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# Public perceptions of networked infrastructure

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**ABSTRACT**

Infrastructure is crucial to the functioning of society and the economy. Yet, to avoid precipitating environmental breakdown, it must undergo transformation. We argue that citizens who rely on infrastructure's services should have a say in how transformation is managed. However, the complex nature of infrastructure means that public dialogue is difficult and rarely done well. Infrastructure has several characteristics, which make elicitation of perceptions challenging: it is connective, relational, obdurate, collective and subject to fragmented governance. We held a series of deliberative workshops in a city in the UK, to examine how public perceptions of infrastructure are shaped by these characteristics. We found that using infrastructure's characteristics as a framework for deliberation built participants' capabilities to articulate perceptions of infrastructure. We argue that using these characteristics also placed more emphasis on the socio-materiality of infrastructure and can address the disconnect between scales of participation and scales of decision making. This offers an alternative way to debate the desirable attributes of infrastructure, which we argue is more productive and inclusive.

## 1. Introduction

Networked infrastructure systems (energy, transport, water, waste, flood protection and digital) are fundamental to addressing social and environmental challenges (Monstadt 2009; National Infrastructure Commission 2018): infrastructure systems support metabolisation of natural resources to provide vital services for society (Monstadt 2009). They are significant 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). Infrastructure systems must undergo transformation to mitigate these issues and respond to change already set in motion (Hall et al. 2017).

The tight coupling between infrastructure and social and environmental wellbeing implies that public perceptions of infrastructure should be better understood and should more clearly influence decisions about transformation (Pidgeon et al. 2014; Demski et al. 2015; Green Alliance 2015). Public dialogue on some infrastructure sectors is gaining traction (Pidgeon et al. 2014), but this is difficult to implement and rarely done effectively. In this article, we explore why eliciting public perceptions of infrastructure is so difficult and suggest ways to address this challenge. We focus on invited forms of participation to elicit perceptions, not on forms of protest against

infrastructure projects or performance, nor on social movements to promote alternative infrastructure futures. Our empirical work is based in a UK city, and related to the material, social and political context of this setting.

Infrastructure is a complex system of interconnected assets that are coordinated to provide infrastructure services to users (Oughton et al. 2018). The physical connection within and between infrastructure systems can partially explain the challenges of eliciting public perceptions; the boundary of the system can be difficult to define. However, a growing body of critical scholarship in urban studies and science and technology studies theorises infrastructures as important sites of social and political change, forcing focus beyond physical assets and connections (Graham and Marvin 2001; Coutard 2008; Monstadt and Coutard 2019; Williams, Bouzarovski, and Swyngedouw 2019). This scholarship highlights the reciprocal relationships between social processes, networks and meanings, and infrastructure assets (Pinch and Bijker 1984; Latour 1996). The role of governance and politics in shaping infrastructure systems also becomes more prominent; the privatisation and liberalisations of many infrastructure sectors has had significant implications for the design and operation of infrastructure (Harvey 1996; Graham and Marvin 2001; Coutard 2008).

A socially constructed and relational view of infrastructure provides more explanatory power about how it shapes our lives and environment. However; it also renders infrastructure less tangible and makes it particularly hard to elicit perceptions: it is difficult to isolate infrastructure's effects at individual locations or from individual assets. We argue that eliciting perceptions of infrastructure needs a different approach to that used for individual technologies or spatial planning. We contribute to scholarship on public participation by describing deliberative workshops that used a socially, politically and materially relational understanding to elicit public perceptions of infrastructure. We argue that allowing publics to deliberate and articulate the social, political and material can improve elicitation of perceptions of current infrastructure and aspirations for future infrastructure.

In the first part of the paper we identify five characteristics that make infrastructure a particular challenge for eliciting public perceptions. We then summarise research about public perceptions of individual infrastructure systems, explaining what is lacking in light of the identified characteristics. Finally, we review current approaches to infrastructure engagement and discuss why this is insufficient to understand and elicit perceptions effectively.

Next, we introduce the methods used to deliberate infrastructure at public workshops held in Leeds, UK. We then outline public perceptions of current infrastructure systems and aspirations for future infrastructure articulated at these workshops. Finally, we reflect on whether the five characteristics affected our participants' articulation of perceptions and how this might affect approaches to public participation.

## 2. Eliciting public perceptions of infrastructure

### 2.1. Infrastructure's unique characteristics

Several studies have identified characteristics that define infrastructure, within the author's disciplinary context. Star's (1999) seminal paper identifies several properties of infrastructure including; embeddedness, transparency, reach or scope, learned as part of membership, links with conventions of practice, embodiment of standards, built on an installed base, visible upon breakdown, and fixed in modular increments. These properties explain the challenges of ethnographic study of infrastructure, and how infrastructure affects culture and society, but do not address the effects of infrastructure on places or on capital accumulation, which have been the focus of more recent infrastructure scholarship. Markard (2009) identifies characteristics that affect innovation or transformation in infrastructure including; capital intensity, asset durability, environmental impacts, public control, regulation intensity, degree of competition, system-ness. These characteristics, understandably because of the technical and managerial literature which underpins them, focus on the technical and governance elements of infrastructure but overlook the social processes, networks and

meanings that shape the evolution and transformation of infrastructure. Shove, Watson, and Spurling (2015) propose characteristics that explain infrastructure's connection with social practices. Characteristics include; connective, "infra" (in the background and sustaining multiple practices), collective, and obdurate.

None of these groups of characteristics fully captures the social, material *and* political aspects of infrastructure nor how it shapes society and spaces. Therefore, we have drawn on this work and critical infrastructure scholarship to develop our own characteristics of infrastructure, including connective, relational, obdurate, collective and having fragmented governance. We argue that these characteristics can explain why it is so hard to discuss and debate infrastructure preferences.

