. Significance was evaluated via 9999 Monte Carlo permutations, with the resultant p-values experiencing a Simes correction to minimise the extent of Type I and Type II errors (Simes 1986).

3. RESULTS

3.1. ENVIRONMENTAL EQUITY

Annual LSOA estimates of road-transport PM_{10} (TPM_{10}) emissions created by individual communities from private modes were derived by combining local vehicle fleet composition counts with local workforce trips, with public contributions estimated via nationally-weighted emission factor and passenger splits applied to bus trips made by the local workforce. Median LSOA emission contributions from private and public road modes were respectively estimated at 81.44% and 18.56%, whereas the median split in commuter travel choices between these mechanical modes corresponded to uptake levels of 74.31% and 25.69%. Statistical measures of association respectively indicate strong and moderate inverse correlations between mobile polluters and communities characterised as socially or environmentally burdened (TABLE 1).

	Employed Persons: 16-74 Years	Carstair's Index: Leicester	Residentially Experienced TPM_{10} (t/y.)
Pearson's R	0.774	-0.768	-0.330
Spearman's Rho	0.786	-0.783	-0.338

TABLE 1: Statistical correlation of community created TPM_{10} emissions from public & private modes (t/yr.) and key demographic markers (P<0.01)

While a situation of environmentally inequality currently can be observed to prevail across the city of Leicester, simply pointing the finger at those affluent communities does not allow for a fair assessment of the current state of environmental affairs, without accounting for a number of other circumstances. For instance, the level of employment will determine some variations in pollutant contributions purely though an increase in required trips (TABLE 1). Under these circumstances, it would be socially unfair to simply place a raised environmental accountability onto these communities, as in many ways such inhabitants are already paying societal contributions (collected via taxation), which in theory should be used to benefit those in vulnerable situations. At present, the UK motorist is faced with two main environmental taxes:

a) Fuel Duty paid on sales of all hydrocarbon fuels, of which around 61% is taken as tax (Environmental Audit Committee 2011)
b) Vehicle Excise Duty paid on car ownership, which respectively ranges from an annual rate of £0 to £515 for vehicles emitting ≤100 and >255 g/km CO_2 (DVLA 2016)..

Arguably a carbon specific taxation is an insufficient regulation measure, as certain vehicle types may meet lower thresholds for the creation of climate change chemicals and still heavily emit compounds of immediate detriment to human health. It is perhaps more justifiable to place environmental accountability on excessive travel distance via polluting modes (in relation to the city norm) and the use of certain transportation measures, which should be viewed after existing societal contributions are accounted for.

As such, community created TPM_{10} emissions from public-private modes were corrected by levels of employment, to form an emission rate per employed person (PEP). With the assistance of the Local Moran's I statistical test, one may notice that a moderately positive level of spatial structuring of community emission contributions PEP exist across Leicester (R^2 =0.47). In particular, peripheral communities with high polluting potentials are defined as socially and environmentally affluent, whereas deprived inner-city communities with a low polluting potential appear significantly burdened by the TPM_{10} contribution of others (FIGURE 1, TABLE 2). Interestingly, relatively low TPM_{10} levels across eastern and south-eastern are located near a missing section of Leicester's outer ring road, with traffic currently forced traffic towards central areas (FIGURE 1).

		Average Residential Markers			
Cluster	**Count**	**Created TPM_{10} (kg/PEP)**	**Experienced TPM_{10} (t/yr.)**	**Carstair's Index: Leicester**	**Annual J00-99 Admissions Per 1,000 Children (2001-05)**
L-L	14	0.01	1.70	3.82	42.43
H-H	12	0.04	0.79	-4.30	30.76
Citywide	187	0.02	1.03	0.00	38.50

TABLE 2: Socio-environmental summary of Local Moran's I spatial correlation structures (P<0.05), of annually corrected community created TPM_{10} emissions from public-private modes (kg/PEP).

Census flow data referencing the origin-destination of intra-urban daily commute movements were extracted for Leicester's 12 highly polluting communities, to further evaluate the contribution-exposure relation. Approximately two-thirds of commuter trips had destinations internal to Leicester, with 87.4% of all trips observed to terminate within 15km of the city centre. The resulting flow map (FIGURE 1) for internal trips was created in ArcGIS 10.2 with the 'Flow Direction' and 'Flow Accumulation' toolboxes, informed by iteratively constructing euclidean distance cost surfaces between LSOA destination and raster grid cells constrained to the major road network, defined by the OS VectorMap District product.

Commutes are shown to have a centric focus, with mechanical forms of transportation from highly polluting communities passing through less affluent neighbourhoods, typically located within close proximity to places of work. It is likely that the movement of commuting vehicles through these neighbourhoods would result in congestion, causing a localised increase in TPM_{10} contributions. Jephcote & Chen's (2012) weighted regression analysis previously indicated that the affluent and highly polluting south-eastern block of peripheral communities experienced some, but still disproportionately low TPM_{10} related health problems. FIGURES 1 and 2 reiterate this mild internal effect, associated with cold-start contributions and the potential for congestion by high volumes of traffic vacating affluent communities.

