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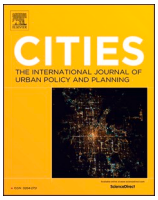

Using composite indicators and city dashboards to promote place-based policy interventions

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ABSTRACT

Spatial inequality is a common urban phenomena in cities around the world, where stark contrasts in a variety of different social and economic outcomes paint a vivid picture of compound inequalities. Tackling these influences from a policy perspective remains challenging, as political economies often span multiple actors and municipal bodies, lacking effective policy instruments to challenge multiple forms of inequality at once. This paper provides a new data-driven perspective, which seeks to improve how policy is developed when trying to mitigate the impacts of compound inequality. Utilising a place-based approach, we present an evidence base which has been co-produced with policymakers, comprising composite spatial indicators and a city dashboard for Liverpool City Region. The assembled evidence base highlights clear patterns of compound inequality across the region, identifying places in greatest need of support. In the paper we discuss how this evidence base is now being used to distribute investment from the City Region Sustainable Transport Settlements, generating positive outcomes for people and places across the region. Finally, we conclude by reflecting on the benefits of building collaborative relationships between academics and policymakers, and the utility of our approach, which uses urban indicators and city dashboards, which we argue can secure a more equitable future for cities globally.

1. Introduction

Despite efforts to address them, social and spatial inequalities still persist in cities. They represent a major global and societal challenge, and as such have received significant attention and focus within the sustainable development goals (Gao et al., 2022; Lowe et al., 2022). When treated as individual problems (e.g., transport availability), inequalities represent significant issues for cities and regions, and are often part of the key objectives ascribed to planners and policymakers to enhance (spatial) justice within cities (Calafiore et al., 2022). However, their manifestation often varies between geographical levels (Olsen et al., 2019), and is typically interacting and compounding, making their measurement and policy treatment more complex. This complexity manifests within the political economies that seek to mitigate these problems, which often span multiple actors and municipal bodies, limiting their ability to tackle them directly. However, this remains an important challenge, as the impact of not having effective policy instruments to understand and tackle the complexities of compounding spatial inequalities, risks maintaining cycles of hardship for the most vulnerable members of society (Moreno & Hickson, 2021).

Our work here is framed within the context of existing research around the multidimensionality of inequality, accounting more directly for the 'compounding' or spatial intersection of inequalities. Research in this area argues that social and spatial inequalities can be most effectively represented as a complex array of different interacting influences (Green et al., 2018). Thus, given that spatial inequality is commonly multifaceted, there is a need to develop and enhance approaches to integrated urban governance that can tackle these issues, with the objective of producing policies that are more likely to create positive outcomes for cities and regions (Feitosa et al., 2023; Higgs et al., 2019; Lowe et al., 2022).

Historically, positive outcomes have been delivered for people and places by directing investment and policy interventions towards specific societal problems, often financed by devolution deals (Sykes & Nurse, 2021). Devolution provides an alternative mechanism for decision-making in the UK, with the most recent stage being the formation of combined authorities (Jeffery, 2022). Combined authorities – legal entities covering two or more local authority areas – were provided with decentralised competencies and powers, bringing together leaders of local authority districts to restore some accountability to sub-regional

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decision making (Sykes & Nurse, 2021). Perhaps the greatest benefit of devolution is that it enables policymaking and planning to operate at a more localised scale (Thompson et al., 2022); combined authorities are awarded fiscal independence and control over land use, so can develop strategic plans over different domains with greater ease (Southern, 2023). However, the nature of devolution as a power relationship between central and local government creates exogenous vulnerabilities, including 'austerity urbanism' (Thompson et al., 2022; Furmedge et al., 2022), and an emphasis on neoliberal economic strategies which are often perceived as insufficient to arrest growing inequality (Thompson et al., 2022).

Liverpool City Region Combined Authority (LCRCA hereafter), located in North West England, is home to roughly 1.6 million residents. LCRCA, which represents the City of Liverpool, Knowsley, St Helens, Sefton, Wirral, and Halton, was established to deliver a transport and economic growth agenda. To date, LCRCA have already invested £1 billion in schemes including establishing 8000 new apprenticeships, start-of-the-art train infrastructure, and large cultural events like Eurovision (LCRCA, 2023). However, Liverpool City Region remains a place of significant inequality. It is home to places with some of the highest and most persistent levels of deprivation, as well as the lowest levels of economic productivity and educational attainment (Dolega & Lord, 2020; Sykes et al., 2013). Furthermore, job densities, average pay, and the quality of housing in many of these places are below average (Moreno & Hickson, 2021), and there are significant variations in accessibility across the city (Calafiore et al., 2022; Moreno & Hickson, 2021; Southern, 2023). In thinking about why such compound inequality occurs, the work of Marques et al. (2021, p.705) provides a useful framing – "the systematic way in which less advantaged people have poorer [accessibilities], must lead us to conclude that it is an intended or unintended product of spatial planning policies".

Historic and ongoing policy interventions developed by LCRCA have made significant progress, as situated within the Metro Mayor's priority for a 'fairer, stronger, cleaner, connected and vibrant city region' (LCRCA, 2021). An example of such policy is the City Region Sustainable Transport Settlement (CRSTS hereafter), which was allocated to LCRCA in April 2022, and comprised £710 m to improve journey times, enable decarbonisation, and provide equitable access to public transport for all (Department for Transport, 2022; LCRCA, 2022). The scheme is placing significant emphasis on transport inequalities, through provision of a 600 km high quality active travel network, a new train station in Liverpool's creative district, and the introduction of green bus corridors (LCRCA, 2022). From a strategic perspective, CRSTS was organised around a series of project and scheme proposals developed by individual Local Authorities (LCRCA, 2022). This is an interesting dynamic, which highlights the how financial investment from political devolution (i.e., LCRCA) can be utilised at local scales (i.e., by Local Authorities) to target specific urban inequalities.

However, in advance of the second iteration of CRSTS, which was announced in October 2023 (Department for Transport, 2023), there is need to think differently about how the scheme should be implemented to derive maximum benefit for people and places. Given that existing literature has demonstrated the heterogeneity of inequality across Liverpool City Region, and that multiple socio-economic outcomes are interacting and compounding negatively in specific places, there is a need for policy instruments that can address the problems unique to each place. A 'place-based' approach, which understands the key issues and relationships unique to each place or neighbourhood, could provide a useful lens to measure city-level differences (Gao et al., 2022). This links well with the work of Olsen et al. (2019) who argues that urban environments can act as a 'lever' to improve equality throughout the city, where investment in specific land covers/uses can help to foster more 'equigenic' environments (Mitchell et al., 2015). Arguably, by framing such ideas within the context of devolved funding schemes such as the CRSTS, and utilising the powers afforded to devolved regions, offers significant scope to address urban inequalities in a number of important areas.

However, such opportunities drive a need for better evidence (Feitosa et al., 2023), especially given the complexity of spatial inequalities in Liverpool City Region. Through the provision of measurable actions and targets, an empirical evidence base of compound inequality could ensure accountability on the part of the policymakers, providing a mechanism through which to monitor the progress and outcomes of policy action (Lowe et al., 2022). In addition, it could help to highlight how the urban landscape is contributing to inequality (Olsen et al., 2019), through 'within-city' comparisons. However, there are also pragmatic challenges in that any evidence base is often constrained by resources; fine-grained spatial data cannot be easily translated into empirical insights without software, training, and knowledge of data science epistemologies (Boeing et al., 2022; Green et al., 2018). Thus, there is a consensus that building productive, collaborative relationships between academic researchers and policymakers can be an effective way to codesign policy-relevant evidence and tools to inform decision making (Boeing et al., 2022; Lowe et al., 2022).

