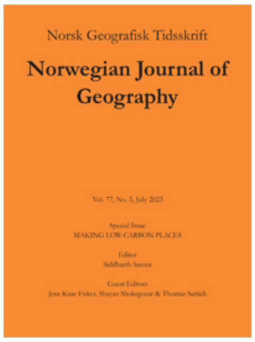

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Where are low-carbon places made? Conceptualising and studying infrastructure junctions and the power geometries of low-carbon place-making

Torik Holmes[1], Carla De Laurentis[2] & Rebecca Windemer[2]

[1]Department of Sociology, University of Manchester, Manchester, UK; Sustainable Consumption Institute, University of Manchester, Manchester, UK; [2]Department of Geography and Environmental Management, University of the West of England, Bristol, UK

ABSTRACT
The making of low-carbon places is crucial for achieving decarbonisation, but where are such places made? In extending and combining existing research and ideas, the authors take electricity networks as their starting point to study what they term three 'infrastructure junctions', which are places where various practices and processes, with material, spatial, and temporal features, collide and combine in ways that shape the power geometries of low-carbon place-making. The authors find that the junctions reveal the conflictual and consensual dimensions of low-carbon transitions and how these features shape and are shaped by the ordering and management of networked hardware. Some features are shared, such as an overarching faith in large-scale provision and unabated demand, whereas others are more unique and rooted in specific contextual realities. Such insights support attempts to assess, steer, and accelerate low-carbon place-making as a relational process that is manifest and mediated through infrastructure. The authors conclude that infrastructure junctions offer ripe grounds to examine where, how, when, and for whom low-carbon places are in the making.

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Introduction

The making of low-carbon places ascertaining to various socio-spatial scales (e.g. hospitals, offices, schools, homes, neighbourhoods, cities, regions, and/or nation states) is a critical component of responses to climate change. It is therefore important to ask: where are low-carbon places made?

In the literature on place-making (Martin 2003; Friedmann 2010; Pierce et al. 2011), including that which directly discusses low-carbon transitions (Mason & Whitehead 2012; Fast & Mabee 2015; Franklin & Marsden 2015; Murphy 2015), emphasis is placed on politically and culturally contested place frames related to neighbourhoods, cities, and/or regions. Key issues concern place-based responses to innovations and the deployment of new technologies (e.g. solar technology and wind farms) in particular places (Fast & Mabee 2015; Murphy 2015). As a consequence, places that help to make up socio-technical networks (e.g. electricity substations, reservoirs, natural gas plants) typically do not form the central sites of enquiry. As much work on infrastructures and energy transitions suggests (e.g. Graham & Marvin 2001; Coutard & Guy 2007; Bulkeley et al. 2010; Hodson et al. 2017), such sites are crucial for the fruition of low-carbon places. This being the case, concepts of place, the types of jurisdiction on socio-technical networks, and ideas relating to place-making have tended not to form central topics in energy transitions research. Indeed, as Bolton & Foxon (2015, 538) note, 'there have been surprisingly

CONTACT Torik Holmes torik.holmes@manchester.ac.uk

few studies which explicitly explore the network components of energy systems' and hence this applies to the sited constituents of infrastructures that shape the form and speed of low-carbon transitions.

Therefore, there remains scope to conceptualise and study the unevenly distributed components of networked assets, the places they make up, and their significance for low-carbon place-making and energy transitions. This presents a conceptual and analytical challenge. In response, a synthesis of ideas is needed. The synthesis presented in this article has the potential to contribute fresh insights about 'where else' low-carbon places are made, the politics of this making, when it happens, who is served, and the nature of constitutive interdependencies between places, place-making, and socio-technical networks.

In response to the challenge outlined, we meld key ideas within socio-technical and energy transitions literature, relational theorisations of place-making (Pierce et al. 2011; Murphy 2015), and Massey's complementary conceptualisation of the 'power-geometries' of place and time (Massey 1999, 28). Based on this synthesis, we introduce 'infrastructure junctions' as a sensitising concept. The notion of a 'junction' has been previously mobilised as part of eliciting the links between service networks, practices, and sustainability (Cass et al. 2018; Rohracher & Köhler 2019). To the best of our knowledge, the concept of 'infrastructure junction' has not been explicitly presented as a primary means of thinking about the places that make up infrastructure networks and low-carbon place-making, including revealing the links between them.

We specifically conceptualise infrastructure junctions as places and meeting points, spread out across and knitted into socio-technical networks, which are cross-cut with, shaped by, and shape multiple practices, processes, and associated spatial, temporal, and material dynamics. It is possible to pinpoint such junctions on maps and network schematics. As meeting points of multiple practices and processes, they have roots that extend beyond any single geographical locale and they are caught up in and reflect various logics and frames. Understood in these terms, infrastructure junctions are places where the 'power-geometries' (Massey 1999, 28) of low-carbon place-making play out, and thus also the detail and speed of energy transitions.