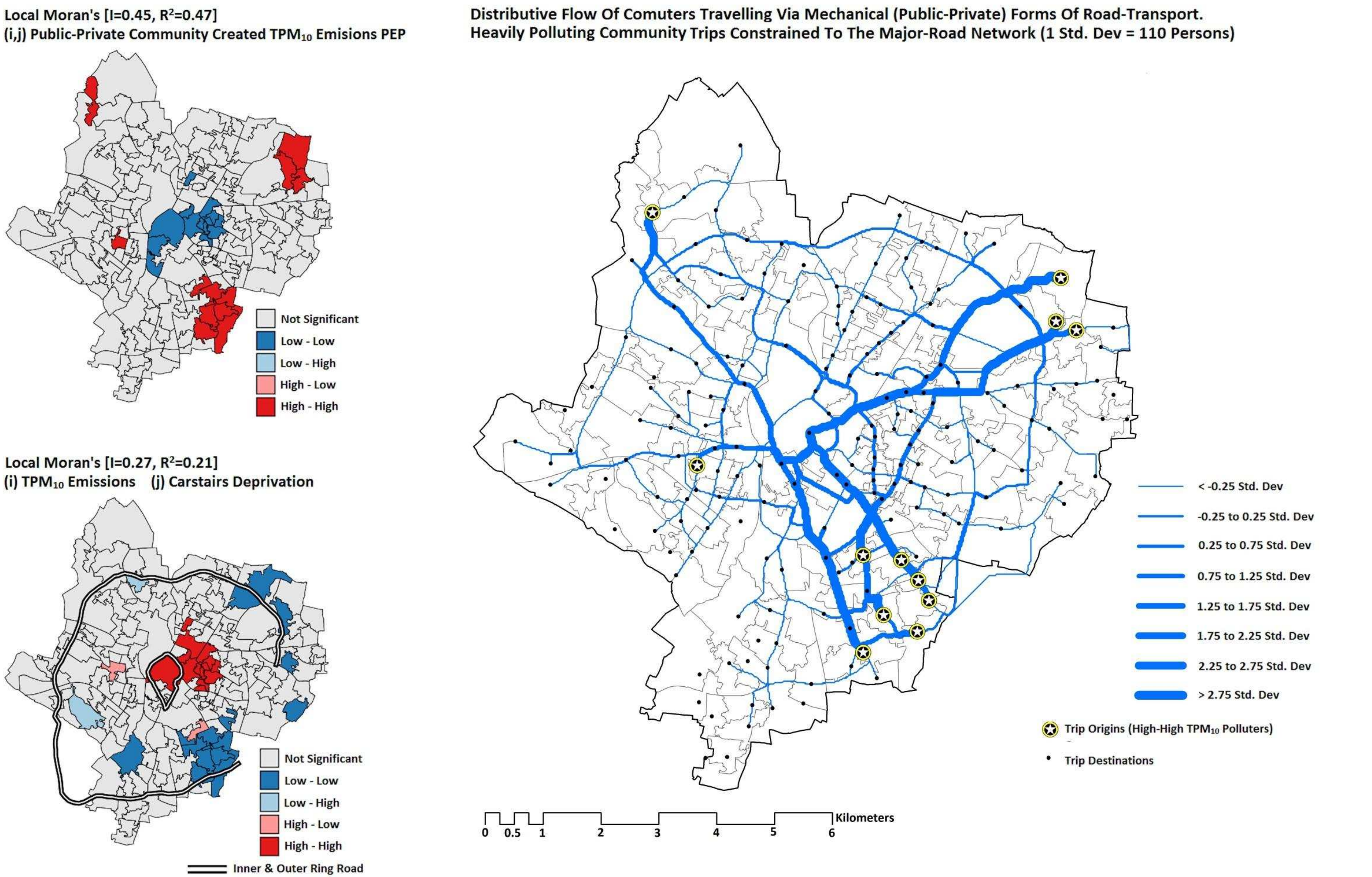

FIGURE 1: Local Moran's I spatial pattern detection of key socio-environmental communities (P<0.05), explored in detail via census flow data referencing the origin-destination of intra-urban daily commutes

Across Leicester, 61.5% of affluent communities (Carstair's Rank <-1) travelled >15km PEP on their daily return commute, whereas 85.9% of the workforce from deprived communities (Carstair's Rank >-1) only travelled 6-15km PEP. This follows the concept that districts of work are located close to deprived communities, and as affluent communities have further to travel the use of less environmentally friendly modes is encouraged. In addition, a common district of destination is likely to create an accumulation of pollutants, which may be further added to by the shorter trips of those less privileged residents living within the nearby vicinity.

Spatial patterns of environmental injustices are illustrated in further detail through a set of contour plots, simultaneously examining residentially experienced TPM_{10} emissions (x-axis) and deprivation (y-axis) against a final metric of interest on the z-axis (FIGURE 2). Children's respiratory cases are shown to rise in relation to increased residentially experience TPM_{10} emissions, the effects of which generally appear to be felt more significantly by those communities which emit lower levels of pollutants from personal modes of transportation. Affluence is also shown to be a powerful means of mitigating the onset of severe health issues.

By assigning emissions created PEP as the final factor, one should note that some communities identified as housing children with severely reduced respiratory health (≥70 J00-99 admissions per 1,000), tend to contributing modest amounts of transport related pollutants (FIGURE 2, TABLE 3), which in an environmentally just situation would result in only moderate health implications. Most unfairly, a second group of communities with severely reduced respiratory health is show to comprise of the cities lowest polluters (FIGURE 2, TABLE 3). Collectively, these residents appear unfairly plagued by the contributions of external communities, whom health wise pay relatively little.