A particularly useful approach is the use of urban composite indicators, maps, and city dashboards (Boeing et al., 2022; Kitchin, 2016; Kitchin et al., 2015). Composite spatial indices represent an attempt to translate complex empirical insights into something intelligible for stakeholders (Kitchin et al., 2015). They are defined as the synthesis of several measures, typically at a small area geography, which are combined into an index that represents a 'domain' of interest (Tanguay et al., 2010). These are very common within lots of policy related fields (Green et al., 2018), with a well-known example being the Indexes of Multiple Deprivation (Ministry of Housing, Communities and Local Government, 2019; Scottish Government, 2020; Welsh Government, 2022). Other methodological approaches have yielded similar outcomes, including generation of local insight reports (Macdonald et al., 2023). Such an approach conveys a large amount of important information, which is limited when compared against the 'at-a-glance' visibility offered by city dashboards (Kitchin & McArdle, 2017), and their benefits for bridging gaps between political devolution and the needs of citizens (Marsal-Llacuna, 2020). Similarly, whilst citizen science programmes have generated positive impact (e.g., Jallad et al., 2022), their 'subjective' nature makes it difficult to eliminate participatory bias when allocating financial investments.

The nature of devolved powers in Liverpool City Region, adds a political element to what interventions can be feasibly implemented, and therefore the selection of inputs to an evidence base (Kitchin et al., 2015). Whilst interventions in domains such as health and green space might result in important societal outcomes, the capacity of LCRCA to develop policies in these areas is limited. As such, it is important that any evidence base of compound inequality is entirely focused to the urban issues in question, through co-creation with policymakers. Therefore, the aim of this research is to develop a composite spatial index of compound inequality for Liverpool City Region, which focuses on domains and areas that are actionable within the strategic remits of LCRCA. To do so three objectives were necessary:

1) Concept definition: establish a conceptual framework for addressing inequalities within the scope of LCRCA strategic remits.
2) Data collection and analysis: construct a composite spatial index that captures the multidimensionality and compounding of inequality in Liverpool City Region.
3) Intervention: use the index as an evidence base to identify areas and neighbourhoods for intervention in Liverpool City Region.

2. Conceptualising and measuring compound inequality

When creating spatial indicators, it is common for these to be situated within the context of a theoretical framework (Steiniger et al., 2020; Tanguay et al., 2010). This is an important step, which prevents the creation of 'Mashup Indices' – a term used to describe indicators

constrained by data availability, without useful meaning (Kuc-Czarnecka, 2019). However, it is also important for a framework to reflect both *parsimony* – capturing all themes and measures of importance - and *pragmatism* - accounting for data availability and political constraints (Higgs et al., 2019). This is a challenge, as the balance between both becomes blurred, where measurement can be dependent on availability of data (Tanguay et al., 2010). There are also further considerations related to the agendas of policymakers when indicators are being developed for practical purposes or in a specific case study location. As such it is important that the evidence base is tailored to best support the needs of the political and geographical setting in question. Therefore, to develop this evidence base, we engaged in a five-part research process, comprising consultation phases, prototyping and two workshops (Fig. 1). This process involved regular dialogue, collaboration, and co-production with policymakers, involving co-production of the study design, methodology and presentation of outputs.

Before describing the process, it is first important to situate how it originated. The research was initiated by LCRCA who approached academic researchers to think broadly about how spatial data could be used to support planning, addressing some of their current resource and skills-based needs (Boeing et al., 2022). LCRCA contains an in-house analyst team, however their focus is much more on short-term deliverables and day-to-day reporting, as opposed to longer-term research projects. Furthermore, it was deemed that the academic researchers would have access to a broader range of spatial methodologies and cartographic expertise, as well as a certain degree of 'political independence'. The evidence base could be designed to be empirically robust, with minimal influence from external stakeholders, which is particularly important in a devolved region where local authorities are competing for the same resources. These ideas have been well situated within existing literature (e.g., Kitchin, 2016; Kitchin et al., 2015), which argues that city dashboards can be designed to 'reveal the world as it actually is'.

The first part of the process was an initial consultation phase (Fig. 1), which aimed to co-design a schema that captured perceptions of inequality in the region, with a particular emphasis on domains where policymakers have strategic powers – transport, economic development, and regeneration.[1] This first consultation was undertaken with policymakers to design the schema, and agree a series of questions they felt empowered to answer. These conversations helped to frame the influences and characteristics of inequality as perceived by local policymakers, and also highlighted the pathways through which interventions could be designed to address them. We set up a collaborative document, structured into each of the four domains, and populated it with the questions posed by policymakers to identify the urban influences of interest. The formal outcome of this consultation process was a conceptual framework of compound inequality, which is outlined below in Fig. 2. The model is orientated around four domains; three of the domains correspond to priority areas for LCRCA - transport accessibility, economic development, and housing - and the fourth captures other inequalities that are known to persist across the city region, specifically deprivation and socioeconomic status. The emphasis was in developing a framework that situates where compound inequalities exist across the Liverpool City Region area, as a way of identifying and differentiating needs for interventions. However, we also wanted to establish a new conceptual model which could be modified and applied to a diverse range of urban settings, based on context-specific geographical and political needs.

Once the conceptual framework had been established, it was important to evaluate whether suitable data was available to effectively represent compound inequality. The secondary consultation phase involved populating the collaborative document with data held by policymakers that would be useful for indicators. Where gaps emerged for specific domains, additional data was supplemented from various open data portals, as outlined below. This demonstrates the importance of balancing parsimony and pragmatism (Higgs et al., 2019), where all domains were captured and represented (*parsimony*), whilst also accounting for data availability and the strategic priorities of policymakers (*pragmatism*). In the case of the latter, there were lots of additional factors that could represent inequality in Liverpool City Region, but given the operational objectives of the outputs, it was important to ensure that the evidence base was closely aligned to LCRCA legislative powers, where interventions could be planned and implemented.

An additional line of discussion in the consultation was around the types of outputs that would best support evidence-led policy interventions. Consultation phase two revealed that providing outputs at a consistent small area geography would best support policymakers. The UK has a variety of small area geographies, with the smallest being postcodes. Postcodes are used to assign households, which typically span one street, to a small area where there are roughly 15 households per postcode (on average). From a cartographic and empirical perspective, it was decided that a slightly larger geography was needed to effectively capture and represent spatial inequalities throughout Liverpool City Region. Phase two revealed that Lower Super Output Areas (LSOAs) were a relatively familiar geographical unit to local policymakers; LSOAs are the mid-sized small area census geography used in England and Wales, comprising around 400–1200 individual households and 1–3000 people (on average). Thus, given existing familiarity and the average size of these units, LSOAs were selected as the target zonal scale at which to construct indicators for the evidence base. Thus, for each domain, a domain-level score would be extracted at LSOA level (Table 1), by integrating different sources of data, some of which are only available at other spatial scales (e.g., postcodes).

For Domain 1 - *Access to the Transport Network* - three individual indicators were developed (Table 1), before being used to assemble a domain-level index. Accessibility to three sustainable transport options was measured, by calculating the walking distance from postcodes to the nearest railway stations, bus stops, and the active travel network, the latter of which comprises detailed information about existing cycle and walking infrastructure across the city. The HERE routing API was used to calculate these distances, by extracting the five closest features based on euclidean distance (as in Calafiore et al., 2022), calculating network distances, and extracting the shortest overall distance. These values were calculated at the postcode-level before being averaged at LSOA level for the three indicators, as calculating accessibility from LSOA centroids could negatively bias neighbourhoods in rural parts of Liverpool City Region. Thus, the outcome was three accessibility indicators at LSOA level, one for each transport mode, which could then be brought together to assemble the domain-level score (Table 1).

