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EDITORIAL

Infrastructure, wellbeing and justice

Katy Roelich[1,*], **Danielle Sinnett**[2] **and Desta Mebratu**[3]

[1] School of Earth and Environment, University of Leeds, Leeds, United Kingdom
[2] Departnment of Architecture and the Built Environment, University of West England, Bristol, United Kingdom
[3] Centre for Sustainability Transition, Stellenbosch University, Stellenbosch, South Africa
[*] Author to whom any correspondence should be addressed.

E-mail: k.e.roelich@leeds.ac.uk

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1. Introduction

This special issue was motivated by an observation that infrastructure's role in environmental and economic sustainability is increasingly recognised, but that social sustainability is often overlooked. As environmental and economic sustainability are increasingly invoked as motivating transformation of infrastructure, it is crucial that the relationship between infrastructure and social processes is examined in detail so that environmentally and economically-motivated transformations do not have negative consequences for social sustainability and that opportunities to enhance it are not missed. Our intention in this special issue is to provide conceptual and empirical evidence to support researchers and policy makers in addressing social sustainability as well as environmental and economic sustainability. We used wellbeing as a lens through which to analyse and address the social sustainability of infrastructure. It is worth unpicking the relationships between infrastructure, sustainability and wellbeing before we reflect on some of the key insights from the special issue.

Infrastructure[4] is a complex system of interconnected assets that are co-ordinated to provide services to users (Oughton *et al* 2018). Infrastructure's complexity arises from the connection of physical components across different infrastructure sectors (Rinaldi *et al* 2001) but importantly also from relations to political and social processes and networks (Graham and Marvin 2001). This requires a broader definition of infrastructure to include socio-political, environmental, material and immaterial factors (Kanoi *et al* 2022).

This complexity means that the infrastructure that results from deployment of technologies, structures and supporting systems (like networks and governance) has several unique characteristics (Roelich and Litman-Roventa 2020). Infrastructure is *connective* in that it links technologies and events across places and over time, including between seemingly different infrastructure systems and activities. It is *relational*; its form emerges from the interaction of different elements of the system (e.g. road networks evolve as land-use patterns, car and shopping behaviours change). It is *obdurate;* long-lasting, built on an installed base and embodying historically-specific ideas about appropriate ways of living. It is *collective;* the services provided are for more than one person and infrastructure is frequently a precursor for a collective goal, such as economic growth or wellbeing.

These characteristics mean that infrastructure shapes environmental and social processes; infrastructure systems support metabolisation of natural resources to provide vital services for society (Monstadt 2009). They are contributors to air, water and land pollution and the climate crisis (Creutzig *et al* 2016). They 'fragment' space and drive inequality in access to resources and exposure to environmental problems (Graham and Marvin 2001). They shape social practices and are in turn shaped by social practices (including the practices of decision makers) (Star 1999, Shove *et al* 2015).

In this special issue, influences on social process become particularly important: infrastructure systems affecting access to resources and exposure to pollution; and the relationship between infrastructure and social practices. Both these attributes can influence wellbeing, which is often used as a measure of social sustainability. The World Health Organization defines wellbeing as '*encompassing quality of life as well as the*

[4] We limit ourselves to discussing the six 'economic' infrastructure sectors of energy, transport, water, waste, digital and flood management.

ability of people and societies to contribute to the world in accordance with a sense of meaning and purpose' (World Health Organisation 2021, p 10). Taking this broad definition, infrastructure affects elements of the wellbeing of those who have access to (or do not have access to) services and those living near infrastructure, but we currently lack a comprehensive understanding of how it does this.