		Average Residential Markers			
	Count	**Created TPM_{10} (kg/PEP)**	**Experienced TPM_{10} (t/yr.)**	**Carstair's Index: Leicester**	**J00-99 Per 1,000 Children (2001-05)**
Moderate Polluters, Health Burdens	3	0.02	1.98	4.27	78.12
Low Polluters, Health Burdens	2	0.01	2.10	5.16	84.67
Affluent, Environmental Burdens	7	0.01	1.55	-1.64	28.03
"Green" Communities: 90th Percentile	19	0.02	1.80	1.76	46.27
• **Socially Deprived**	8	0.01	1.94	4.79	63.08
• **Socially Affluent**	3	0.02	1.38	-1.77	26.14

TABLE 3: Socio-environmental summary of community groups identified to be of interest by the contour plot analysis (see FIGURE 2)

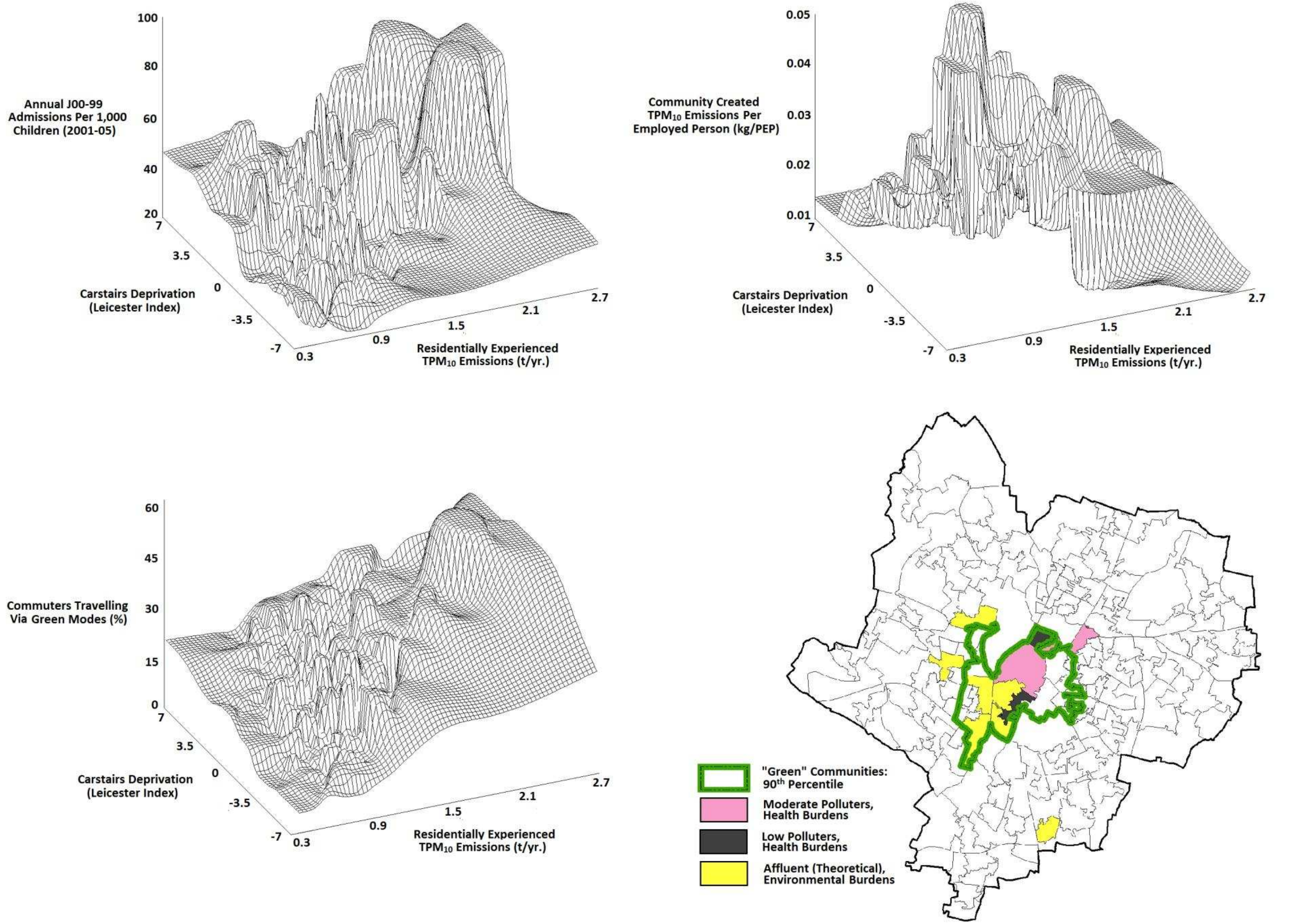

FIGURE 2: Response Surface modelling (contour plots) depicting the relative likelihood of a metrics occurrence in socio-environmentally characterised communities