For Domain 2 - *Deprivation and Socioeconomic status* - two indicators were developed. One which described the deprivation of LSOAs, utilising the scores from the English IMD, and the other which calculated the ratio of LSOA populations in the top versus the bottom National Statistics Socio-economic Classification (NS-SEC) categories, using data from the latest census. For Domain 3 - *Economic Development* - innovative populations were calculated as the proportion of the workplace population from sectors deemed as innovative,[2] using data from the Business Register and Employment Survey (BRES). Furthermore, an indicator which described the total floorspace of major employers was derived, using data provided by LCRCA at postcode-level, which was processed by removing duplicate values and aggregating to LSOA level. Finally, for *Housing Opportunities* (Domain 4), future housing projects data, again provided by LCRCA, was used to calculate the total number of dwellings at postcode level, before aggregating to LSOA to derive the final indicator.

[1] https://www.wirral.gov.uk/councillors-and-committees/liverpool-city-region-combined-authority.

[2] https://kene.partners/insights/what-are-the-most-innovative-industries/.

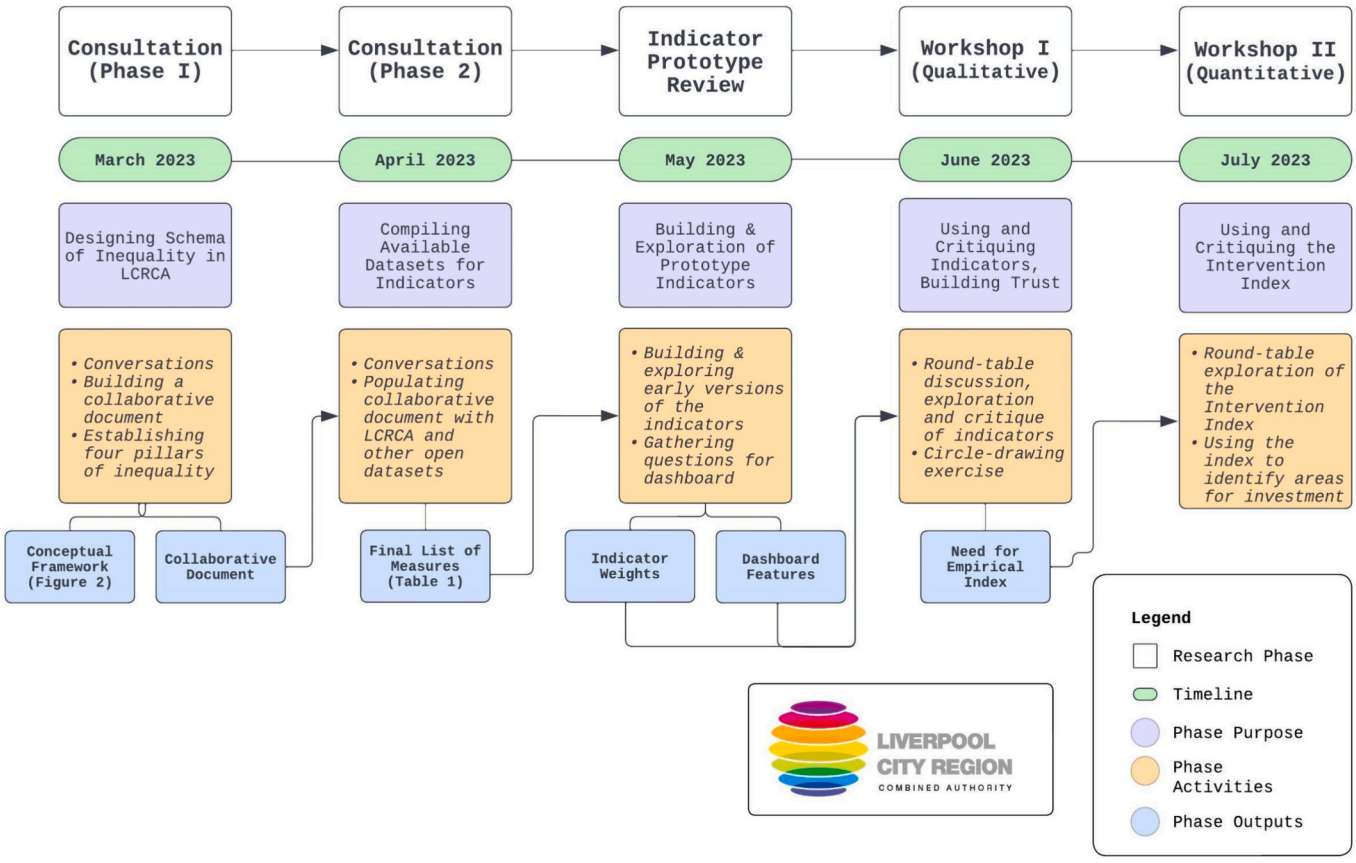

Fig. 1. Research process flow diagram.

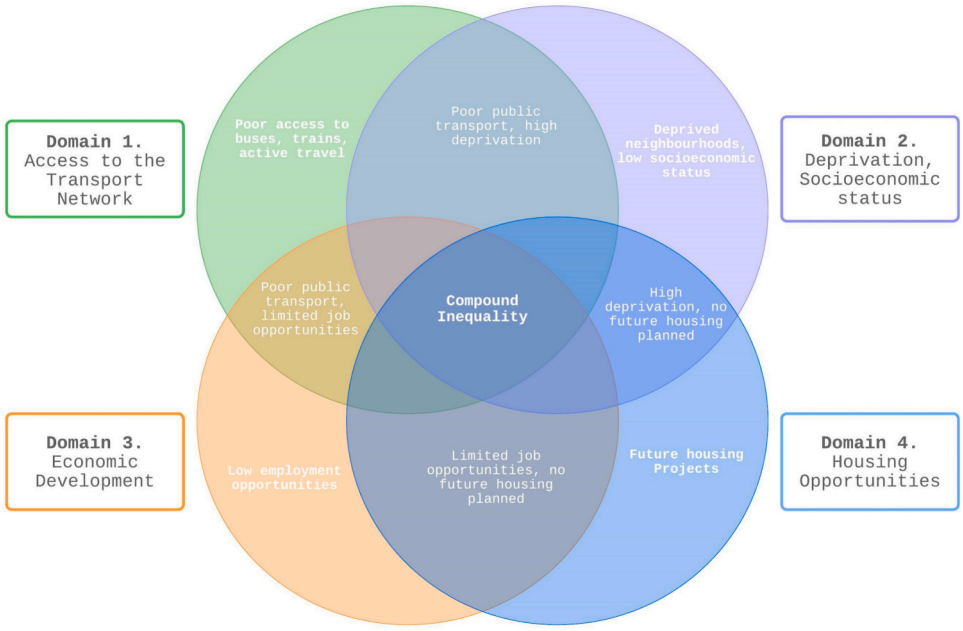

Fig. 2. Conceptual framework of compound inequality in Liverpool City Region, co-produced with local policymakers.

Once the individual indicators had been developed, an individual domain-level index was assembled for each of the domains at LSOA level. Following other similar work which has developed spatial indicators (Higgs et al., 2019; Singleton et al., 2016), the individual indicators were normalised to ensure direct compatibility of indicators. For domain-level index assembly, we adopted a linear normalisation approach (−1 to 1), as whilst z-scoring provides a useful way of integrating disparate indexes with different data distributions (e.g. Singleton et al., 2016), it was deemed that domain-level indexes ranging between −1 and +1 would be sufficient to integrate the relatively similar domain inputs, and would be more accessible for policymakers in the workshops. Once normalised, the individual indicators could be

Table 1
Data used to capture indicators in each of the four domains.