There are many ways that infrastructure can affect wellbeing and there is empirical evidence of some aspects of wellbeing for some types of infrastructure. However, the research questions, study location and designs, weight of evidence and findings vary by the nature of infrastructure (Buser *et al* 2020). For example, a rapid evidence review (Buser *et al* 2020), suggested that in the Global North, the obduracy of infrastructure systems related to energy, waste, wastewater and water supply has made them 'invisible' in terms of the wellbeing benefits they provide—it is a given that when one switches on a light or turns on the tap the infrastructure will provide. Therefore, research focused on the wellbeing impacts of the provision of these infrastructures tends to be focussed on the Global South. Whereas, in the Global North infrastructure systems are looked at in terms of the negative local impacts especially if these are related to inequalities, for example, of living near a landfill or power station, or where there has been a breakdown in infrastructure (e.g. power outages) or a relatively recent change in need (e.g. flood management) (Buser *et al* 2020). The exception to this is for newer forms of infrastructure, such as digital infrastructure and those that represent a change from the traditional form of infrastructure where evidence is needed to demonstrate efficacy or cost effectiveness, such as active travel and green infrastructure. Many of the studies, understandably concentrate on one form of infrastructure and/or a relatively narrow measure of wellbeing, which misses opportunities to examine the interactions between them, trade-offs and co-benefits.

Conceptually, there are several frameworks seeking to explain some element of the relationship between infrastructure sectors and wellbeing but these are fragmented by sector and context. Approaches to wellbeing can be broadly categorised as eudaimonic (relating to flourishing in the broader context of society) or hedonic (relating to maximising individual happiness), and objective and subjective.

Brand-Correa and Steinberger (2017) take a eudaimonic, needs-centred, and objective understanding of wellbeing (as opposed to a hedonic, subjective view) to develop a framework relevant to energy use. This framework separates what must be morally met (human needs) from how these needs are met (satisfiers) and suggests that the services provided by energy, not the energy infrastructure itself, meets these needs. The framework helps to identify culturally appropriate ways to improve wellbeing while reducing energy use, by changing how needs are met or how energy is used to meet those needs.

The National Infrastructure Commission (2022) in the UK, by contrast, takes an entirely hedonic understanding, defining wellbeing as how happy or satisfied people are in their lives. They recognise that this is affected by a range of factors operating at different scales which can be measured objectively or subjectively, including; where and how people live and work; physical and mental health; relationships with family and friends; social and cultural norms; and how much control people have in their daily lives. They measure the impact of infrastructure on wellbeing across six domains, seeking to capture cumulative effects across sectors; the direct impacts on physical and mental health, the direct impacts on the local and natural environment, the physical and digital connections that link people communities and businesses; the cost of infrastructure service and the overall cost of infrastructure over time; satisfaction derived from using services infrastructure as an enabler of employment. Crucially, this approach excludes participation in infrastructure governance.

Reardon and Abdallah (2013) bring together hedonic and eudaimonic approaches into a dynamic model for wellbeing and transport with the psychological experience of wellbeing at the centre. The model identifies a combination of external conditions (like employment and physical health) and psychological resources (like optimism and self-esteem) that influence how people meet their psychological needs and have positive subjective feelings, which in turn influence external conditions and psychological resources. This dynamic model highlights the complex relationships between transport policy and wellbeing, including the diverse ways that transport policy can affect different elements of individual wellbeing, the tensions between positive and negative effects and the cumulative effect of multiple parallel policies.

A more instrumental approach to linking infrastructure and wellbeing has been taken by Thacker *et al* (2019) who analyse the extent to which infrastructure systems influence general sustainable development outcomes. They map the influence of five infrastructure systems (energy, transport, digital communications, water (including flood management) and waste management) on the 17 Sustainable Development Goals (SDGs) and their 169 underlying targets. Influence was defined as direct (where the targets is defined directly in terms of the service the infrastructure system provides) or indirect (where there is published evidence that indicated achievement of the target will be enhanced through provision of improved infrastructure services). They find that these infrastructure systems either directly or indirectly influence all 17 Sustainable Development Goals and 72% of the 169 underlying targets. Energy and water infrastructure sectors were found to have the largest direct influence on individual SDGs.

A large portion of research on infrastructure and wellbeing relates to the Global North, but Mebratu (2019) introduces a conceptual model specifically focussed on the Global South. Mebratu (2019) introduces the concept of the 'Wellbeing Economy' as one that strives for continuous fulfilment of basic human needs and aspirations within the limits of natural resources and ecosystems. In this conceptualisation, infrastructure plays a crucial role in mediating the metabolism of natural resources and maintaining ecosystem services that deliver wellbeing. Therefore, there is more focus on the connection between social and environmental processes than in other conceptualisations. Importantly, this conceptualisation rejects the obduracy of the 'western view of infrastructure' which opens up the possibility of leapfrogging existing ideas of what infrastructure is or should be.