To demonstrate the concept's value and thus examine infrastructure junctions, we focus on three infrastructure junctions in this article, through a series of empirically informed vignettes. These are linked to the provision and consumption of electricity. In each case, we consider and reveal the different power geometries at play, and draw attention to themes of conflict and consensus.

The first infrastructure junction concerns the emergence of grid bottlenecks in Apulia, a region in Italy's 'heel' and one with plentiful renewable resources. We show how pre-established network capacities, configured in reference to a nationalised logic of provision, materialised in 1962, as well as how they posed challenges to a contemporary paradigm of transnational renewable generation and distribution in order to accommodate 'large-scale' national and European renewable energy targets. The second infrastructure junction is the Rampion Offshore Wind Farm, located off the south coast of England. Proposed plans for extension have been bogged down in planning processes and objections about visual impacts. We show how locally rooted framings of the countryside and natural beauty conflict with the national government's support for offshore renewable generation, which is anchored in attempts to achieve net zero emissions by 2050 (HM Government 2021). In switching our attention away from the contested delivery of a large-scale wind farm, we focus on a 33 kV electricity substation in Central Manchester, the site of our third infrastructure junction. Our analysis shows how what are arguably unsustainable views of demand pertaining to the city, as well as extended trends and norms of consumption, proceed unquestioned, flying under the radar of contestation and making certain low-carbon futures more likely to materialise than others.

We show that each infrastructure junction is uniquely placed as a point of articulation, cross-cut with material, spatial, and temporal dynamics, which articulates forms of contestation and consensus that act to shape the details and speed of unfolding transitions. Revealing these shared and divergent details and what is and is not struggled over provides a means of exploring where low-carbon transitions are in the making, how such changes unfold, what and whom they are (and are not) serving, and what is needed to speed up equitable transformational shifts across energy supply and use.

The article is structured as follows. In the next section, we flesh out our argument that socio-technical networks form a logical starting point for those interested in exploring where low-carbon places are made. As part of doing so, we discern three dominant analytical themes: materiality, spatiality, and temporality. Thereafter, we combine the themes together with a relational conceptualisation of place and place-making, and more specifically Massey's notion of 'power-geometries' (Massey 1991; 1999; 2005). The combining is done as part of introducing our conceptualisation of infrastructure junctions. Then, we switch attention by describing the empirical roots of each infrastructure junction examined in this article. In the penultimate section, we consider what the examples reveal in isolation and in combination, and the associated implications. We conclude by inviting researchers to identify and examine infrastructure junctions as part of revealing the contested and consensual power geometries of low-carbon places in the making and critiquing how, when, and for whom such places and energy transitions are made.

Socio-technical networks and the 'spatial', 'temporal', and 'material' dimensions of energy transitions

Over the past four decades, scholars have increasingly taken socio-technical networks of provision as a starting point for research aimed at understanding various societal issues and challenges. Hughes (1987, 51) discusses these networks in the following terms:

> They are both socially constructed and society shaping. Among the components in technological systems are physical artefacts, such as the turbogenerators, transformers, and transmission lines in electric light and power systems. Technological systems also include organisations, such as manufacturing firms, utility companies, and investment banks, and they incorporate components usually labelled scientific, such as books, articles, and university teaching and research programs.

The study of socio-technical systems has taken many different directions over the past four decades, the history of which defies easy summation. Nevertheless, in what follows, we discern three dominant analytical themes: spatiality, temporality, and materiality. Only one or two of these themes are commonly foregrounded in research. However, research suggests that each theme is important when it comes to exploring the relationships between low-carbon place-making and the components and associated places of provision tied up with socio-technical networks.

Spatiality

Socio-technical networks are physically ordered and extended socio-spatial formations. With regard to the hard physical geographies of socio-technical networks, Hughes (1983, 405) states: 'of the circumstantial factors that shape the style of a regional system, geography is the most obviously influential'. This is because socio-technical systems are configured with reference to sited vicissitudes of climate, as rendered clear in recent years, for example, by the vulnerability and grid failure in Texas caused by extreme cold (Leslie 2021).

Furthermore, socio-technical networks of provision are spatial in the sense that they are caught up in, shaped by, and support multiple socio-political and economic scales of action (e.g. domestic, commercial, local, urban, regional, national, international). Some scholars have drawn attention to the socio-spatial 'splintering' of systems of provision and consumption as an outcome of changing socio-economic paradigms (Guy et al. 1997; Graham & Marvin 2001). Other scholars have questioned the agency of city authorities and the roles they can play in shaping transitions and addressing sustainability challenges (Hodson & Marvin 2010; Hodson et al. 2017), while others still have conceptualised and studied 'energy peripheries', typically rural areas and places 'that are systematically disadvantaged through the whole energy system due to their inferior position' (Golubchikov & O'Sullivan 2020, 1).