Domain	Indicator	Source
Domain 1. Access to the Transport Network	Rail station accessibility	Darwin API
	Bus stop accessibility	NaPTAN
	Active travel accessibility	LCRCA
Domain 2. Deprivation and Socioeconomic Status	Deprivation	IMD (2019)
	Socioeconomic status	2021 Census
Domain 3. Economic Development	Innovative populations	Business Register and Employment Survey (BRES)
	Major employer locations	LCRCA
Domain 4. Housing Opportunities	Future housing projects	LCRCA

added together to assemble a domain-level score at LSOA level. An example of this can be seen below in Eq. (1), which highlights how the first domain score was assembled (A_i), where higher overall values are associated with longer walk distances to transport infrastructure (bus, rail, and active travel).

$$A_i = b_i + r_i + at_i \quad (1)$$

where:

A_i = domain-level score for 'Access to the Transport Network' in LSOA *i*.

b_i = average walking distance (m) to nearest bus stop in LSOA *i* (normalised −1, +1).

r_i = average walking distance (m) to nearest railway station in LSOA *i* (normalised −1, +1).

at_i = average walking distance (m) to nearest active travel infrastructure in LSOA *i* (normalised −1, +1).

Weighting was considered to allow greater or lesser representation of specific indicators within each domain. In practice, weighting is often discussed in consultation with experts (Kuc-Czarnecka, 2019), and upon discussion with local policymakers in the Indicator Prototype Review exercise (Fig. 1), it was decided that each indicator should be represented equally (as in Green et al., 2018), and that weighting should only be considered when trying to combine the four domain-level indices into an overall index – 'Intervention Index'. The benefit of the latter is that by combining the four indices together, there would be a direct quantification of where multiple inequalities are intersecting negatively, and the need for interventions in these areas. The index would provide an overall scoring, considering indicator values relative to the rest of the city, and summarising their distribution into an overall score which is easier to understand (as in Jaroszewicz et al., 2023). An additional benefit of this analytical framework is that it can be abstracted, based on data landscapes in different settings, to design urban indicators that capture the intersection of multiple inequalities in other urban settings.

In designing what the overall index would look like in the Indicator Prototype Review (Fig. 1), the four domain-level scores were normalised (−1, +1) before combining them together, again using the approach seen in Eq. (1). A variety of different approaches could have been adopted for assigning weights, including factor analysis, principal component analysis and sensitivity analysis (Kuc-Czarnecka, 2019). However, these tools often overlook 'conflict' between competing values and interests, and the groups and communities that represent them (Attardi et al., 2018). Empirical techniques, commonly referred to as Linear Aggregation Rules (LARs) imply that input variables can be completely substituted based on the marginal contribution of each. However, in our applied case study, there were different dimensions of value in 'conflict', where Local Authorities are all vying for shared resources from CRSTS, resulting in a need to receive additional input from decision makers, to ensure equitable representation across these areas. As a result, a variety of prototype composite indexes were produced, each applying different weighting strategies, following sensitivity analysis to quantify the impact of weighting on the distribution of rankings between Local Authorities. This represents an example of what Attardi et al. (2018) described as 'continuous interaction between analyst and social actors', whereby feedback is actively used to recalibrate the model. The final weighting – 40 %, 30 %, 15 % and 15 % - represented the outcome of these 'continuous interactions', but also the idea that CRSTS is primarily a transport investment, so from a conceptual and empirical perspective, it was important that this domain receive the highest overall weighting.

3. An exploration of (compound) inequality in Liverpool City region

Before considering what the Intervention Index tells us about the existence of compound inequality across Liverpool City Region, it is important to consider patterns of inequality represented by the individual domain-level indicators. Fig. 3 displays the deciles for the four indicators, highlighting a relatively uneven distribution of inequality when examined laterally across the four domains. In terms of transport accessibility, there are large pockets of poor accessibility in Knowsley, St Helens, and the west of the Wirral, with smaller concentrations in places like Speke (South Liverpool) and Halton. Many of the large pockets are related to an overall absence of rail and bus infrastructure (as in Southern, 2023), but also reflect places where active travel infrastructure is much lower than in the city of Liverpool, Birkenhead, and Southport. The latter makes this indicator particularly interesting when evaluating transport opportunities in Liverpool City Region, as active travel inequalities have not been directly incorporated into other similar studies (e.g., Calafiore et al., 2022; Southern, 2023).

Domain 2 displays a distinctly different pattern to that of Domain 1, where parts of North Liverpool and Birkenhead appear to experience the highest regional levels of deprivation and low skill populations, albeit relatively good accessibility to transport opportunities. However, what is particularly interesting is that transport inequalities and deprivation/socioeconomic inequalities appear to be spatially intersecting in many places. For example, parts of Knowsley and St Helens remain in the top deciles for both of these domains. Given that public transport has been shown to be a pathway to positive economic outcomes for disadvantaged populations (Southern, 2023), this highlights the importance of viewing inequality as having a compounding influence. Furthermore, given that the policymakers at LCRCA are particularly empowered to deliver transport policy and infrastructure, new transport infrastructure in these areas could represent a pathway to mitigate the impacts of compound inequality in these places. On the other hand, there are many places in Liverpool City Region where transport accessibility is excellent, serving a relatively high-skill population in some of the least deprived parts of the region (e.g., Mossley Hill, New Brighton, Formby).

In terms of Economic Development (Domain 3), there is a clear 'belt' of innovation and employment opportunities along the waterfront in Liverpool city centre, as well as in places like Birkenhead, South Liverpool, Halton, and Knowsley. In addition, many of these locations are where future housing is planned (Domain 4). This is particularly interesting, as some of these locations were revealed to be particularly disadvantaged in terms of transport opportunities (e.g., Knowsley, Speke). This observation therefore suggests that these places would benefit from improved rail, bus, and active travel infrastructure, given that the demand for these services is likely to be higher in the future. On the other hand, there is a broader question about the suitability of housing projects that have been planned in the future. Given that a large concentration of these will be situated in the City of Liverpool and North Liverpool, there are questions about how accessible and affordable this new housing will be for local populations. However, in summary, this lateral comparison of inequality across the four domains (Fig. 3) shows that individual inequalities are clearly compounding in specific places