The complexity and characteristics of infrastructure as obdurate, relational, connective and collective mean that the boundary of analysis can be difficult to define. However, analysing different parts of infrastructure systems will affect the outcome of analysis so a paper's framing of infrastructure is crucial to interpret and synthesise findings. Similarly, the contrasting conceptualisations of wellbeing will lead to different measures of success and different relationships between infrastructure and wellbeing. This could lead to different recommendations about interventions in infrastructure systems to improve wellbeing so it is important to understand the breadth of conceptualisations of wellbeing. Conceptualisations of the relationship between infrastructure and wellbeing tend to be specific to sectors and disciplines. Illustrating this; a recent perspective piece in this journal discussing infrastructure and wellbeing was written primarily from an anthropological perspective and did not reference any of the frameworks discussed above (Myntti 2024).

In the following sections we consider how the papers in this special issue framed infrastructure and wellbeing; the relationships between infrastructure and wellbeing that emerged as important; and the strong focus on justice that emerged across all papers. The breadth of work included in the special issue highlighted a need for clarity and transparency when researching the relationship between infrastructure and wellbeing, which we discuss in the concluding section.

2. Framing infrastructure

A range of infrastructure systems were represented in special issue papers including energy (Das *et al* 2022, Lashof and Neuberger 2023, Velasco-Herrejón *et al* 2024), transport (Creutzig *et al* 2022, Das *et al* 2022), water (Das *et al* 2022), waste (Kalonde *et al* 2023), digital (Creutzig *et al* 2022, Das *et al* 2022, Yuan *et al* 2022) and flood risk management (Yuan *et al* 2022, Lashof and Neuberger 2023), which raised different aspects of infrastructure's relationship with wellbeing. For example, infrastructures implicated in driving the climate crisis (such as energy and transport) were undergoing transformation to deliver the societal benefit of avoiding the climate crisis but this transformation has potential to create negative impacts on individuals, such as noise and visual intrusion or loss of social capital (Velasco-Herrejón *et al* 2024). Other infrastructure systems were having to respond to environmental change, which exposed issues of sustaining wellbeing through disruption (Yuan *et al* 2022).

The notable sectoral difference was accompanied by substantial differences in how boundaries of analysis were set. The majority of papers included social elements of infrastructure as well as physical but defined social elements in different ways. Governance was a key aspect of many infrastructure system boundaries, constituting a route to wellbeing (by contributing to decision making (Velasco-Herrejón *et al* 2024)), and a moderator of goals and visions through spending decisions (Lashof and Neuberger 2023) and competence/preparedness (Creutzig *et al* 2022). Social practices were included in the boundary of analysis for several papers, recognised as creating obduracy and holding current infrastructure in place (Creutzig *et al* 2022), as a key point of interaction between physical infrastructure assets with skills and meaning highlighting the relational nature of infrastructure (Ahamed *et al* 2023) and as a determinant of infrastructure use (Kalonde *et al* 2023). Social aspects, such as organisation of work and 'social infrastructure' such as education, and healthcare were included in several papers (Ahamed *et al* 2023, Lashof and Neuberger 2023) and actors such as emergency responders were included in infrastructure systems in Yuan *et al* (2022).

It was interesting that citizen agency was addressed explicitly as part of the social system in the two papers from the Global South (Kalonde *et al* 2023, Velasco-Herrejón *et al* 2024). The agency of certain actors in blocking change (for example landlords in Kalonde *et al* (2023), and of giving agency to those who had none, emerged as particularly important (Velasco-Herrejón *et al* 2024). Both papers identified the value of local knowledge to ensure that local culture and worldviews were integrated in decisions and plans to avoid infrastructure colonialism and dispossession (see Velasco-Herrejón *et al* 2024 in particular). This is important when integrating knowledge about infrastructure transformation; the context within which knowledge is created or deployed is of crucial importance and it is incumbent on those in the Global North

to be more specific about the context in which their research took place and whether insights are transferable to other contexts.