### 2.1.1. Connective

Infrastructure is (but not always) *connective,* which makes it hard to establish a system boundary. The connection between different sectors has received attention in both academia and in policy making (Rinaldi 2004; Mayor of London 2015; Roelich et al. 2015; Hall et al. 2017; National Infrastructure Commission 2018). Connections can be direct, created during the production of infrastructure products (e.g. energy and water) or indirect, during the act of consumption e.g. using electricity to heat water for a shower (Kenway 2013). Infrastructure also connects places (e.g. roads connecting two cities or electricity networks connecting sites of generation and production) (Graham and Marvin 2001; Shove, Watson, and Spurling 2015). It also connects across time; e.g. telephoning rather than travelling to see a friend. However, connectivity is not universal, e.g. a radial railway system from a wealthy suburb to a city centre fails to connect inner city areas to the city centre or to each other. Inner city areas could be spatially close to city centre facilities but poorly connected, which might create or aggravate inequalities (see Graham and Marvin 2001 or Latour's Tyranny of Distance (1996)). Considering this connectivity (and dis-connectivity) can make the depth and scale of public engagement challenging. Simple enquiry about preferred options is not possible when the implications and trade-offs created by these connections are so complicated.

### 2.1.2. Relational

Infrastructure is *relational* in that it only acquires its form and attributes through relations between assets and actors. For example, a culture of consumption and expansion of the automotive industry has increased car ownership, which prompts and increase in provision of car infrastructure, which enables car owners to travel further to shop or work, which encourages urban sprawl (Mattioli et al. 2020). This emphasises the networked character of infrastructure; not just of physical assets but of institutions; the cultural values and social practices of the people that design, operate and use it; the politics underpinning decision making; the resources metabolised by infrastructure (e.g. fossil fuels); and the environment and geography in which is it located (Graham and Marvin 2001; Rydin 2013; Shove, Watson, and Spurling 2015).

A consequence of infrastructure's relationality is the difficulty in distinguishing the co-ordinated aspects of infrastructure, rendering it invisible to some users (Star 1999). This makes it hard to engage publics, because many people do not consider how infrastructure influences their social and material arrangements (Niewöhner 2015). However, this invisibility is not universal, it can vary dramatically across infrastructure sectors, between places (Coutard 2008) and between users; for example, many people in fuel poverty are acutely aware of the energy system (Middlemiss and Gillard 2015).

Sustaining relations requires continuing effort over time, even within mature infrastructure systems so stability is an active process, rather than a given characteristic (Bingham 1996). This "controlled instability" leaves infrastructure vulnerable to disruption, interruption and even failure (Graham 2009). Infrastructure failure can render it more visible and perceptions can be formed by these instances of failure (Star 1999). This negative association could have a significant influence on current perceptions of and future aspirations for infrastructure.

### 2.1.3. Obdurate

Infrastructure is generally made from durable materials and its construction involves major investment and significant sunk costs. Therefore, it is very long-lasting and built on top of the installed base. Its configuration is the product of historic events and once established, relations between technologies, networks, institutions and users stabilise that configuration and constrain the development and adoption of alternatives (Arthur 1989; Unruh 2000; Klein and Kleinman 2002). This path dependency or *obduracy* can make it hard to re-imagine infrastructure (Hommels 2005; Shove, Trentmann, and Watson 2018). However, as discussed above, the maintenance of infrastructure's obduracy requires continual effort and it is vulnerable to disruption, despite its "veneer of permanence, stability and ubiquity" (Graham 2009, 9).

Obduracy also manifests itself in the implicit, politically and historically specific, understanding of what infrastructure is and what it does (Pinch and Bijker 1984; Hommels 2005). Nevertheless, infrastructure is discussed in terms of scientific impartiality and the political ideology is rarely made explicit (Williams, Bouzarovski, and Swyngedouw 2019). Publics rarely get an opportunity to debate the ideology underpinning infrastructure planning but it shapes how publics are engaged and could shape their perceptions.

Obduracy is not universal across infrastructure systems (or even within them); some, such as transport, are highly embedded in the physical structure of cities, others, such as parts of the digital network, are far more flexible and less fixed (Harvey 1985). Disentangling perceptions of infrastructure from the current configuration and from the hegemonic understanding of infrastructure presents a real challenge for public engagement.

### 2.1.4. Collective

Infrastructure is *collective* in that its physical assets provide services to a multitude of people. Value arises from the metabolism of natural resources to generate infrastructure services that contribute to collective goals (such as wellbeing and economic growth) (Kaika and Swyngedouw 2000; Monstadt 2009). The reconfiguration of infrastructure will also mitigate collective environmental problems, such as the climate crisis (Creutzig et al. 2016). The importance of infrastructure to societal outcomes can make it hard to determine the object of engagement. It is not necessarily the asset that is important, but what that asset does for people (Brand-Correa and Steinberger 2017).

Infrastructure is often considered a "public good" and users have not been excluded because of its role in enabling wellbeing. This has been eroded in some sectors by privatisation, liberalisation and smart technology that enables infrastructure services to be commodified and sold in capitalist markets. This has led to some sectors or places being "selectively" collective. For example, prioritisation of broadband roll out in profitable areas and high speed trains; services are prioritised for profitable customers or only available to those who can afford them. The regulation of markets reduces the chances of excluding some users but does not completely stop the withdrawal of services from poorer or less profitable groups.