In viewing the graphical representation of the uptake of ‘green’ transportation modes (on foot, and bicycle), one may observe a low average uptake of 15.76% by socially and environmentally rich communities in the visualised ‘double burden’ relationship (FIGURE 2). It would appear that ‘green’ transport use dramatically increases with respect to residentially experienced levels of TPM_{10}, regardless of social status; uptake rates >30.0% are achieved once residential TPM_{10} levels exceed 1.5t/yr. Although one should also note that levels also increase with deprivation, suggesting that this trend could be driven by necessity rather than personal choice. While beneficially keeping additional vehicles off the road, an increased uptake in physical exercise across polluted neighbourhoods may not actually decrease respiratory cases, with the health benefits of some communities offset by increased periods of exposure (TABLE 3). Alternatively, an increased use of affordable low grade vehicle stock by such communities may exacerbate levels of respiratory admissions. Therefore, the encouragement of ‘green’ modes appear a means of mitigation rather than an out-and-out solution, with further measures required to limit how external communities shift their share of pollutants onto these inhabitants. The implementation of a small but targeted strategy providing assistance with vehicle maintenance and or encouraging alternative transportation modes in vulnerable communities could also have a noticeable impact.

3.2. BEHAVIOURAL INFLUENCES AND TRENDS IN TRAVEL

A degree of Environmental Injustice has been shown to prevail in Leicester. To assist policy-makers and planners in addressing such imbalances, this section of the paper seeks to demonstrate the application of spatial pattern detection techniques to understand local travel behaviour. A targeted policy approach would allow for a tailoring of broader transport strategies to community needs, potentially improving any implemented measures chance of success.

Intra-urban commuter travel choices are evaluated in terms of: (a) person adjusted quantitative travel contribution metrics, and (b) the uptake of transport modes within each community. Underlying information from the 2001 census was used to produce person adjusted quantitative metrics, summarised by pattern detection techniques in FIGURE 3. Here, community contributions of emissions (from private or public modes) and distances covered by ‘green’ travel are adjusted per employed person (PEP), with the uptake of carpooling calculated by a ratio of passengers to drivers. The pure uptake (or split) of transport modes among commuters in each community was available from both the 2001 and 2011 census, thus allowing for the discussion of long-term trends in travel behaviour. It should be noted that the 2011 entries in TABLE 4 provide Carstair’s Index markers of deprivation relative to the expected community level in Leicester, for 2001 and 2011. While there have been changes in underlying information behind the expected Index value of 0 since 2001 [-8.9% unemployment levels; +17.49% vehicle ownership, +39.5% overcrowding; -20.2% social status], the two years remain highly correlated (R^2=0.91) with index measurements between years varying by ±0.76.

Pattern detections for the uptake of journeys taken via private transport and TPM_{10} emissions PEP for private modes in 2001, show strong signs of spatial structuring, and are inversely related to deprivation and environmental exposure (FIGURE 3, TABLE 4). Of particular concern is the 10.56% citywide increase on journeys taken via private modes by 2011, along with an apparent strengthening of the spatial division in which these trips originate, as designated by a 0.18 rise on the 2001 Moran's Index value. This would suggest that alternative transport schemes are either absent or not fulfilling the local requirements of these relatively affluent eastern and south-eastern peripheral communities, and thus require further evaluation. In particular, communities along the south eastern periphery had a particularly low use of public transportation (9.43%) in 2001 compared to the expected citywide level (15.63%), with this modes uptake decreasing further by 2011. As these peripheral communities are located the furthest away from zones of work a more viable solution to remove vehicle numbers may be carpooling.

Pattern detection outputs for private commutes with a passenger in 2001, identified a rate of 11.36% for cold-spot communities predominantly along the south-eastern periphery; despite such areas having a high use of private transport (52.14%). In contrast, carpool hot-spots are located in deprived inner-city neighbourhoods with low levels of vehicle ownership, thought to be of a poor condition. Here, financial constraints appear to be behind the sharing of resources, which enable residents to access distant work zones with the intention of improving their socioeconomic status. The implementation of a small but targeted strategy providing assistance with vehicle maintenance may prove essential in minimising local influences across environmentally burdened communities, without impeding their mobility. While their use of public transportation is comparable to the citywide rate, anecdotal evidence indicates that private modes offer greater flexibility for employment during irregular working hours, and further evaluation is required of the local public services to check that they meet the needs of such communities.