Some of the papers had an explicit definition of infrastructure, for example Ahamed *et al* (2023) used the concept of provisioning systems within which infrastructure was embedded and highlighted the relational aspects of infrastructure: 'Provisioning systems can be understood to encompass *material* infrastructures, such as water and energy, grocery stores, farmers markets, and neighborhoods that allow home gardens; *transportation* infrastructures that shape access to goods, services, and people; parks and nature trails and other *outdoor areas* to recreate; as well as *immaterial* infrastructures, which include the organization of work, education, healthcare, and information, which people rely on in daily life.' (Ahamed *et al* 2023, p 2). Lashof and Neuberger (2023, p 3&5) took a more technology-oriented definition of Climate Smart Infrastructure as 'clean electricity generation; short and long-duration energy storage; electricity distribution and transmission; charging and refueling infrastructure for zero-emission vehicles; and clean hydrogen and carbon dioxide capture, transportation and storage' and 'new or modified physical structures that increase resilience and adaptative capacity to expected future impacts in our changing climate'. Das *et al* (2022) provided a more implicit definition in the variables they tested in a survey of infrastructure's contribution to subjective wellbeing, which includes physical household attributes (such as electrical supply, heating and cooling, water supply), physical neighbourhood and city scale attributes (such as parks, walking/cycling facilities, drainage, waste collection, community facilities etc), social neighbourhood and city attributes (such as safety, childcare, medical facilities, educational institutes and governance) and environmental characteristics (such as noise, air and greenery). This highlighted both the collective nature of infrastructure, as providing services to more than one person, and the important interaction with environmental systems highlighted in Mebratu (2019).

Providing a clear definition of infrastructure aids understanding of the boundary of analysis, making possible comparison and synthesis of findings, even when different methods and assumptions have been used. Unfortunately, this is not common practice in infrastructure research, which makes integration of insights from such a distributed field of research challenging.

Only one of the papers considered water and sanitation explicitly as an infrastructure sector (Das *et al* 2022) but did not classify water and sanitation as foundational to wellbeing, despite Thacker et al's (2019) finding that water contributed to most SDGs. This echoes findings from Buser *et al* (2020) that wellbeing from infrastructure service provision is underemphasised in the Global North. This is exacerbated by the obduracy and invisibility of some infrastructure sectors, particularly in the Global North and in urban areas. It may also be a function of the conceptualisation of wellbeing; a more hedonic and subjective conceptualisation may not prioritise more basic human needs (discussed in more detail in the next section). This raises questions about how we analyse social sustainability and perceptions in relation to complex and obdurate systems like infrastructure and highlights the importance of conceptualising and characterising infrastructure clearly (Roelich and Litman-Roventa 2020).

This suggests that research on infrastructure needs to be more open about the contested definition of infrastructure and how much the boundary of analysis shapes the outcomes of research. A more explicit framing and account of disciplinary assumptions and narratives would make it easier to integrate knowledge produced from a broad range of disciplines and contexts. It would also help to challenge some long held (and often unhelpful) assumptions about how change happens; particularly those assuming change emerges from technology development alone. The importance of citizens and institutions as active in system change was highlighted in all special issue papers particularly those from the Global South, emphasising the relational characteristic of infrastructure.

3. Defining wellbeing

There was a similarly broad range of conceptualisations of wellbeing, based on different theories and assumptions. Both the difference in underlying theories and the implicit nature of assumptions makes it hard to compare or synthesise research on wellbeing.

Velasco-Herrejón *et al* (2024) used a eudaimonic conceptualisation of wellbeing, mobilising the Capabilities Approach to examine locally-defined priorities and perspectives, which captures how infrastructure technology (wind turbines in this case) is enhancing or constraining the capabilities of individuals. This enables identification and weighting of valuable things that people can do or be, as opposed to an hedonic approach, which examines how they feel. Priorities included increasing the opportunities for people to live in good health, skilled employment in the industry, engaging and integrating local culture, values, worldviews and needs, and having a collective approach to economic benefit distribution to strengthen social networks (Velasco-Herrejón *et al* 2024).