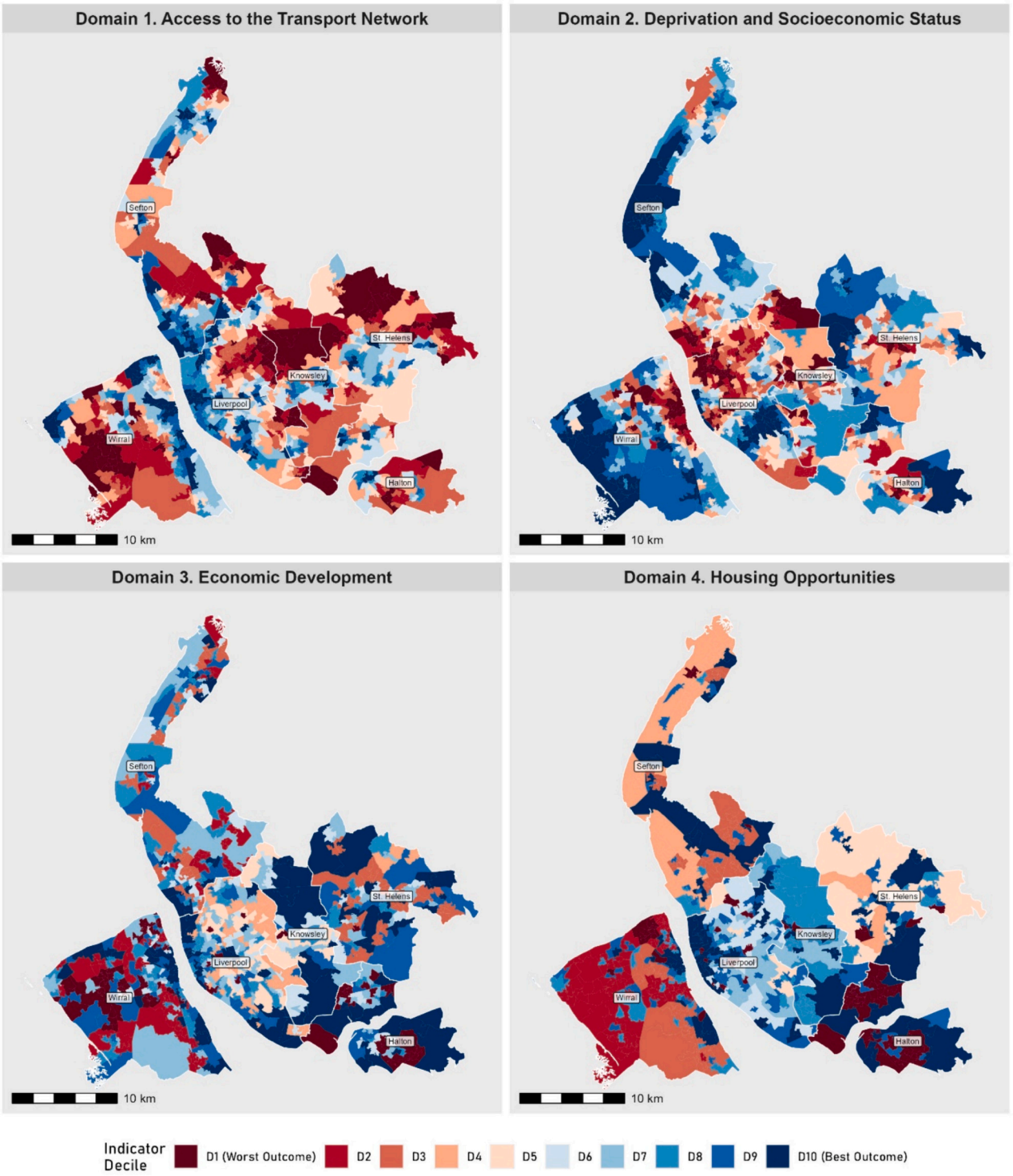

Fig. 3. Domain-level indicators highlighting patterns of inequality across Liverpool City Region. Indicators were produced and mapped at LSOA level (see Section 2).

and neighbourhoods in Liverpool City Region (e.g., Knowsley, Speke), maintaining cycles of hardship for some of its most disadvantaged residents. Thus, this provides an important evidence base about the existence of compound inequality, and the need for direct intervention to mitigate its impacts across the region.

4. Interventions in compound inequality – composite indicators and city dashboards

A major challenge with urban indicators like those above, is how they are presented and distributed to enable a variety of audiences to engage (Kitchin et al., 2015; Lowe et al., 2022). Previous research has demonstrated the effectiveness of city dashboards in 'opening up' urban indicators to citizens and policymakers (Kitchin et al., 2015), providing an immediate portal for them to make sense of their city and environment, without the need for specialist analytical skills (Kitchin, 2016). In the initial consultation phase, LCRCA indicated their early preference for a city dashboard, which they believed would be the most effective medium to disseminate the urban indicators, and develop policy interventions with Local Authorities. Before designing the dashboard, in

the Indicator Prototype Review phase of the project we gathered a series of questions, drawing inspiration from the work of Kitchin (2016). The questions were gathered from policymakers at LCRCA, and captured what they felt the city dashboard should be able to answer, including "*how is compound inequality distributed throughout the city region?*" and "*what are the specific pathways through which interventions can be designed to reduce these inequalities?*"

Once these questions had been identified, we considered how the dashboard could be designed to answer them, evaluating the principles and necessary functionalities of the dashboard, and discussing the overall look and feel of the interface. In particular, we were largely influenced by the Consumer Data Research Centre (CDRC) Mapmaker dashboard,[3] which upon discussions with LCRCA, appeared to offer the necessary components. Mapmaker is supported on the backend by a CARTO data platform, and supports point-and-click web mapping, enabling users to display multiple layers and spatial information all at once. A simple city dashboard, which represented a user-friendly mapping and visualisation tool for the indicators, was constructed between phases three and four (Fig. 1), comprising the deciles and quintiles for each of the domain-level indexes. However, the cartographic representation of the indicators remained a key consideration, particularly in relation to the size of LSOAs, where some of the participants of the Indicator Prototype Review were drawn to areas with larger LSOAs and negative results. To control for this, a modified set of LSOAs were adopted, following the CDRC Mapmaker cartography approach, which clips LSOAs to areas that are predominantly 'built up', using data from Ordnance Survey.

Once the overall appearance and functionality of the dashboard had been agreed upon (Fig. 4), we engaged in the first workshop with policymakers to think about how the dashboard could be used to allocate investment. A workshop was held between academic collaborators and members of the Merseytravel team at LCRCA (approx. 15 people in total). The workshop participants comprised a large number of transport development managers, officers, and transport analysts from LCRCA, who held significant expertise in utilising devolved powers to deliver transport policies and infrastructure across Liverpool City Region. Many of the participants previously held social science degrees or analyst roles, and have previously used (and produced) dashboards (McClelland & Mason, 2020), so exhibited relatively high, though differing levels of (spatial) data literacy. However, as described above in Section 2, the data analyst team at LCRCA – who are experts in data and analytics - were unavailable for this project.

The overall objective of this workshop was to utilise the city dashboard to identify areas for intervention, based on the distribution of compound inequalities throughout Liverpool City Region. Given that there were differing levels of spatial literacy among workshop participants, a secondary objective of this workshop was to establish a good level of trust and 'buy-in' in the dashboard. The approach to doing so was co-designed in the workshop, where workshop participants were encouraged to manually annotate the dashboard, highlighting areas of interest (i.e. greatest inequality) in each of the four domains, as below in Fig. 5. This approach invited people with varying levels of spatial literacy to become confident in summarising the patterns displayed by the indicators, through encouraging them to become more familiar with choropleth mapping as a visualisation technique. This qualitative approach was an important part of the research process, as dashboards are not objective platforms (Kitchin & McArdle, 2017), and it is important to bring in as many different agents to gather a range of different opinions and views. By engaging with the indicators directly, and highlighting areas based on patterns they observed, the policymakers became more confident about the evidence, through consideration of how the patterns relate to their own local knowledge and expertise. This exercise represents an important stage of the research process, which should be given significant attention when seeking to generalise our approach into a variety of different urban settings. For an evidence base like this to have societal impact, it is crucial that local policymakers feel a certain degree of ownership and exhibit good levels of trust and understanding in the indicators.

However, an unexpected discussion emerged about the balance of '*what does the data tell us?*' versus '*how feasibly can we implement policy in these areas?*'. The latter is often overlooked in data-driven work, where less consideration is given to the challenges of implementing policy action that is relevant and effective, and more emphasis is placed on what the data suggests. For example, it was highlighted that interventions funded by devolution need to be evenly distributed across all six Local Authorities. This reinforces the importance of regular communication with policymakers when providing empirical evidence for policy, and the need for flexible conceptual frameworks that account for these challenges. Integrating these considerations and building trust in the empirical evidence, arguably helps to facilitate evidence-led decision making, by empowering policymakers to utilise evidence in their decision-making process.