Scale of participation also becomes a challenge in when considering the collective nature of infrastructure. For example; many agree that increasing solar energy is beneficial to address the climate crisis. However, those in close proximity to solar farms, who lose valued landscapes, may not feel that the local cost is worth the collective benefit. Allowing people to debate these scalar issues in perceptions of infrastructure remains a significant challenge (Bell, Gray, and Haggett 2005; Bell et al. 2013).

### 2.1.5. Fragmented governance

Infrastructure has undergone an extensive programme of unbundling which has fragmented governance across sectors, space and the public and private sector (Graham and Marvin 2001; Williams, Bouzarovski, and Swyngedouw 2019). This distributes responsibility for infrastructure transformation across multiple organisations, operating at different scales, and within different regulatory regimes (Hall et al. 2012). This leads to complex governance arrangements that cannot fully address the

connective nature of infrastructure across sectors and places (Monstadt 2009). It also exacerbates the mismatch between place-specific and systemic participation and outcomes. This forces participants to trade off costs (that they will feel) with benefits (that they may not feel) and provides no mechanism through which they can deliberate these issues (Upham et al. 2018).

It is rare that an organisation has oversight of all infrastructure sectors and the capacity to engage publics. Some countries have developed national advisory bodies, such as the UK National Infrastructure Commission and Infrastructure Australia. Nevertheless, the focus of these bodies is on the national scale, which overlooks the role of local government and the concentration of infrastructure in urban centres (Monstadt and Schmidt 2019).

## 2.2. Public perceptions of infrastructure

Studies examining perceptions of individual infrastructure systems find that perceptions are heavily driven by context, because of the relational and obdurate nature of infrastructure, making generalise about perceptions between places or between sectors difficult. However, there is consistency in some drivers of perceptions including familiarity, institutional trust, and the values that underpin perceptions.

Publics draw heavily on experience when constructing perceptions of technologies or policies (Whitmarsh et al. 2011). Perceptions of risk in particular are influenced by familiarity with the risk source (Scheer, Konrad, and Wassermann 2017). Familiarity is not the same as scientific knowledge but draws on a range of experiences that may not be directly related to the technology or system under consideration. Therefore, the "deficit model" frequently used implicitly by industry and government when dealing with publics in stable democracies is deeply flawed because it assumes that publics express opposition because they lack appropriate scientific knowledge (Rayner 2010).

Familiarity does not take into account the contingent nature of perceptions which are particularly apparent when decisions are made about technology siting. Locality, as well as the nature of the technology, becomes important (Devine-Wright 2011a; Bell et al. 2013). Perceptions may be qualified by limits on the impact of the technology on valued attributes, such as landscape (Bell, Gray, and Haggett 2005). This highlights the challenge of framing "publics" in relation to infrastructure; publics could be those in the locality of a particular asset and/or those in multiple locations that might benefit from networked infrastructure (Upham et al. 2018). These different framings must be recognised to take into account the effect of place attachment (Devine-Wright 2011) and mismatches between scale of shared interest and scale of decision making (Natarajan 2019) on perceptions.

Support is also contingent on how engagement is conducted, who is conducting the engagement (Whitmarsh et al. 2011) and whether participants trust those organising the processes to act fairly (Ricci, Bellaby, and Flynn 2008). This is important because many studies have found a lack of trust in political and industrial actors involved in infrastructure, which could negatively influence perceptions (Fielding et al. 2015; Scheer, Konrad, and Wassermann 2017). The complexity of these relationships and the lack of trust exacerbates the challenge of fragmented governance, because publics may be required to engage with multiple agencies whom they trust to differing extents.

Public perceptions of complex, socio-material issues emerge from a process of interpreting new knowledge with existing values, world views and socio cultural understanding of the world (Jasanoff and Wynne 1998; Stenekes et al. 2006). Values are "*identifiable cultural resources people draw on to guide their preference formulation about particular aspects of ... change*" (Demski et al. 2015, 59) and go beyond identifying attitudes or the acceptability of technologies.

Perceptions of infrastructure transformations can pertain to broader concerns about how society or the environment might develop in the future. Engagement with publics that explicitly addresses these concerns could help address some of the challenges associated with relationality and obduracy. It can allows publics to engage with the connectivity and collective nature of infrastructure and examine the associated contingencies and trade-offs. This can reveal a more complex picture

of public perceptions and the values that underpin positive or negative views of particular technologies. However, perceptions about abstract system change must address the potential for conflict with perceptions of place-based technology siting (Roddis et al., 2020; Devine-Wright 2011; Bell et al. 2013)

## 2.3. Current practices in eliciting public perceptions of infrastructure

Public participation in infrastructure takes a wide variety of forms and stems from a diverse range of agencies, organisations and social movements but is becoming increasingly institutionalised in stable democracies (Chilvers and Kearnes 2016; Chilvers, Pallett, and Hargreaves 2018). In this section, we focus on participation pertaining to infrastructure, formally orchestrated by institutions in stable democracies, and which seeks to elicit perceptions. Participation of this kind is frequently required by law (Jager et al. 2016; Natarajan et al. 2019) or acknowledged as being beneficial to achieve a particular policy goal. However, it is predominantly framed as aiding acceptance of a particular issue, technology or project (Pallett, Chilvers, and Hargreaves 2019).

Participation is usually invited; i.e. input is sought at a particular time or from a particular audience, and is highly orchestrated; the problem/project is tightly framed and specific questions are asked of respondents. Participation can occur at both a strategic (for example, pertaining to strategic spatial planning) and at a project level. Traditionally, participation has involved members of the public responding to surveys or proposals to express individual preferences about a pre-framed problem or solution (Elling and Nielsen 2018). These are aggregated into a collective opinion that is designed to be weighed against other factors influencing a decision (McAndrews and Marcus 2015). The extent to which processes for collecting and aggregating individual preferences are able to address the tension between place-based issues and more systemic issues, is debated (Natarajan 2019).