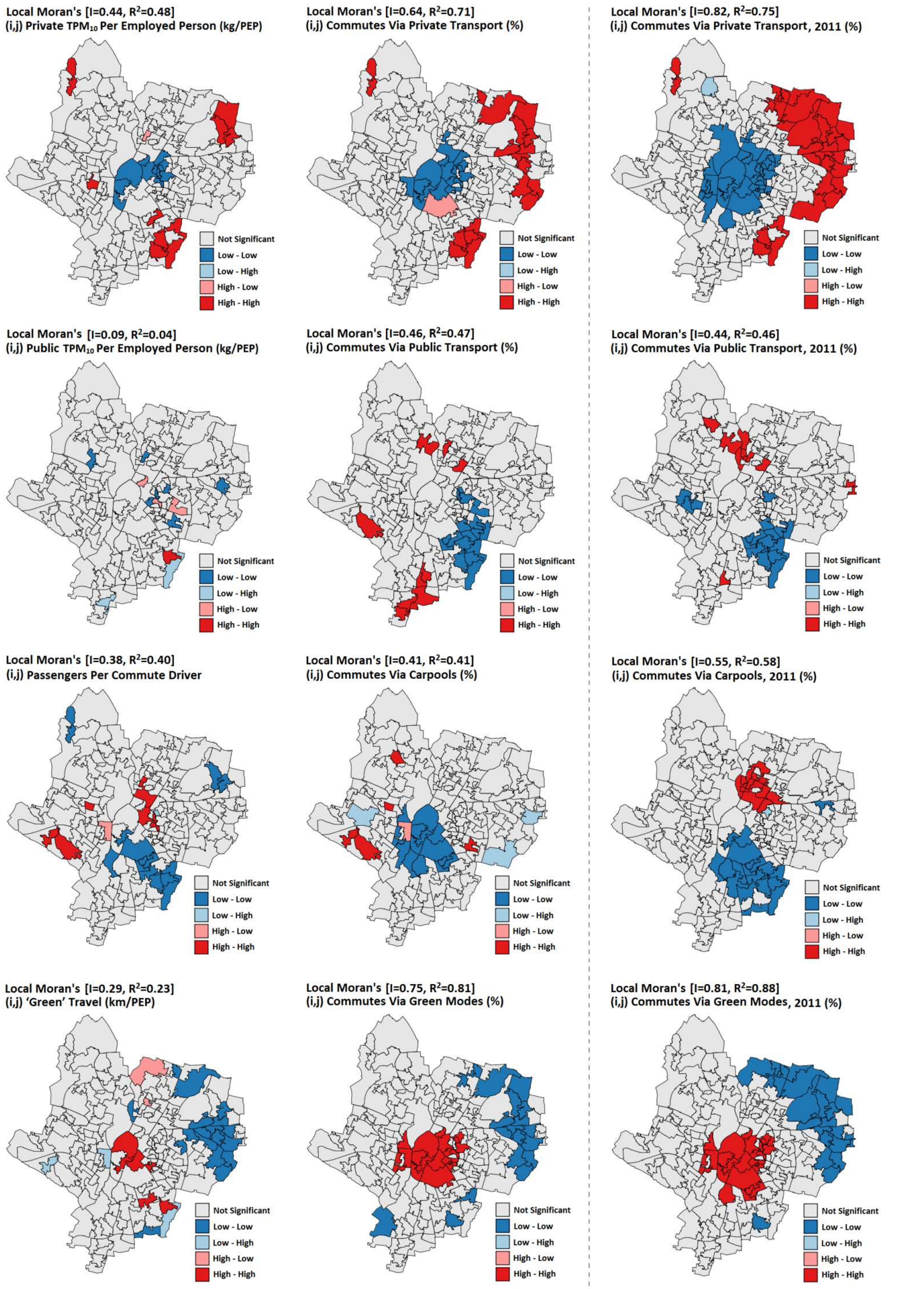

FIGURE 3: Local Moran's I evaluation of intra-urban commuter travel choices in terms of person adjusted quantitative travel contribution metrics (left), or community uptake of transport modes in 2001 (centre) and 2011 (right) (P<0.05)

Variable Of Interest (VOI)	Year	Cluster Analysis			'Double Burden' Measure		Travel Mode Uptake (%)			
		Cluster	*Count*	*VOI Value*	*Experienced TPM_{10} 2008 (t/yr.)*	*Carstair's Index: Leicester 2001 (2011)*	*Private*	*Public*	*Carpool*	*Green*
Private TPM_{10} Per Employed Person (kg/PEP)	2001	L-L	12	0.01	1.76	3.84	33.70	14.32	6.87	34.65
		H-H	10	0.03	0.77	-4.16	57.33	12.02	6.60	14.49
Public TPM_{10} Per Employed Person (kg/PEP)	2001	L-L	7	0.00	1.22	1.80	43.76	12.91	9.09	23.29
		H-H	1	0.01	0.77	-6.03	65.23	6.98	4.46	14.56
Passengers Per Commute Driver	2001	L-L	14	0.11	0.99	-3.69	52.14	11.21	5.75	21.61
		H-H	8	0.23	1.38	3.43	38.63	15.21	8.78	27.11
'Green' Travel (km/PEP)	2001	L-L	18	0.62	0.76	-1.73	55.61	14.90	8.32	11.17
		H-H	6	3.64	1.65	-0.68	38.40	10.92	4.29	36.80
Commutes Via Private Transport (%)	2001	L-L	19	33.52	1.77	3.33	--	14.48	6.60	34.94
		H-H	18	59.88	0.69	-3.63	--	12.62	7.44	10.28
	2011	L-L	36	36.88	1.61	2.34 (2.73)	--	13.85	8.85	34.31
		H-H	29	64.99	0.68	-2.74 (-2.77)	--	12.23	6.84	9.99
Commutes Via Public Transport (%)	2001	L-L	17	9.43	1.02	-2.31	51.17	--	7.17	21.02
		H-H	9	20.53	1.00	1.31	44.57	--	8.55	17.60
	2011	L-L	17	8.49	0.97	-3.72 (-4.09)	54.87	--	6.07	21.87
		H-H	9	17.98	1.09	1.66 (1.80)	48.39	--	10.86	18.78
Commutes Via Carpools (%)	2001	L-L	14	5.76	0.99	-3.69	52.14	11.21	--	21.61
		H-H	8	8.78	1.38	3.43	38.63	15.21	--	27.11
	2011	L-L	19	5.12	1.08	-3.39 (-3.33)	49.51	10.92	--	26.70
		H-H	13	12.14	1.22	2.49 (2.48)	43.88	17.54	--	21.42
Commutes Via 'Green' Modes (%)	2001	L-L	19	9.70	0.70	-2.77	58.71	13.86	7.85	--
		H-H	20	36.54	1.77	2.10	34.55	13.32	5.84	--
	2011	L-L	23	9.14	0.67	-2.22 (-2.33)	65.79	12.88	7.03	--
		H-H	26	37.03	1.62	1.44 (1.67)	36.22	12.70	7.45	--
Citywide	2001	--	187	--	1.03	0.00	47.08	15.63	7.72	20.36
	2011	--	187	--	1.03	±0.76 (0.00)	52.05	13.90	8.18	20.54