However, a major limitation of the qualitative workshop was that the outcomes (i.e., circles) represented relatively large parts of the city (Fig. 5), cutting across a wide range of domain values. Thus, it was important to think about how useful these circles were for targeted interventions as part of CRSTS. Without input from the academic researchers, policymakers suggested that it would be beneficial to consider how these large circles could be refined, with a particular emphasis on places where there are multiple overlaps between domains. This represented a major achievement, as it illustrated that the policymakers were confident that the trends they had identified – i.e. circles – represented places they know to be disadvantaged from their lived experiences in the city. However, it also demonstrated a shift in thinking, in that policymakers who exhibited varying degrees of spatial literacy and 'trust' in data-driven policymaking, were now actively seeking additional empirical insights to refine the outputs of this workshop. Thus, we proposed using a final 'Intervention Index' (as described above in Section 2), and seen below in Fig. 6, to represent areas of the city where compound inequality is greatest across Liverpool City Region.

The final stage was to add the 'Intervention Index' deciles to the dashboard (Fig. 6), to form the primary evidence base in the next stage of CRSTS. Upon examination of only those areas in the top 60 % of priority in the second workshop, a threshold selected by policymakers, clear patterns were revealed about the distribution of compound inequality in Liverpool City Region and the need for interventions to tackle these. Areas with particularly high need for interventions included large parts of Knowsley, Tuebrook, Speke, Seacombe, as well as the surrounds of major towns like Widnes and Birkenhead. This is interesting as it demonstrates that compound inequality is spread throughout the entire city region, and not just concentrated in the City of Liverpool, or conversely in its suburbs or urban-rural periphery. Whilst this approach is empirically simple, it represents an attempt to simplify multiple composite indices into something that can serve as an intelligible tool for policymakers, providing the critical information needed to 'operate the vehicle at a glance' (Kitchin et al., 2015).

5. Discussion and policy implications

The compounding of multiple forms of inequality in cities represents a significant challenge for city planners and policymakers, but is a vital priority if we want to secure a more equitable future for cities. This paper represents an attempt to develop an evidence base that can be used to target interventions and investment from the City Region Sustainable Transport Settlements to places where compound inequality is greatest, focusing on Liverpool City Region as a case study. We have provided an overview of a new evidence base which uses composite spatial indices and a city dashboard to summarise and represent the

[3] https://mapmaker.cdrc.ac.uk/#/index-of-multiple-deprivation?m=imdh19_dc&lon=-2.9169&lat=53.433&zoom=8.58.

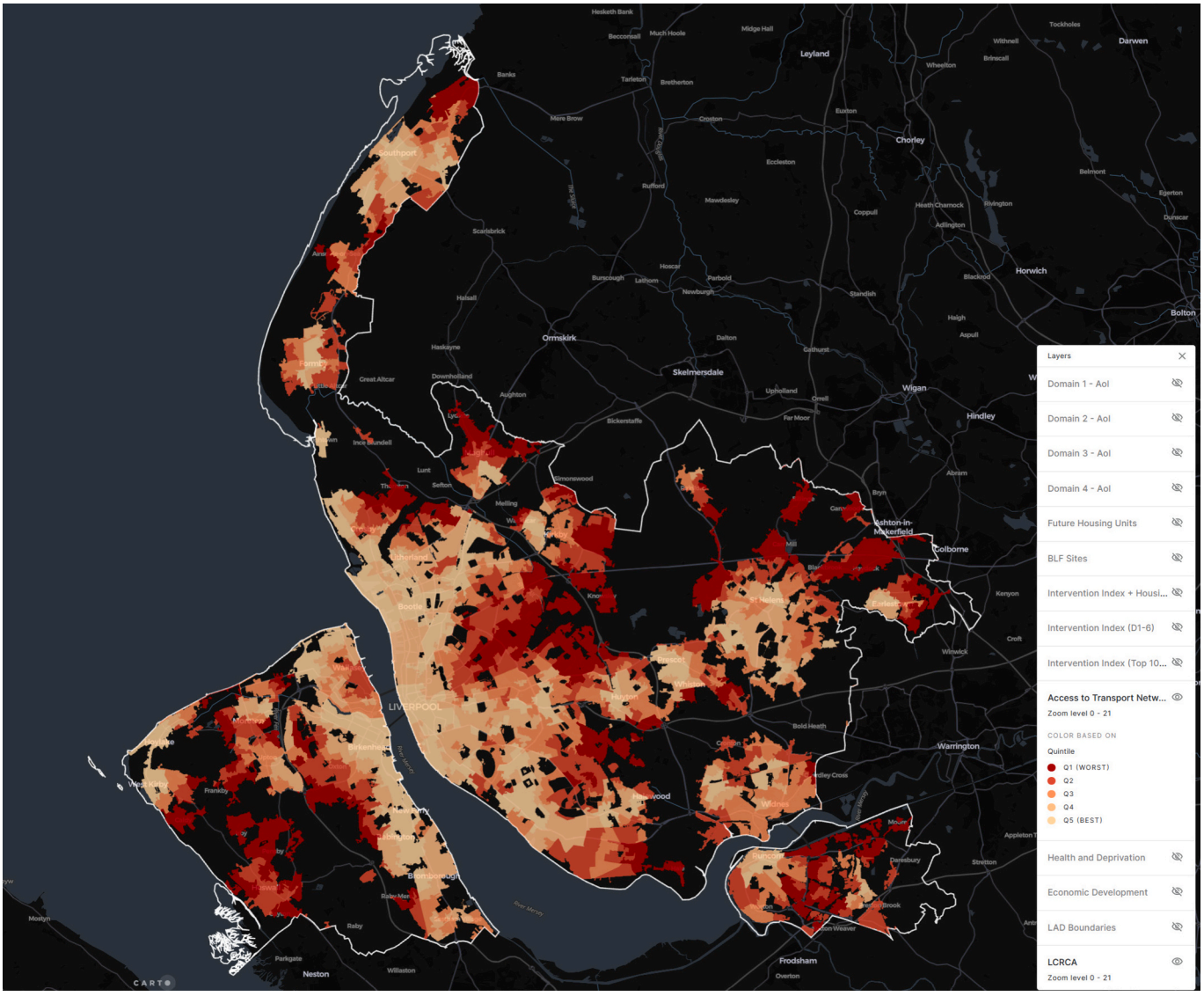

Fig. 4. City dashboard displaying quintiles for the Access to the Transport Network domain-level indicator.

complexity of inequality in the city. Through co-production of four domain-level indicators, covering inequalities related to Transport, Deprivation/Socioeconomic Status, Economic Development and Housing, we were able to identify pockets of inequality specific to each domain, which align with those seen in the literature. However, our main contribution is in highlighting pockets of 'compound' inequality, where these four domains are intersecting spatially to maintain hardship for the most vulnerable residents of Liverpool City Region. This work not only highlights that Liverpool remains a city of inequality (Sykes et al., 2013), but illustrates the importance of viewing inequality as an inherently multidimensional and challenging phenomena to measure and tackle.

This paper has advanced our understanding of how we can use urban indicators and city dashboards to support policymaking in cities. We have established a conceptual framework which situates compound inequality in a way that reflects underlying inequalities in Liverpool City Region, whilst also reflecting domains of interest for policymakers in LCRCA. This theoretical framework can be adapted; different devolved regions have different powers and focuses, which can be integrated as core pillars of this conceptual framework when targeting urban inequalities with devolved funding programmes. Furthermore, the assembly of composite indices provides a useful way to summarise the complexity of inequality into a meaningful and interpretable representation for non-academic audiences (Boeing et al., 2022; Higgs et al., 2019). As an empirical tool, this creates significant potential for evidence-led policymaking in a diverse range of urban settings, each of which will have their own unique challenges and data landscapes. Through engagement with the five-part research process, continuous co-production with local policymakers and adaptation of the conceptual and analytical framework(s) presented here, we argue that researchers remain better positioned to tackle the complex challenge of identifying, communicating, and addressing compound inequalities in different urban settings. Furthermore, this research contributes to the discussion in Marsal-Llacuna (2020), that digital technologies (i.e. city dashboards) can generate positive outcomes for people in politically devolved settings.