Participation through surveys selects a group of participants, based on a set of demographic characteristics, in an attempt to represent an aggregate population (Pallett, Chilvers, and Hargreaves 2019). Open calls for participation, for example in response to a planning application or a spatial strategy, have less control over who participates. This can create a democratic deficit because a vocal minority can dominate the responses and exert greater power over a decision making process (Toke 2002). Expressing perceptions of complex systems, such as infrastructure, requires capabilities to understand the system and articulate insights about that system, which means that those who possess these capabilities, could be empowered at the expense of others and create systemic inequality of participation (Brownill and Inch 2019; Pallett, Chilvers, and Hargreaves 2019).

There has been a turn towards more deliberative forms of participation where smaller groups are convened to debate specific issues in detail (for example the Sciencewise programme in the UK (Pallett 2015), and the recent Convention Citoyenne pour le Climat in France or the UK Climate Assembly). Some deliberative exercises have been designed to inform policy direction more generally and allow participants to engage in dialogue with policy makers and experts. Others are designed with more concrete ends, such as the preparation of draft laws in the case of the Convention Citoyenne pour le Climat. Evaluations have shown that deliberative processes can inform policy development (Department of Energy and Climate Change 2011), overcome polarisation (Dryzek et al. 2019), shape a shared understanding of an issue, and help participants to articulate their underlying "will" more effectively (Niemeyer 2011).

The dominant approach to participation presents several challenges for elicitation of perceptions on infrastructure. The tight framing of the issues under discussion and the limited scope of data requested, even in deliberative processes, can limit publics' ability to grapple with infrastructure's connectivity with the relations between infrastructure assets and society (Wynne 2006; Pallett, Chilvers, and Hargreaves 2019).

There is currently no space for citizens to debate infrastructure needs and alternative ways of meeting these; the focus of participation is infrastructure assets, not what those assets <u>do</u> (Wynne

2006; Owens 2011; Green Alliance 2015). This makes it very difficult to address the collective nature of infrastructure and its strong relationship with wellbeing. Furthermore, the majority of public engagement seeks to aggregate individual preferences, which overlooks the heterogeneity of views and the possibility for development of collective positions.

Where public engagement is undertaken at the strategic level, for example during consultation about spatial planning documents, this engagement is undertaken at a scale dictated by administrative requirements, which are usually local or regional government boundaries (Natarajan 2019). Cartesian assumptions about locality (that assets in close proximity have the most impact on citizens' lives) underemphasise the connectivity between infrastructure across space and scales and overlooks the collective characteristic of infrastructure (Green Alliance 2015; Natarajan 2019). The statutory focus of these spatial plans on housing and employment places infrastructure in the background (with the exception of perhaps transport) and exacerbates its invisibility.

Engagement is framed around acceptance of projects, which is driven by an obdurate view of infrastructure pertaining to the development of assets, to create infrastructure commodities that support economic growth. This framing, which is present even in deliberative processes, can affect what views are elicited or how data is used (Pallett, Chilvers, and Hargreaves 2019). For example concern over the direction of the UK energy transition or different underlying relationships with the local landscape are largely ignored (Butler, Parkhill, and Luzecka 2018).

Thus, it is clear that current approaches to eliciting infrastructure perceptions are not addressing, but are in fact exacerbating the challenges outlined in Section 2.1.

## 3. Methods

We held three deliberative workshops with activities designed to examine the connective, relational, obdurate and collective nature of infrastructure. Our methods encouraged participants to relate to each other to reflect the socially constructed nature of infrastructure. We explicitly encouraged discussion of infrastructure governance to examine whether the fragmented governance affected perceptions or engagement in infrastructure decision making.

Deliberative workshops are a facilitated group discussion where participants are provided with an opportunity to consider an issue in depth. They are widely used to explore public perceptions of emerging areas of science, technology and policy (e.g. Chilvers 2010; Corner et al. 2013; Demski et al. 2015).

Deliberative workshops were conducted in three locations in Leeds, UK. This geographic scale was selected because infrastructure is inherently place-based and the contextual views of local people are more important than a generalised view of infrastructure in the abstract.

Each workshop was attended by 8–10 participants ($n = 26$) who were recruited through a professional agency. Criteria were used to recruit a spread of gender, age, socio-economic groupings and ethnicity, summarised in Table 1.

**Table 1.** Deliberative workshop participant characteristics.

| | | |
|---|---|---|
| Gender | Male | 11 |
| | Female | 15 |
| Age | 18–39 | 8 |
| | 40–59 | 12 |
| | 60+ | 6 |
| Children | No | 12 |
| | Yes | 14 |
| Socio-economic grouping | AB | 7 |
| | C1 | 8 |
| | C2 | 5 |
| | DE | 6 |
| Ethnicity | White British | 20 |
| | BAME | 6 |

The majority of participants were residents of Leeds but each workshop included participants from neighbouring cities, including Wakefield and Sheffield. Participants were recruited to a workshop about infrastructure but were not informed of the specific focus of discussions and were given a small monetary honorarium for their participation. The process for reimbursement followed the University of Leeds' protocol on reimbursement of research participants to ensure it did not interfere with the voluntariness of consent or act as undue inducement.

The workshops were facilitated by the authors and lasted five hours. They were designed to engage members of the public as active, imaginative agents (Jasanoff 2003). Activities focussed on what the UK's National Infrastructure Commission calls "economic" infrastructure sectors (i.e. transport, energy, water and sewerage, flood risk, digital and waste), because these sectors have the most significant impact on the social and environmental challenges motivating this work. Activities were tailored to allow systemic examination of social, political and material aspects of infrastructure.