Velasco-Herrejón *et al* (2024) and Kalonde *et al* (2023) highlighted the importance of citizen engagement in developing infrastructure plans. Velasco-Herrejón *et al* (2024) made explicit links between this engagement in decision making and wellbeing showing how participation itself contributes to wellbeing and provided opportunities for further enhancement of wellbeing including feeling respected and protecting indigenous identity.

Resilience was invoked in Ahamed *et al* (2023) and Yuan *et al* (2022) as a proximate concept of wellbeing, conceptualised as the perturbation a system can withstand while maintaining a certain function (to deliver wellbeing). Neither explicitly defined the wellbeing that should be maintained through perturbation. However, a focus on retaining a certain 'function' through a process of change was pertinent to this editorial's focus on maintaining wellbeing through infrastructure transformation. Ahamed et al's focus on the potential unhelpful resilience of social practices through external perturbations (in their case the Covid-19 pandemic) helps to explain how changes to infrastructure might reduce the wellbeing of some, who do not have the capacity to adapt social practices within new infrastructure configurations and thus cannot benefit from new infrastructure services.

Lashof and Neuberger (2023) and Creutzig *et al* (2022) took a more instrumental approach, using the SDGs as objective measures of wellbeing. Creutzig *et al* (2022) used a range of qualitative links (e.g. reduced motorised transport improving air quality) and quantitative measures (e.g. reduced CO_2 emissions) and resulting wellbeing impacts to trace changes in these measures following the Covid-19 pandemic. They found that the pandemic initiated a range of responses, often 'pop-up' initially, but that the planning and institutional context was important in shaping cities' ability to respond and the permanence of that response. This highlighted the importance of context in the improvement of wellbeing but did not identify causality.

Das *et al* (2022) used evaluative subjective wellbeing which, similar to Reardon and Abdallah (2013), includes a combination of eudaimonic and hedonic measures of wellbeing; as judging life positively (evaluative), frequently experiencing positive emotions in balance (emotional), and feeling fulfilled (eudaimonic). The specific measure of wellbeing used was Cantril's self-anchoring striving scale which asks 'overall, how satisfied are you with your life nowadays'. The authors controlled for correlates to subjective wellbeing (such as health, personality, household attributes and neighbourhood attributes) to isolate the impact of infrastructure on wellbeing. This provides important local context but does not capture place-specific conditions, such as culture, and socio-economic and population characteristics (Das *et al* 2022).

Instrumental and evaluative measures of wellbeing can highlight key relationships but do not provide insights into causality. A lack of focus on the mechanisms causing any changes in measurement can reduce the explanatory power of analysis (Dalkin *et al* 2015).

The concept of collective wellbeing emerged, both explicitly (Velasco-Herrejón *et al* 2024) and implicitly through the concept of community resilience (Yuan *et al* 2022). The focus on collective wellbeing may have been driven in part by the collective approach to reflection employed by Velasco-Herrejón *et al* (2024), and in contrast to the more individualistic approaches to wellbeing employed in other studies. Velasco-Herrejón *et al* (2024, p 14) found that '*that positive impacts of wind farms are primarily experienced collectively*' and that limited benefits were perceived at the individual level. Importantly the wind energy developers had taken a very individualised approach to wellbeing, promoting the benefits to individuals. These individual benefits did not accrue as expected and the individualised approach conflicted with collective aspects of local traditions (such as consensus decision making), which further eroded perceived individual benefits, because culture was not sufficiently respected in engagement processes. This balance between individual and collective wellbeing is crucial and is context specific so it should not be assumed that they are separate, nor that one is universally a priority.

The broad range of conceptualisation of wellbeing mobilised in this special issue, suggests that research in this area needs to be more open about the different approaches to wellbeing employed and how this shapes analysis. A more explicit framing of wellbeing (and/or resilience) would help to integrate knowledge more effectively. The impact of engagement in infrastructure transformations was highlighted as important in the Global South (where eudiamonic conceptions of wellbeing were used), suggesting a need for caution when transferring knowledge between contexts. Importantly, the collective characteristic of infrastructure means that collective wellbeing is materially important as is the tensions between collective and individual wellbeing.