We identified a number of data-driven and design-related considerations which can aide this process substantially. Firstly, the use of deciles (and decile thresholds) was found to be highly useful when trying to convey the key messages from the indicators (see Fig. 6), removing 'noise' from the maps, and making it easier for users to establish confidence in using the dashboard to identify insights. In a similar light, there were notable considerations about the visualisation of indicators at small area geographies. As discussed in Section 4, an inherent bias

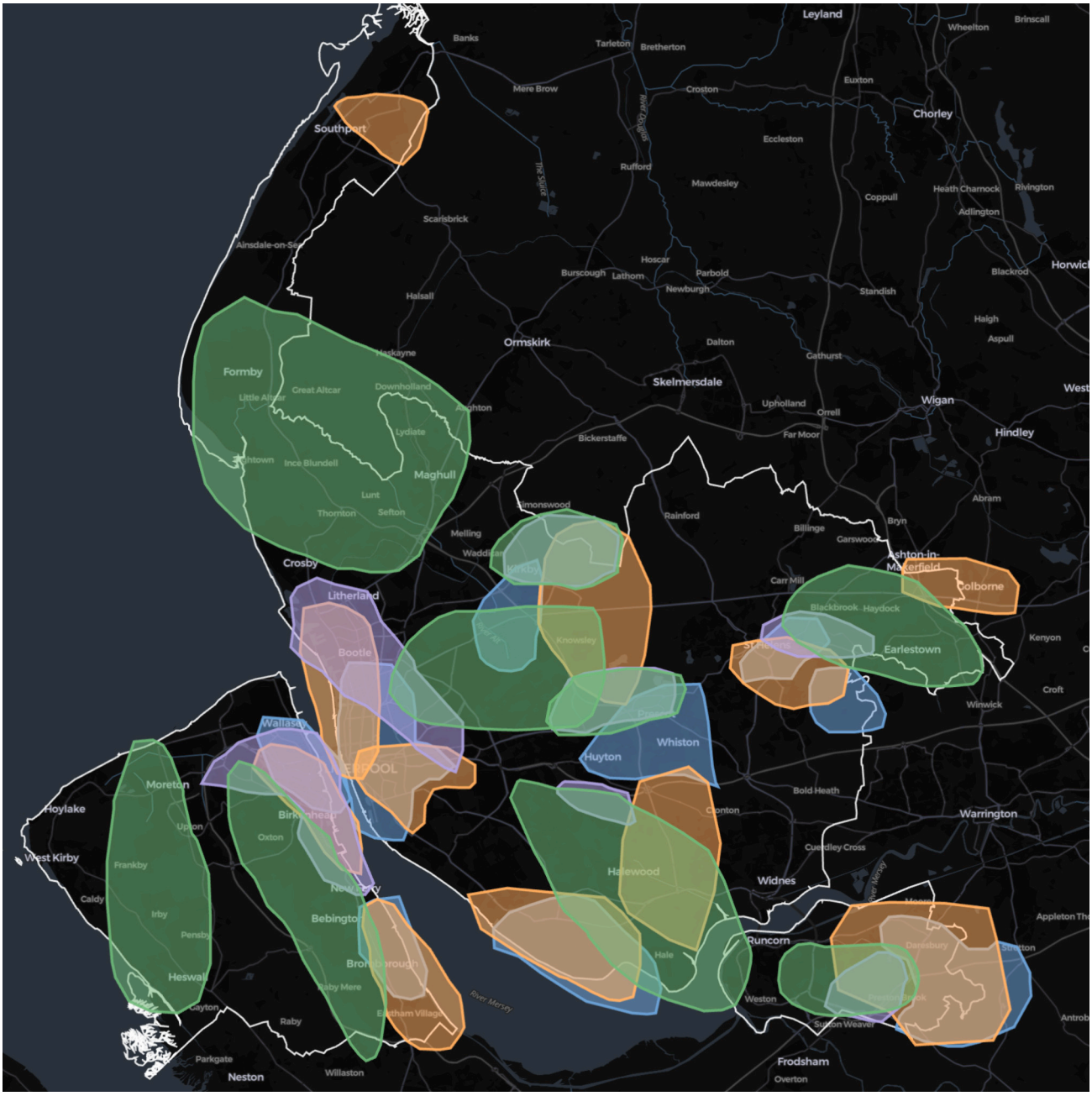

Fig. 5. Outcome of the qualitative mapping exercise where areas of interest for each domain-level indicator were identified. Circles were user-contributed, and the different colours correspond to the four domains - Access to the Transport Network (green), Deprivation & Socioeconomic status (purple), Economic Development (orange), and Housing Opportunities (blue). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

emerged where LSOAs larger in size were the focus of attention, despite pockets of smaller LSOAs with higher negative scores. Thus, consideration should be given to the representation of indicators at small area geographies before they are presented to non-academic audiences, through modification to better represent urbanities using the approach outlined above. Finally, we found that engaging with policymakers in a qualitative 'circle-drawing' exercise was an effective mechanism through which to establish trust in the city dashboard (and indicators), encouraging policymakers to develop individual-level advocacy.

Before considering the policy implications of our research, it is important to reflect on the limitations of this research. Our conceptualisation and measurement of place-based compound inequality does not fully reflect the complete nature of inequalities in Liverpool City Region. For example, our work is unable to truly represent (in)equity: 'people start from different places and might need different resources to achieve similar outcomes' (ACE Project, 2024). In addition, from a spatial planning perspective, our work does not attempt to better understand whether (compound) inequalities are the result of territorial structures or unjust distribution of resources, as in Marques et al. (2021). Thus, it is unfair to consider our research as situating and measuring all (compound) inequalities and inequities that exist in Liverpool City Region. Instead, what this research does is represent those distributional inequities that LCRCA have the capacity and strategic powers to deliver improvements in. These domains are inherently limited, as a result of the nature of the devolved powers afforded to LCRCA by central government, overlooking the importance of the social economy in Liverpool