The workshops used a range of deliberative techniques including:

(1) Defining infrastructure: discussing what infrastructure meant to participants, involving whole group discussion and a presentation by facilitators;
(2) Visualising infrastructure: small group discussions (*n*=4–5) of infrastructure in the vicinity of the workshop venue using visual prompts and stimulus material to overcome invisibility. Participants were encouraged to share their knowledge, experiences and concerns about local infrastructure;
(3) Linking infrastructure and wellbeing: small group discussions (*n*=4–5) of the link between each infrastructure sector and wellbeing using Max-Neef's (1991) conceptualisation of human needs to represent facets of wellbeing and pre-prepared worksheets to structure discussion. This aimed to stimulate the exploration of socio-material relations; and
(4) Designing future infrastructure: small group discussions (*n*=2–4) of desirable future infrastructure. Participants designed infrastructure for a virtual, anonymous city in the future, represented on 3D maps and in the computer game Minecraft. Participants were able to consider all infrastructure sectors to allow them to address connectivity and there were no objectives for future infrastructure, other than being a nice place to live, to address obduracy. Participants developed their infrastructure futures as a group over a period of one hour concluding with a whole group discussion of key features of each future.

As facilitators, we prompted participants' reflections, for example highlighting the impact of proposals for one infrastructure system on another infrastructure system or asking what the city might be like for residents.

Audio-recordings of the workshops were transcribed verbatim, anonymised and checked by a third party for accuracy. All data was coded using NVivo qualitative analysis software and was analysed together to identify insights across activities. Data was coded against the five characteristics identified in Section 2.1 to analyse how these characteristics shaped perceptions of current infrastructure and aspirations for future infrastructure. Within these themes, sub-themes were identified to expose a more detailed narrative and data was re-coded to ensure a better "fit". For example, we found a strong collective view of the desirable attributes of infrastructure, which aligned closely with the public values for energy system change described by Demski et al. (2015). Therefore data were re-grouped as sub-themes that aligned with these values and grouped under the broader collective theme.

## 4. Results

1. This section presents the results of the deliberative workshops in relation to the five characteristics of infrastructure identified in Section 2.1; connective, relational, obdurate, collective and subject to

fragmented governance. Results relate to perceptions of infrastructure in the UK, where there are variable levels of privatisation and liberalisation, and where infrastructure remains highly centralised both physically and institutionally.

## 4.1. Connective

The connectivity of infrastructure systems was widely recognised by participants and was frequently exploited when designing future infrastructure systems. An example of this was the co-treatment of waste and wastewater to produce heating and electricity:

> You could send your food waste to your waste[water] treatment plant, because the food waste is the same as human waste, really: you can get energy from it. **(Harehills)**

There was similar support for using spaces for multiple purposes. This was most frequently discussed in relation to green space and water; using it for flood alleviation, leisure, energy generation and transport. Participants were also able to manage temporal changes in this connectivity – accepting that a particular area might be out of use for leisure when it was required to store water for flood alleviation:

> We did […] a lake which we would use as a flood defence and have some leisure use, […] and, then we looked at the existing river and thought that […] a good workable water taxi would actually benefit the transport around the city. **(City Centre)**

Infrastructure's role in connecting places was discussed, in relation to transport and digital infrastructure. The potential for dis-connection was mentioned several times, particularly the uneven connection created by current public transport systems:

> if you go in to the city centre you'd use a tram but it all depends where you live, because I live a little bit further out, so for me to – I'd need to get a bus to get a tram, so it wouldn't really be cost effective for me. **(Harehills)**

Dis-connection was also discussed in relation to proposed infrastructure projects, e.g. High Speed 2 railway project connecting London to Northern cities (including Leeds). Several participants expressed concern that the project would connect a few large cities but would reduce the quality of local connections, by physically severing places or by reducing funding for local transport.

This demonstrated that citizens can understand a broad spectrum of connections between infrastructure systems, actively exploit those interconnections and address disconnection when designing future infrastructure.

## 4.2. Relational

Several participants struggled initially to describe infrastructure, claiming they "did not think of anything", when they thought of infrastructure, highlighting its invisibility. Many noted how extensively infrastructure shaped daily lives, using terms like "it's how a city operates" or "how we get things about", showing recognition of the relations between infrastructure, society and the economy. However, most participants only referred to transport and energy systems, indicating differential visibility of some systems.

During the exercise on connecting infrastructure to wellbeing participants identified numerous relations between all six infrastructure sectors and many of the nine aspects of wellbeing. This included direct relationships, for example clean water's contribution to health. Participants also identified more nuanced relationships, such as using energy to produce clothing for protection, or having a say in the process of infrastructure development to support the need for participation:

> But, it's everything. Bikes, you need energy to make the bikes. Even going for a walk in the park, you need energy to produce clothing. Energy is in everything. **(Headingley)**

Many participants were surprised by how extensive the relations were and how easy it was to identify them, when provided with a framework of "needs". This indicates that although participants were aware of these socio-material relations they weren't sure how they manifested themselves.

> Yes, when you look at waste and you think, "Well what have I got to say about that?" and then you've got lots to say about it. Just didn't realise there were so many that were connected to one that we were doing. **(Headingley)**

Some participants felt the invisibility of infrastructure was problematic, particularly when learning about new or proposed infrastructure. Participants expressed surprise that infrastructure projects did not have a higher profile in the media:

> I must admit, I don't particularly watch the news as a habit, and so I might have missed it there, but I still feel like a new station in a city that is striving like this, should be a big thing. **(Discussion, Headingley)**

When reflecting on designing infrastructure futures, participants specifically reflected on the challenge of infrastructure's invisibility, for example:

> I think you just take a lot of things for granted. You take gas, electric, water, roads, buses, trains, you expect it just to be there. But when you sit down and try to design one yourself, you've no idea where to start. **(Harehills)**

Providing a structure (of the nine aspects of wellbeing) to support their analysis enabled participants to identify how infrastructure affected their wellbeing and how it might be designed to maximise wellbeing. This contributed to overcome infrastructure's invisibility and allowed participants to explicitly consider its relations to society and wellbeing.