TABLE 4: Socio-environmental summary of community groups identified of interest by the Local Moran's I evaluation of intra-urban commuter travel choices

4. DISCUSSION

Whilst Polluter-Pays Principles are traditionally theorised at an international level, the authors sought to develop on Mitchell & Dorling's (2003) localised implementation of such principles by exploring a collection of spatially detailed intra-urban communities, within the context of social, environmental and health outcomes. Statistical measures of association respectively indicate strong and moderate inverse correlations between mobile polluters and communities characterised as socially (-0.78) or environmentally burdened (-0.34).

A fair exploration of environmental accountability considering existing societal contributions noted these moderate and positive spatial structuring of community emission contributions, to prevail across Leicester (R^2=0.47). The cities greatest polluters reside predominantly within affluent communities located along the cities periphery, whereas those creating the least emissions resided in central locations, and experience a range of socio-environmental health burdens. Intra-urban daily commute flows were identified to be centrically focused, with private vehicle commuter journeys from affluent polluting communities passing and terminating near less affluent neighbourhoods. The less affluent areas use active ('green') travel modes, although any health benefit may be offset by increased periods of environmental exposure. Whilst some inner-city communities moderately contributed towards their environmental demise, these contributions were substantially outweighed by those made from external communities, whom appear to largely avoid the social, environment and physical cost of their actions. In its current state, the city's traffic management strategy seemingly operates in an environmentally unjust manner.

Across Leicester, the majority of trips are completed via personal transport. Affluent communities particularly favour private modes, but a strong disassociation with the uptake of public transportation reveals that they do not inconveniencing external communities across a spectrum of motorised modes. In addition, those poorest inner-city communities are not observed to have a raised uptake of public transport, despite the central hub operating out of these areas. A low uptake of public services is perhaps an issue of concern, with some inner-city communities starting to favour the use of inexpensive and often poorly maintained private vehicles; with this newfound mobility seeking to address their social standing, but at the cost of their environmental attributes. To tackle such issues, perhaps these central communities require further incentive to use public modes, rather than adding vehicles to the road network. However, any measures should not be conducted in a manner which impedes the social climb of such communities.

The likely negative stigma of public services amongst affluent communities also requires further investigation. For these communities, a more likely and immediate response for mitigating their environmental contributions would appear to involve the use of carpooling. Here, the convenience and luxury of personal transportation is likely to be favoured, and could mark a substantial reduction in the volume of vehicles which enter inner-city areas. However, at present, the uptake of carpooling appears most prominent across those most deprived communities conducting the fewest and smallest trips via personal modes, and thus offers few benefits.

Within Great Britain, the Department for Transport has shown car occupancy levels to remain at a relatively stable level of 1.60 persons per vehicle between 1996 and 2008 (Dft 2009); and parliamentarian records have indicated that in 2005 a bus carried on average 9 passengers per vehicle (UK House of Commons 2005). Using this information, fleet weighted emission factors for buses outside of London (0.1381 g/km) were identified as equating to the PM_{10} contributions of either 53 petrol or 7 diesel cars (R-AEA 2014, Dft 2009), which would hold approximately 11-84 passengers. Therefore, a direct shift from private to public modes of road-transport may not necessarily be the best solution to a cities air quality problem, without fleet renewal or retrofitting strategies for existing stock. Perhaps, the implementation of small but targeted measures providing assistance with vehicle maintenance in vulnerable communities would be of greater effect in reducing their proportionally high pollutant outputs per vehicle. If private vehicles are to remain the predominant mode of travel, localised incentive and carpool schemes are best placed within a citywide transport scheme (two-layer policy strategy).