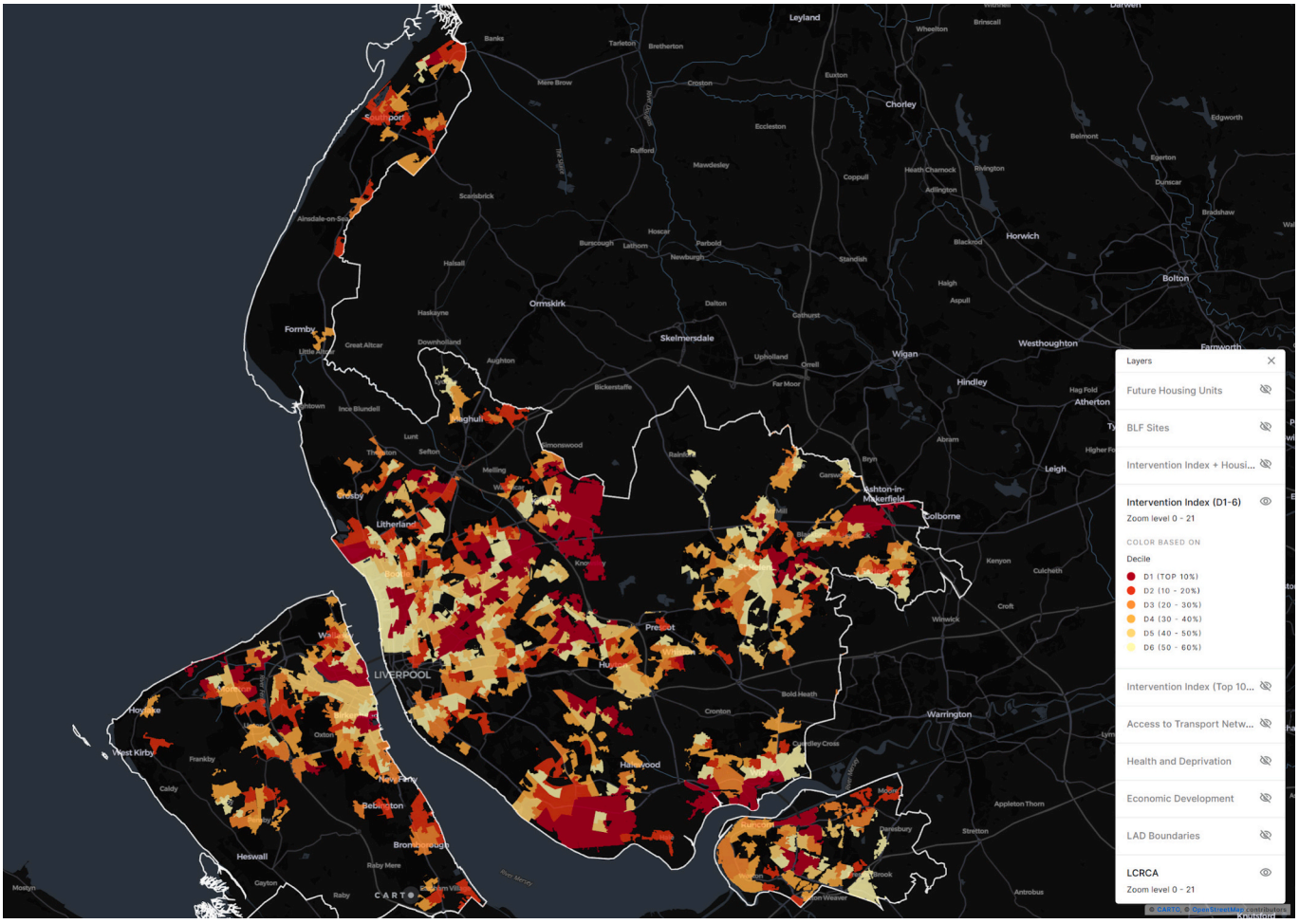

Fig. 6. Intervention Index highlighting areas of Liverpool City Region where policy intervention is needed most, based on the highest levels of compound inequality.

and the needed for more 'grounded' cities (Thompson et al., 2022). However, through co-production and engagement with local stakeholders, the evidence base we have generated enables clearer identification of where these distributional inequities exist, supporting 'top-down' interventions that can alleviate inequalities in the places that experience them most.

In a similar light, there are also some practical limitations to this research. Aswell as being restricted to specific themes of inequality, this study was also limited by the availability of data. There are many additional questions and measures that could be derived to capture all of the domains, such as the use of e-scooters, energy performance and demand for public transportation, as opposed to proximity to transport infrastructure (Feitosa et al., 2023; Ryan & Pereira, 2021). However, upon consultation with policymakers, it was deemed that a smaller set of intelligible indicators were more preferable, serving as an example of balancing *pragmatism* and *parsimony* in the development of urban indicators (Higgs et al., 2019). The second practical limitation relates to the design of indicator weights, which in our case involved additional input from policymakers to minimise 'value conflicts' between areas and domains (Attardi et al., 2018), potentially subjecting the evidence base to participatory biases. It would have been more preferable to utilise techniques such as ELECTRE III (Attardi et al., 2018) or sensitivity analysis (Kuc-Czarnecka, 2019) to calculate optimal weights that also reflect stakeholder opinions. However, given that this research provides the first empirical evidence base supporting devolved investment in Liverpool City Region, there is significant scope to utilise such techniques in expansion and enrichment of the analytical framework established here.

Our research serves as an example of the benefits of building productive, collaborative relationships between academic researchers and policymakers (Boeing et al., 2022; Lowe et al., 2022). Through co-design of the indices and city dashboard, as well as the underpinning conceptual and analytical framework, we have been able to provide a robust evidence base that can support decision making by policymakers in LCRCA. This approach to designing a bespoke set of indicators offers a unique perspective on using indicators of inequality for policymaking; by co-producing indicators in this way, the evidence base can be targeted to support targeted interventions in domains that are actionable. Whilst national-level classifications such as the IMD are useful for similar purposes, when policymaking operates within a specific set of parameters, such as in LCRCA, future research should explore designing similar bespoke evidence to support such efforts. Arguably, by working collaboratively with policymakers to design such an evidence base, a certain degree of 'buy-in' or ownership has been obtained, making defence of a local set of indicators to external stakeholders and Local Authorities much simpler.

As a result, this evidence base is now beginning to generate significant impact, through being used in ongoing discussions with Local Authorities and Councils (Liverpool City Region Overview and Scrutiny Committee, 2023). In these discussions (see item 14), members have agreed that future projects and planning proposals funded by CRSTS should be in line with the priorities identified by our evidence base. This represents a significant achievement, as it illustrates that we have been able to take the decision out of decision making, clearly highlighting priority areas for intervention and investment, based on robust empirical evidence. Furthermore, it shows that there is appetite within the

planning of cities for a more holistic and 'place-based' lens on how interventions and investment should be allocated to benefit those that need it most, directing investment away from places where well-being and equality is at its best (Feitosa et al., 2023).

Looking ahead, a series of scheme development option workshops have taken place with Local Authorities (Liverpool City Region Overview and Scrutiny Committee, 2023). In these workshops, planners, policymakers and external stakeholder groups have been scrutinising and using the evidence base to design creative interventions, which tackle inequalities in areas identified as particularly disadvantaged. Given that urban environments are continually changing, the use of the urban environment as a 'lever' for equality in this way is likely to prove popular, given that these types of city-level interventions are often seen to be easier, cheaper, and more politically acceptable (Olsen et al., 2019). Furthermore, these activities add significant credibility to our approach, increasing the transparency of decisions made by LCRCA, with positive implications about how empirical evidence can be used to support regional decision making in the future. Given that the emphasis of this project was in identifying neighbourhoods where compound inequality is greatest, we have also provided an empirical basis to evaluate the interventions that result from these workshops, as well as developing more formal ways to represent outcomes (e.g., digital twins).

Future research can actively critique such outputs in two ways. In the short-term, researchers can evaluate the siting practices of new investments in the city, and how these relate to pockets of compound inequality identified by our evidence. For example, adopting the approach of Southern (2023), researchers can analyse whether new transport infrastructure is found in places identified as particularly disadvantaged like Knowsley, Speke, and North Liverpool. In the longer-term, researchers also have an empirical basis upon which to evaluate the impacts of these interventions on the complexity of compound inequality in Liverpool City Region. By recalculating the composite indices, they can ascertain the measurable impact of these interventions on the distribution of compound inequality (Lowe et al., 2022). This is an area of great research and impact potential, as there is likely to be a pipeline of devolution deals and financial settlements into the future, at a time where there is increasing recognition of the importance of emerging economies in the city, such as social enterprises and creative industries (Thompson et al., 2022). By supporting development of robust and co-produced evidence bases, and integrating direct critique of the resulting urban policies, researchers and policymakers can generate the best possible outcomes for people across Liverpool City Region. Such efforts could be particularly strengthened when integrated within a London-style data assembly, which has proven effective in the past (Singleton & Longley, 2024). Thus, to conclude, these ideas and outcomes have broad implications for the tackling of social and spatial inequalities in cities, providing new and important insights about the benefits of building collaborative relationships between academics and policymakers to deliver equitable futures for cities globally.

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CRediT authorship contribution statement

Patrick Ballantyne: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Formal analysis, Data curation, Conceptualization. **Alex Singleton:** Writing – review & editing, Visualization, Methodology, Investigation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

Dr. Patrick Ballantyne reports financial support and article publishing charges were provided by University of Liverpool. If there are other authors, they declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The authors do not have permission to share data.

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