### 4.3. Obdurate

The context within which perceptions are expressed and the nature of the installed base can have a significant impact on perceptions. This was particularly apparent for transport infrastructure, where assets are visible, extensive and durable. For example, several participants expressed deep frustration with cyclists sharing the road with them, which taken on its own would have suggested they prioritised motorised transport over active transport. However, participants recognised that these challenges were caused by the nature of current infrastructure.

> But, they never make our roads big enough now for a cyclist lane, and the cyclists will always say, 'Well, the cycle lane that we have to use has got so many dips in it blah, blah, blah … **(Harehills)**

The exercise to design future infrastructure removed this physical obduracy, to some extent, and allowed participants to think more freely and creatively about future infrastructure. Notably, all participants prioritised infrastructure for cyclists in future cities, where the installed base had less influence. Allowing participates to engage with the relational nature of infrastructure and reducing the influence of historical infrastructure allowed participants to exploit the inherent instability of infrastructure and challenge obduracy:

> But, that's the difference between that and the cities that we live in, they emerged, you know in some cases hundreds of years ago and we keep on building little bits you know around, and we will put that there, we will put that there, but truthfully I do think there has to be different thinking. We shouldn't be afraid to change, or to move, or to be adventurous. … I still think that actually it's good that we are challenged that way, like does it have to be the same way? Because, it doesn't have to be. Just because it was like that 100 years ago, you know there is no reason why it has to stay that way. **(Headingley)**

Participants recognised the influence of political ideology on infrastructure decision making, citing the productivity-driven motivation for High Speed 2 and the imbalance in funding between London and the North. The government's framing of infrastructure, and the power vested in that framing, was a cause of frustration for many participants, and resulted in some strong and negative perceptions of individual projects.

> P1: But, the government's take on it is this, 'If you can get to Leeds, London, or Manchester even, that 40 min quicker, and you're a businessman, and you have got two meetings in a day. Instead of making one, you can make them two' …
>
> P2: So, most of it's not for the general public then is it? It's not for our benefit, it's for business isn't it? London to wherever. **(Discussion City Centre)**

There was a mismatch between the political framing of infrastructure and what participants perceived infrastructure should be for. When combined with the influence of the installed base of infrastructure, this obduracy had a noticeable effect on perceptions, causing frustration and strong negative perception. Yet framing and context are rarely explicitly addressed during public engagement, which could overlook some significant effects on perception.

### 4.4. Collective

Many groups designed with others in mind and overcame strong individual preferences expressed in the first exercise, particularly for private transport. This included provision of cycling lanes by those groups who expressed strong anti-cycling views; and exclusion of private cars from city centres by those who identified themselves as car dependent. Many considered the needs of specific groups, such as older people or those with disabilities and debated how infrastructure could meet their needs most effectively. This demonstrates our participants' ability to understand the perspective of others and to meet collective goals, not personal aims. It also represented a concerted effort to overcome the "selective collective" nature of some current infrastructure, where services are not universally accessible.

> There is lots of green areas, so we are creating a nice environment for people to live and work in, so […] you can move around the city without even having to think about getting into a car, you can cycle through it, you can walk through it, it will be as friendly as possible .[…] We have also looked at people with disabilities, making it as easy as possible for them to be able to move around and enjoy the various aspects of the city, whether it is work or leisure. **(Headingley)**

Whilst there were some differences in the type of infrastructure proposed, the outcomes that participants were seeking to achieve in their future visions of infrastructure were remarkably consistent between groups. We found strong alignment between these outcomes and the public values for energy system change described by Demski et al. (2015), who reported six clusters of values: efficient and not wasteful, environment and nature, security and stability, social justice and fairness, autonomy and power, and progress and change. Our analysis identified an additional value in our workshops, which we have termed "place", to capture the use of infrastructure to create an attractive, distinctive place that contributes to quality of life. A summary of these values and evidence from our deliberative workshops is provided in Supplementary Information 1.

### 4.5. Fragmented governance

The lack of co-ordination between sectors and institutions responsible for infrastructure was raised several times as an example of inefficient decision-making processes. This was particularly apparent for co-ordination across scales of governance:

> I just feel that down in London, they click their fingers and it gets done. […] When it comes up to here, it's, "We're thinking about it, we're thinking more about it" – like the tram and it's gone up, inflation by a couple of hundred million and this council now and their partners don't have the money and the council and the Government are not prepared to put any more money in to it and then it's shelved. (**City Centre**)

There was a great deal of confusion around who governed infrastructure and a suspicion of private sector operation. Many groups specifically stated that their future infrastructure would be publicly owned and operated to address their negative perceptions of private sector control. Furthermore, few participants trusted centralised governance to represent the needs of places outside London

(particularly in Northern England, where the workshops were held) and many supported local governance.

There was a widespread, fatalistic view of public engagement, with many assuming that decisions had already been made by the time that publics were engaged and that even then, little effort was made to communicate plans:

> P1: But if it's already done and dusted, it's just a matter of time and it doesn't matter what like Joe Public think really if the bigwigs go ahead with it, it's going to go on no matter what.