4.1. LOW EMISSION NEIGHBOURHOODS

Recently the implementation of Low Emission Zone's (LEZ) have been seen as one of the more promising options to 'Actively' introduce greater numbers of cleaner vehicles and reduce the numbers of older more polluting vehicles on the road networks of capital cities (Tonne et al 2008, Cesaroni et al 2012). Whilst a theoretical application of comparable road user charging schemes has been seen to provide appropriate results across the considerably smaller UK municipal centre of Leeds (Mitchell 2005, Namdeo & Mitchell 2008), in practice the overall outcome of such measures remain unclear. For instance, is the draw of smaller commercial centres sufficient to retain business and a viable flow of consumers, if such a charge was in operation at a local rather than regional or national scale? One must also question the fairness of a scheme seeking to prevent the movement of highly polluting non-commercial vehicle stock in certain urban neighbourhoods, typically owned by the lower social classes that reside in such areas at risk. To avoid this issue requires either the use of vehicle maintenance schemes in vulnerable communities, or the exemption of resident vehicles in communities unfairly burdened by others. It is estimated that an 'Active' LEZ in the comparably sized city of Oxford could achieve PM_{10} reductions of up to 70% with respective feasibility study and set-up costs of £30,000 and £50,000; yet the running and enforcement costs remain an unknown entity (Oxford City Council 2006). Perhaps it would be more viable for a city the size of Leicester to adopt a 'Passive' form of LEZ, known as 'Environmental Zones' (EZs), which have been in operational force across the Swedish city centres of Stockholm, Gothenburg and Malmo since 1996.

EZs act to remove heavy-duty diesel vehicles (commercial and public transportation) older than 8 years from the roads through the use of windscreen permitting. Exceptions to this age requirement may be permitted for vehicles with particularly low emissions or if vehicles are equipped with approved exhaust gas-purification equipment. Whilst remaining enforced, these zones are yet to experience updates akin to the stringent emission standards for such vehicles found in 'Active' LEZs. Still, these passive low emission charges with self-regulation would appear to have remained a largely successful measure with the proportion of vehicles not entitled to enter the Stockholm, Göteborg and Malmö's EZ's in 1997 and 2004, respectively recorded at 5% and 3% (Göteborg's Stad Trafikkontoret 2006).

In Göteborg, the EZ covers around 15 km^2 housing approximately 100,000 inhabitants and 100,000 work places, which has respectively experiences traffic volumes of 30,000 and 39,000 per day in 1996 and 2004 (Göteborg's Stad Trafikkontoret 2006). Scenario models for Göteborg in 2005 indicate that the EZ could contribute as much as a 33.2% reduction in PM_{10} emissions (2,767 kg/year), which are substantial gains considering the schemes low implementation and running costs (Göteborg's Stad Trafikkontoret 2006). The Stockholm EZ was established in 1995, covering around 14 km^2 housing approximately 25,000 inhabitants and 280,000 work places (Rapaport 2002). Relative change traffic emission models show that maximum roof-top $PM_{2.5}$ concentrations with and without an EZ (relying on a natural fleet renewal) would respectively exist at 0.40μg/m^3 (-49%) and 0.40μg/m^3 (-25%); implying that the EZ scheme directly reduced $PM_{2.5}$ concentrations by 26% over the period 1995-2001 (Rapaport 2002).

In 2008, another EZ variation was implemented in the cities of Berlin, Cologne and Hanover, in response to German anti-air-pollution implementing EU Framework Directive 1996/62/EC and Daughter Directive 1999/30/EC on ambient air quality and fine particles. Here, all vehicles were required to display a €12.5 special traffic-light coded environmental badge (Umweltplakette) for legal entrance to designated urban sectors known as “green zones”, with non-compliance met by a €80 fine. While the LEZ has had no measurable impact on traffic flows, the turnover of the national fleet towards cleaner vehicles has speeded up considerably; after two years of enforcement, >50% of the commercial fleet and 66% of diesel passenger fleet fall within the green category (Euro 4 or retrofit) required of badge holders, compared to respective figures of 20% and <50% outside “green zones” (Lutz & Rauterberg-Wulff 2010). In terms of local environmental benefits, areas within the Berlin ‘Passive’ LEZ have been estimated to experience a 4.5% reduction in PM_{10} (Lutz & Rauterberg-Wulff 2010).

A fourth option to consider across road systems is the use of discriminatory pricing, which attractively provide a means for matching demand to capacity in a particular location and at a given time of day, more precisely than under a single or tiered pricing system. Discriminatory road pricing could be a means to reconcile a charging mechanism aimed at regulating demand with the social objective of avoiding exclusion of low-income motorists from access to employment, shops, and other facilities (Metz 2005). A 2000-03 analysis of adjusted average household expenditure on vehicle purchase and operation of personal transport across the UK respectively indicate an expenditure of £38 and £120 for the country’s poorest and richest 10th percentile (Metz 2005). When compared to current weekly road charges in Britain of £25 entry into the London congestion charging zone and £30 for two-way use of the M6 toll road, it is apparent that existing schemes have a risk of unfairly pricing those most vulnerable in society off the roads.

4.2. FUTURE CITIES

Rudlin et al’s (2014) winning submission for the 2014 Wolfson Economics Prize, presents a visionary, economically viable and popular approach for a modernised version of Ebenezer Howard’s utopian Garden City blueprints of 1989. The revised snowflake design, is applicable to a multitude of small (~200,000 residents) yet historically established British cities, formed of three satellite extensions each housing 50,000 people, located within 10km of the city centre. These are to be served by tram or Bus Rapid Transit (BRT) running from the existing mainline station on disused lines, switching to an on-street loop through the new neighbourhoods.