4. Infrastructure-wellbeing relations

Not all papers explicitly discussed the relations between infrastructure and wellbeing but many relations emerged in their analysis. Relations were affected by the type of infrastructure studied, by a range of broader factors mediating wellbeing (or changes in social practices required to maintain wellbeing) and by the extent to which wellbeing was acting as a driver for, or constraint to, transformation of infrastructure.

The broad range of infrastructure systems studied in the special issue papers highlighted a variety of relationships with wellbeing. Two papers emphasised the importance of resilient infrastructure in retaining functionality during climate events to avoid the negative impacts on wellbeing (Yuan *et al* 2022, Lashof and Neuberger 2023). Similarly, the decarbonisation of transport and energy infrastructure was cited as being essential to avoid long-term detriment to wellbeing associated with climate change (Creutzig *et al* 2022, Lashof and Neuberger 2023) and the shorter-term negative health impacts of air pollution (Creutzig *et al* 2022).

Papers also highlighted positive impacts, from health benefits of waste collection and disposal infrastructure (Kalonde *et al* 2023) to jobs and income created by renewable energy infrastructure (Velasco-Herrejón *et al* 2024). Importantly, the different approaches to infrastructure delivery had diverse outcomes for wellbeing, for example active travel through bike lanes may improve health for bike users, whereas active travel through open streets can provide opportunities for leisure and socialising as well as exercise; so the delivery approach is crucial, not just the mode (Creutzig *et al* 2022).

Das *et al* (2022) characterised different infrastructure sectors as foundational, consistently important or an 'added bonus' based on relationships to (subjective) wellbeing. Home heating and cooling and public transport were classified as foundational, but as noted earlier, infrastructure that meets more basic human needs, such as water and sanitation, was not mentioned. The obduracy of infrastructure can make it hard to reveal important relationships, particularly when subjective measures of wellbeing are used.

Several studies highlighted the interaction between infrastructure sectors required to support wellbeing, for example the digital infrastructure required to improve resilience of flood protection infrastructure (Yuan *et al* 2022) or the energy infrastructure needed to support decarbonisation of the transport sector (Lashof and Neuberger 2023). This connective characteristic of infrastructure means that studying separate sectors might miss interactions essential to delivering wellbeing.

Factors in the wider infrastructure system that mediated the relationship between infrastructure and wellbeing were identified in several papers. Governance was identified as a mediator in Kalonde *et al* (2023) where a lack of enforcement limited the ambition for infrastructure development and in Creutzig *et al* (2022) where governance was crucial to accelerate the necessary transformation of infrastructure to improve wellbeing.

Individuals' access to certain factors also mediated the relationship between infrastructure and wellbeing, which highlighted severe concerns for justice if this access was uneven. Ahamed *et al* (2023) highlighted access to economic, social and cultural capital as a determinant of the ability of individuals to access infrastructure and the wellbeing-delivering social practices it supports. They and Kalonde *et al* (2023) also highlighted the importance of knowledge and skills as mediators. The structural inequalities that affect the distribution of access to these forms of capital and to skills and knowledge can affect access to infrastructure (and wellbeing) as well as access to technologies and practices that can maintain wellbeing through infrastructure transformation (such as electric vehicles or well-insulated homes).

The relationship between infrastructure and wellbeing can vary over time, as these mediating factors change and as a result of changes in citizen aspirations and circumstances. The effects of the Covid-19 pandemic on the relationships between infrastructure and wellbeing were discussed at length in Creutzig *et al* (2022) and Ahamed *et al* (2023). A further example, in Velasco-Herrejón *et al* (2024) was the perceived increase in inequality that has resulted from an imbalance in those benefitting financially from wind farm infrastructure and those who have not. Some of the anticipated investments in social infrastructure have not been realised or have not resulted in the expected improvements to wellbeing. Therefore, it should not be assumed that relationships are static; a more systems-based approach is required.