> P2: Just like rubberstamping it. **(Discussion City Centre)**

The lack of co-ordination and transparency is causing publics to disengage with infrastructure decision making. This could present a real barrier to understanding public perspectives and incorporating them into infrastructure planning. Furthermore, it could exacerbate the systemic inequalities of infrastructure participation, if people are actively excluding themselves from participation.

> Sometimes you just stop listening because you hear about it for about three years and nothing ever gets done, so you just – when it turns up on your doorstep or when it inconveniences you, that's when you deal with the situation or you hear about it. It's just that they just take too long; it's a conversation that goes on for far too long and I just get bored, I'm not going to lie. **(Harehills)**

Explicitly discussing decision making and ownership of infrastructure identified the important role of governance in shaping perceptions of current and future infrastructure. Governance is both a source of frustration, potentially negatively affecting perceptions, and also as a means to identify alternative solutions.

## 5. Discussion

In this section, we discuss the impacts of using the five characteristics of infrastructure to frame elicitation of our participants' perceptions and how our findings might inform participation in practice.

Infrastructure systems are highly connective between assets and systems and across places and time. This understanding is well established in critical debates about infrastructure (Graham and Marvin 2001; Monstadt 2009; Shove, Watson, and Spurling 2015) but the influence of this understanding over infrastructure strategy and policy remains limited, particularly around the potential for dis-connection. Participants in our workshops were able to recognise connections and dis-connections and to actively exploit or correct them when designing future infrastructure. However, opportunities for citizens to debate connections remain limited when articulating concerns about infrastructure.

The relationality of infrastructure can make it hard for publics to distinguish the several co-ordinated aspects of infrastructure. This can normalise infrastructure and make it hard for publics to engage in debate. Our workshops were designed to render infrastructure visible, by relating it to the material and social arrangements it is embedded in, before exploring aspirations for future infrastructure. This allowed us to engage participants in discussing the positive contribution that infrastructure makes, rather than just the negative contributions from disruption, which is when infrastructure is normally made visible (Star 1999). Furthermore, explicitly addressing infrastructure's socio-materiality takes the focus away from assets towards how it shapes participants' daily lives (Shove, Watson, and Spurling 2015). We argue for a more co-productionist view of participation, which recognises that science, politics and society are intertwined and enables debate of connections and relations (Jasanoff 2003; Chilvers and Kearnes 2016). This can reveal different preferences than if technologies or systems are considered in isolation from each other or from their social and material context (Bellamy, Chilvers, and Vaughan 2014).

There was a marked difference between perceptions of current infrastructure and visions for future infrastructure, demonstrating the influence of infrastructure obduracy. For example, participants who expressed a strong resistance to giving up their car were supportive of restricting or

banning cars in a future city. The contingencies surrounding this support, that cars could only be banned if there was accessible and effective public transport, contribute to explaining this difference and it is important that engagement explicitly addresses obduracy and reveals these contingencies. The modification of views could also have been affected by the collective nature of the future infrastructure activity, which is discussed below.

We avoided the obdurate, economic framing of infrastructure systems, particularly when designing future infrastructure, and only required participants to design infrastructure that made the city a "nice place to live". The open framing adopted in the workshops provided a more nuanced and contingent view of how perceptions are constructed, and empowered participants to articulate their aspirations. It also produced several results (such as support for car-free city centres) that contradict current narratives of public perceptions. It is understandable that the pressures of policy-making processes drive more rigid framings for participation (Pallett, Chilvers, and Hargreaves 2019). However, this risks missing important findings about how participants make sense of the world and how this affects their perceptions (Jasanoff 2003).

Engaging publics in group design activities provided participants with an opportunity to engage with the complexity of infrastructure systems and use the collective knowledge of the group to make sense of that complexity. This might have contributed to moderating pro-car and anti-bike views of some of our participants. Allowing sufficient time and space for this deliberation is crucial (Chilvers and Pallett 2018). This collective, relational form of participation can more effectively elicit perceptions about complex and uncertain issues, such as infrastructure, than seeking to isolate individual preferences (Bellamy, Chilvers, and Vaughan 2014; Chilvers and Longhurst 2016; Stirling 2008; Wynne 1992). We suggest that methods used to engage publics should better reflect the collective sense-making that underpins socio-technical change.

Participants in our workshops were engaged in debating a collective problem, one of designing infrastructure to maximise societal wellbeing. Participants frequently designed future infrastructure to meet the needs of others, rather than prioritising their own preferences, and were deeply concerned with distributional justice. This again supports the call for more collective and relational forms of engagement. We also suggest that approaches to engagement should more explicit embed concepts of justice to ensure that the linkages between participation, procedure and distribution are more clearly articulated (Schlosberg 2007).

When analysing participants' justification of proposals we identified several values that underpinned their designs, which align closely with values articulated in Demski et al.'s (2015) research about energy system transformation. We argue that these values are more instructive of what publics want from infrastructure than soliciting individual perceptions. There is evidence that groups are capable of agreeing principles or values around infrastructure transformation, even if they object to a particular technology involved in that transformation (e.g. Demski et al. 2015; Roberts and Escobar 2015). This form of visioning, to identify underlying values, can be an effective way to overcome objection to specific technologies or changes in specific places (Upham et al. 2018). In addition, using the characteristics of infrastructure to frame deliberation (particularly connective, relational and collective) helped participants to debate costs and benefits within networked infrastructure, which distributes value to multiple places and sectors (Upham et al. 2018).

The fragmentation of infrastructure governance presented real concerns to participants both in terms of the coherence of visions for future infrastructure and the effectiveness of procedures to elicit their views. Fragmentation is deeply rooted in the political ideology of liberalisation and privatisation underpinning infrastructure governance in the UK, therefore it seems unlikely that co-ordination in governance will improve in the near term (Monstadt and Coutard 2019). A more ecological reading of participation, which considers how diverse forms of participation interrelate in wider systems, might offer a means through which to achieve this coherence (Chilvers, Pallett, and Hargreaves 2018). This means that forms of engagement must be connected to each other but also to other seemingly non-infrastructure issues, such as social welfare (e.g. Butler, Parkhill, and Luzecka 2018).