In the absence of large scale subsidy development can only be attained through the ‘unearned increment’. For each urban extension a City Trust (jointly owned by local and central governance, land owners, and the local community) vested with commissioning the master plans is initially required to raise £50.1M (Year 0), with land equity reinvested in successive infrastructure, until a point is reached where initial investments are repaid in full and local communities take on the stewardship (Year 14: Cumulative balance = £62.5M profit). Transport infrastructure per urban extension is costed at £410M, with the 12km of tramline connecting neighbourhoods to the central hub costing £180M. This has been designed around the “Freiburg Model”, a German university city of 218,000 persons which successfully used trams to link the urban extensions of Vauban and Rieselfeld to the historic centre.

Constructed between 1993 and 2010, both districts contain a range of socially inclusive housing options developed around the use of public transport, with direct lines running to the centre in <15 minutes, and many neighbourhood roads designated “home zone” status, restricting traffic to 7km/hr. Residents who decide to own a car can purchase a parking garage space at the edge of the development for approximately £15,500, with residents who wish to live car-free simply paying a one-time fee of £3,100 to preserve open space at the edge of the development in lieu of a parking spot. This arrangement has proven successful, with a recent survey showed that there are 150 cars per 1,000 inhabitants in Vauban, compared to roughly 420 for the City of Freiburg and over 560 for Germany.

In the Freiburg model, successful implementation of citywide policies complementary to such developments were achieved via a multi-modal strategy, restricting non-resident parking to periphery of the city centre, while incentivising public and green modes as viable alternatives through fare subsidies, improvements to travel quality, and the complete integration of public services. In 1984, Freiburg’s public transport offered an attractively priced unified ticketing system that saw a 42% increase in ridership by 1990, with expansion of the so-called ‘‘environmental ticket’’ into adjacent counties increasing region-wide public transport trips by 70% between 1991 and 2007.

The foundations for a citywide sustainable transport first materialised in 1973 with 29 km of unconnected cycling paths set aside and the pedestrianisation of the city centre; walking in Freiburg’s old town has thrived, with 69% of all trips on foot in 2007. The total number of bike trips in Freiburg nearly tripled between 1976 and 2007 (from 69,500 to 211,000), with almost one bike trip conducted per inhabitant per day following the construction of 410km of bike lanes, and the requirement for all new developments to include secure bike parking. Fundamentally, citizen involvement has proven to be an integral part in the collective success of Freiburg’s district, citywide and regional policy development measures that have enabled the complete integration of transport and land-use planning.

Major car manufacturers in the form of Audi, BMW, Ford, Smart and VW are beginning to explore the development of high-performance electric bicycles (e-bikes). Whether this is in response to increased demand for versatile and sustainable forms of transportation or as a marketing ploy ("green tokenism") remains to be seen. In concept, the automotive industry sees e-bikes as a lifestyle accessory, with car-owners driving to out-of-town parking or a train station in the suburbs (continuing their journey by public modes), before motoring electrically to the office a mile or two away. This lifestyle choice has the potential to remove the environmental burdens of persons residing beyond the city limits (external contributions).

The BMW i-Pedelec (Pedal Electric Cycle) concept is envisioned to complement the BMW i3 electric hatchback, which is capable of semi-permanently storing and in transit, charging two e-bikes with a range of 16-25 miles (The Independent 2012). Alternatively, the prototype 'Audi e-bike Wörthersee' is designed as an out-and-out car replacement, with an achievable top-speed of 50mph in 'pedelec' (pedal and electric assist) mode and a 2.5 hour charge providing a range of 31-44 miles (Audi MediaInfo 2012). This luxury form of e-bike could provide a viable transport solution for suburban commuters, but at the cost of a small car, its future applicability is most likely restricted to affluent members of society.

4.3. LEICESTER ACTION PLAN

In order to provide a traffic management scheme across Leicester, which reduces the level of air pollutants and adheres to the PPP, one should collectively address both personal and public contributions. In terms of higher level schemes, EZs appear effective in creating a cleaner fleet entering the city. A central 'Bus Gate Enforcement' zone would likely curb the magnitude of environmental burdens placed on vulnerable inner-city residents from peripheral communities, who could switch to using existing-park-and-ride infrastructure if a cleaner fleet was introduced. Finally, the completion of the outer-city ring road should be viewed as a necessity in the prevention of traffic entering central locales regardless of whether these schemes come into fruition; although it would assist with any schemes enforcement.

5. CONCLUSION

Local Indicators of Spatial Association (LISA) facilitate the modelling of localised intra-urban interactions, and are shown to be useful tools in the exploration of complex interactions across different communities at the heart of the local environmental debate. The wider implementation of these practices is considered beneficial to the development of future local transport policy. In focusing the consultation process, environmentally friendly initiatives may be tailored towards the needs of local populaces, potentially increasing a travel schemes chance of success where prior uptake has been low. Similarly, by identifying and targeting the transport scheme with the highest potential for uptake amongst the more polluting communities, we aim to improve our chances of delivering greater benefits in the areas where the impacts are most pronounced. As we see it, there is ethical complexity of the situation and a need to focus on policies that are most likely to be amenable to the polluters in a situation, where the polluters are not the most polluted and a world where maybe a focus on ethics alone is not going to deliver the best results. That is obviously an ethical efficiency and, while we might feel it goes against the fundamental ideals of L-PPP, we acknowledge it as a necessary component of any strategy if we seek to deliver more change sooner.

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