Concern for wellbeing has acted as a driver of change in infrastructure for centuries. Historically, this has tended to be limited to arguments to improve physical health such as opening up streets to fight cholera, providing green space to improve health conditions and more recently, addressing respiratory impacts from transport-induced poor air quality (Creutzig *et al* 2022). Concern for wellbeing can also acts as a constraint to infrastructure transformation; concern about potential negative impacts of new infrastructure on wellbeing can affect its acceptance (Velasco-Herrejón *et al* 2024). More research is needed on the relations between infrastructure and wellbeing to move discussions beyond the physical health aspects of wellbeing and to support honest discussions about the tensions and trade-offs between infrastructure and wellbeing.

The breadth of relationships highlighted in this special issue suggests that further work is needed to better map, characterise or conceptualise these relationships. The connective, obdurate, relational, and collective characteristics of infrastructure mean that relationships are extensive but not always visible, therefore more explicit focus on revealing them and more creative methods to support stakeholders and citizens to articulate them may be needed. Crucially, these relationships will change as infrastructure transforms, so analysis must be both systemic and dynamic to ensure that unhelpful relationships do not endure and that new relationships are developed to promote positive impacts of infrastructure transformation on wellbeing.

5. Justice in infrastructure transformations

Justice emerged as a theme across all papers, despite having no mention in the call for papers, and there were clear common themes.

Distributional justice was noted as important in several papers, recognising that disadvantaged groups were more likely to suffer harm and least likely to benefit from current infrastructure (Creutzig *et al* 2022). When considering infrastructure transformation, many papers argued that changes should be designed to benefit, or at least not further burden, communities that have been under-served, overburdened by pollution and discriminated against (Das *et al* 2022, Ahamed *et al* 2023, Lashof and Neuberger 2023, Velasco-Herrejón *et al* 2024). Access to factors mediating the infrastructure-wellbeing relationship, such as different forms of capital, skills or knowledge were identified as important, especially in relation to potential changes in social practice without detriment to wellbeing (Das *et al* 2022, Ahamed *et al* 2023, Kalonde *et al* 2023). Ahamed *et al* (2023) highlighted that social hierarchies create structural inequalities, which in turn shape practices and thus certain individuals may be unable to shift practices to retain wellbeing as infrastructure transforms.

Issues of representation were highlighted, for example; data-led approaches may exclude areas with poor data coverage or with limited participation on social media so findings do not represent their conditions (Yuan *et al* 2022). This would be particularly problematic if those areas with poor data coverage or social media engagement were disadvantaged groups, exacerbating issues of distributional justice. The challenges of understanding indigenous voices were raised by Velasco-Herrejón *et al* (2024), who showed the benefit to wellbeing, and to acceptance, of finding ways to articulate that voice and understanding culturally-specific values.

Participation was cited as important in several papers and there was recognition that involvement of stakeholders was crucial to successful plans (Kalonde *et al* 2023) and that inclusive community engagement was vital (Velasco-Herrejón *et al* 2024)

The emergent concept of collective wellbeing brought new issues of justice; of balancing individual wellbeing with collective wellbeing (Ahamed *et al* 2023, Velasco-Herrejón *et al* 2024). This also raised issues of representation, where a lack of understanding of the cultural importance of collective outcomes and processes in local traditions resulted in an individualised approach, which reduced wellbeing and acceptance of a wind energy project (Velasco-Herrejón *et al* 2024).

The consistent focus on justice suggests that explicit consideration is required when analysing the relationships between infrastructure and wellbeing. This is particularly important during transformation, when the complex relationships and connections within infrastructure systems will change and injustices might arise. There is no unified framework for analysing just infrastructure transformations—climate justice (Schlosberg and Collins 2014), energy justice (Wood and Roelich 2020), environmental justice (Schlosberg 2007) and mobility justice (Mullen and Marsden 2016) all have relevance but do not address all aspects of infrastructure transformation. This makes it even more important to be explicit about the framework used and its assumptions and limitations.