Our discussion has concentrated thus far on infrastructure as a whole. However, as we discussed in Section 2.1, the characteristics are not universal across all infrastructure sectors and our results showed some difference in how participants treated different sectors. When examining participants' perceptions of current infrastructure, despite providing visual prompts for all sectors, transport dominated the discussion. Flood management and plastic waste were also discussed at length, because of the recent history of floods in the workshop locations and a recent high profile documentary about plastic waste.[1] This dominance could be explained by the more obvious socio-materiality of these sectors in terms of their visible impacts on the environment and landscape (from experience or influential media) and of transport's direct influence over social practices (Birch 2017).

Conversely, when asked to think about the influence of each infrastructure sector on wellbeing, participants identified an even balance of connections between all sectors and wellbeing, with no sector dominating the outputs of this section. When aided to make connections between the social and material, a broader and more nuanced range of issues were identified, even when this connection is more subtle and less visible.

In the final exercise, participants were asked to choose three sectors to focus on, to limit the scope of the final exercise. In every workshops these sectors were energy, transport and water, which reflects the greater visibility of these sectors. Nevertheless, many participants addressed waste and flood management by connecting them with these core sectors, for example through co-treating sewage sludge and organic waste, generating energy from waste, or sharing land for flood alleviation with other sector, such as transport.

In the transport and energy sectors, many participants tried to make the connection between the social and the material more direct, for example engaging residents in energy generation and creating green travel corridors connecting active travel with nature. In the waste sector there were concerted efforts to separate the social and material spheres, for example, creating underground collection systems, despite evidence that increasing the socio-materiality of waste can lead to more effective management (Hultman and Corvellec 2012). Digital infrastructure was poorly represented throughout. Finding ways to highlight the socio-materiality of all sectors, either through specific prompting or allowing participants to explore connections with more visible sectors will be crucial to ensure that debates are not dominated by the most visible or high profile sectors.

## 6. Conclusions

In this paper, we examined how public perceptions of networked infrastructure in the UK are shaped by infrastructure's characteristics as a connective, relational, obdurate, collective system that is subject to fragmented governance. We argue that using the characteristics as a framework for deliberation built the capabilities of our participants to articulate perceptions of a complex system, like infrastructure. Building capabilities for deliberation could have many consequences; it could reduce the systemic inequalities that prevent some citizens from participating and exercising power; it could improve the quality of outputs from deliberation to include more nuance and complexity; and it could improve the experience for participants, which for many is not a positive one (Inch 2015).

The characteristics encouraged debate about costs and benefits created by networked infrastructure, which can be distributed to multiple places and sectors. In combination with the collective values that emerged from deliberation, this helped our participants to overcome some conflicts between support for projects or technologies in the abstract and resistance to projects and technologies in a place.

Our participants' deliberation reinforced the fluidity of infrastructure's characteristics. For example, participants identified examples of both the connective and dis-connective role of infrastructure and described how its collective nature was often highly selective, particularly in the case of transport. Participants challenged some the negative implications of the characteristics, particularly dis-connective, selective collective and obduracy, by actively building connectivity, making

infrastructure accessible to all, and challenging current physical and institutional structures. This shows that the characteristics are not fixed and should be treated a fluid. Participants should be allowed to identify ways to change relations in infrastructure to overcome some of the more negative implications of current characteristics.

These results emerged from the specific context of our workshops, which involved engaged participants and neutral, expert facilitators in one location in the UK. These factors have clearly shaped the conclusions we reach above. As has the fact that no real decision or outcome was at stake, which might have enabled participants to be more critical and creative. We framed the workshop as addressing social, material and political aspects of infrastructure and recognise that this framing affected our participants' responses. Reaching firm conclusions about the validity of the specific framework we used would require more in-depth analysis in different settings and with different participants.

Despite these limitations, we think that our approach could improve the elicitation of perceptions in several ways: (1) engaging participants in discussing a systemic issue within the context of a specific place could overcome the negative aspects of place attachment or place-based contingent support. Recent local climate assemblies have successfully reached agreement over very challenging issues, including private transport and airport expansion (Shared Future 2019). This could be used to agree a set of place-specific principles for infrastructure development to inform the design of specific projects. (2) Building capacity about how the system of interest works before asking for perceptions about that system. This requires additional time but could increase the quality of deliberation and reduce inequalities in participation. (3) Allowing a broader framing that engages with the socio-materiality of infrastructure, in particular its link to wellbeing, and explicitly address how this framing affects insights. (4) A more explicit focus on interconnection, which may require sectors and places to collaborate. This is being developed at a national level in the UK, through the NIC, and at a sub-national scale in some places (e.g. Greater Manchester Combined Authority 2020) but the sub-national level is not universal and is where the influence of place and spatial connectivity is most significant. Many of these recommendations require more time, resource and skill to deliver participation, particularly those linked to build participant capabilities and on framing infrastructure in a very different way. However, they could result in principles or values that could be used as a basis for improved dialogue and more effective decision making overall, leading to more just outcomes and reducing public resistance.

## Note

1. The final episode of David Attenborough's Blue Planet II series included a focus on plastic waste on the oceans, which was mentioned by several participants.

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## Data access statement

Due to the potentially personally sensitive nature of the deliberative workshops, permission to submit the original data into a repository was not sought from the participants, and their consent permitted only the use of anonymised transcripts within the research group.

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