6. Conclusions: a future pathway for research in infrastructure transformations

The array of potential definitions and boundaries used when analysing both infrastructure and wellbeing can affect the outcomes of analysis and make it hard to synthesise work in this area, limiting the potential to draw more general conclusions and progress the field. More explicit definitions and boundaries would help to improve consistency, while recognising that the connective nature of infrastructure will always make it hard to clearly define boundaries. Nevertheless, the obduracy of infrastructure, which compounds this challenge by rendering it invisible, will not be overcome unless there is more openness and contestation about definitions and boundaries.

The context within which analysis takes place also requires more attention—to identify the broad range of mediating factors affecting the relationships between infrastructure and wellbeing and to help to transfer knowledge between contexts. The relational characteristic of infrastructure is particularly important here—recognising that change emerges from interactions between assets and between assets and actors. Citizens and institutions are an active part of the infrastructure system and play a key role in its transformation. This increases the importance of recognising the unique culture and attributes of citizens and institutions in a particular place and how this affects aspirations for wellbeing and the relationships between infrastructure and wellbeing.

It is particularly important to address the context of the Global South to avoid epistemic injustices—to ensure that work there is given more prominence and that work undertaken in the Global North helps those in the Global South to make sense of their experience. Examples of this are the benefits of infrastructure that

are invisible in the Global North, but which are important where infrastructure in under-provided, and the potential to 'leapfrog' the obdurate western view of infrastructure.

More work is needed to understand the mechanisms of how infrastructure affects wellbeing. The papers in this special issue highlighted the extensive relationships between infrastructure and wellbeing, but the obduracy of infrastructure, particularly in the Global North, can render these relationships invisible. More work is needed to map, characterise, and conceptualise relationships between infrastructure and wellbeing to make them more visible, and potentially easier to analyse going forward. This is particularly crucial in places where the obduracy of infrastructure has meant that it has been neglected and underfunded and its resilience, particularly to climate change, is now uncertain. In these places, research can support the case for ongoing investment in maintenance of infrastructure.

The dynamic nature of relationships between infrastructure and wellbeing, which change over time and will change further as infrastructure is transformed, will be particularly important (but also challenging) to capture. Resilience was used in several papers in the special issue to represent the maintenance of important functions through perturbation of infrastructure. This is often considered in relation to retaining the function of an asset through unexpected perturbations, such as a global pandemic (Ahamed *et al* 2023) or flood events (Yuan *et al* 2022). However, resilience may become a less useful concept as we seek to transform infrastructure. Pelling (2011) argues that considering resilience as protecting core assets can limit the significant change in social and political relations needed to transform infrastructure. Either resilience needs to be more clearly articulated as resilience of wellbeing delivered by infrastructure or an alternative term, less susceptible to misinterpretation is needed (Pelling 2011).

Improving the conceptualisation of the relationship between infrastructure and wellbeing will be a significant development but only useful if there is similar progress in how to use this knowledge in decision making processes. The importance of collective wellbeing, highlighted by Velasco-Herrejón *et al* (2024) in particular, and perhaps inevitable in light of infrastructure's contribution to collective goals, presents challenges here. Trade-offs between collective and individual wellbeing can be difficult to reconcile, particularly in decision making processes designed to efficiently allocate scarce funding and assess projects on an 'equal footing' (Lyons and Marsden 2021).

Finally, the emergence of justice as a central theme was a welcome phenomenon. This highlighted that distribution (of impacts and access to the benefits) was crucial and mediated by a range of structural issues, such as social hierarchy, that should be addressed when considering infrastructure transformation. This cannot be addressed without representation of those most disadvantaged. Participation was viewed as a crucial way to ensure this representation, but care is needed to ensure that the most disadvantaged are able to articulate their knowledge (Velasco-Herrejón *et al* 2024). Returning to the original definition of wellbeing as '*encompassing quality of life as well as the ability of people and societies to contribute to the world in according with a sense of meaning and purpose*' (World Health Organisation 2021) it is clear that meaningful participation contributes directly to wellbeing. Providing opportunities for citizens to contribute through deliberation and direct action should be a core part of infrastructure transformation.

Data availability statement

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ORCID iDs

Katy Roelich https://orcid.org/0000-0001-6979-5401
Danielle Sinnett https://orcid.org/0000-0003-4757-3597
Desta Mebratu https://orcid.org/0000-0002-2460-4787

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