Many of the above-mentioned contributions and similar ones (e.g. Bridge et al. 2013; Hui & Walker 2018; Bridge & Gailing 2020; Coenen et al. 2021) are part of a broader and burgeoning body of work that is representative of a 'spatial adventure' in energy research (Bridge 2018; Broto & Bake 2018). Contributions in the field of energy research treat space as relational, fluid, and contested. They highlight how systems of energy provision and consumption, and associated technologies and policies are unevenly configured and have equally uneven outcomes. Adding spatial sensitivity to accounts that draw on the multi-level perspective, which has typically seen a foregrounding of temporality over spatiality (Coenen et al. 2012), Murphy (2015) discusses successful couplings and alignments between innovations and regimes as 'contextual' affairs and rooted in the ongoing making of places.

From the broader perspective of energy researchers engaged in spatial adventures, energy transitions can be explored in terms of the playing out of different socio-spatial, scalar and contextual relationships through socio-technical networks. In this regard, energy transitions are as much affected by the performativity of place as they are a 'space-making process' (Bridge & Gailing 2020, 1038), that is shaped by and shapes wider processes of experience, emotion, accumulation, innovation, competition, and social mobilisation.

Contributions that reveal the spatial dimensions of infrastructures and transitions are linked by a shared understanding that 'scalar structures do not have causal powers in themselves; rather they are arenas for articulating the relationships and networks that enable and constrain […] low-carbon transformations' (Bouzarovski & Haarstad 2019, 261). Moreover, Bridge & Gailing (2020, 1037) state that 'pathways to decarbonisation are conditioned by existing geographies' and by their hard' physical attributes and legacies, including those built into infrastructure. To summarise, socio-technical networks and related transitions are imbued with and configured with reference to multiple, overlapping, and constitutive physical and socio-spatial scales and frames.

Temporality

Temporality has come to form another key domain of study concerning the ordering and management of socio-technical networks (Sovacool 2016; Grandin & Sareen 2020; Moss 2020; 2022). As is well established, infrastructural management, maintenance, and investment are value laden 'historical sequences in which contingent events set into motion institutional patterns or event chains that have deterministic properties' (Mahoney 2000, 507). Echoing Adam's conceptualisation of 'timescapes' (Adam 1998), socio-technical systems and transitions in the making, such as physical landscapes, are cross-cut with the multiple temporalities, rhythms, routines, and demands of practices and institutions. These temporalities and associated forms of path dependency mean that efforts to accelerate sustainable and just transitions to greener energy systems benefit from apprehending the multiple temporal dimensions of infrastructural configurations and their various historical, concurrent, and future-oriented features (Moss 2014; Meadowcroft 2016).

A large body of work, much of which mobilises the multi-level perspective (MLP), which is an explanatory analytical framework with roots in evolutionary economics, has examined the longer term development of socio-technical networks, related periods of stability and moments of change (Geels 2005; Geels et al. 2016; Verbong & Geels 2007). Attention has particularly been drawn to the effects of technological innovations, experiments, and interventions aimed at disrupting the status quo of networks, and indeed places and communities of consumption (Murphy 2015). At the heart of this work lies a concern with the 'tardiness' and 'speed' of transitions. For example, Grandin & Sareen (2020, 73) highlight the importance of examining the relative 'ephemerality and permanence of local transitions' as socio-technical transformations in the making.

There is, more broadly, an awareness that socio-technical networks and their components are both caught up in and help bring about periodic shifts in ways of life. These shifts are unevenly manifest, both in space and across time, in line with the uneven reordering of infrastructures as socio-technical and hence socio-material arrangements. Thus, both the spatial and temporal features of infrastructures are materially embedded in socio-technical networks. Materiality forms yet another central theme in studies of such networks.

Materiality

Researchers have long emphasised the material dimensions of socio-technical systems (Hughes 1987; Mayntz & Hughes 1988; Star & Ruhleder 1996; Star 1999). Their work acknowledges that infrastructures must be made, maintained, and remade, and that they can become big, bulky, obdurate arrangements that are institutionally diffuse, physically extended, and embedded with social, economic, and political values, scales, and temporal frames (Star & Ruhleder 1996; Star 1999). As Winner (1980) shows, Robert Moses' New York bridges were, in their time, materially inscribed with economic and racial politics. Likewise, the Parisian subway system was, in its time and place, built to protect it from private railway companies (Latour 1988). Also, as Moss (2009) reveals, political divisions in post World War II Berlin shaped the material ordering of energy and water services on either side of the divided city. In highlighting the importance of everyday material interventions, others have pointed to the practices of maintenance and repair that infrastructural assets demand (Graham & Thrift 2007). For example, electricity substations require oil changes, and asphalt roads develop potholes that need to be filled. In this regard, great amounts of material resources and labour, and wider networks of provision are drawn on in order to maintain various socio-technical systems.

As argued elsewhere, understanding the material dimensions of infrastructures and energy transitions thus require sensitivity to (1) the mutual constitution of social and physical nodes that make up networks (De Laurentis & Pearson 2018; Svensson 2021), (2) the importance of specific configurations of agency in shaping constitutive relations (Kuzemko & Britton 2020), and (3) the opportunities for 'capturing the type of participation they foster and the various (more or less liberal) political tropes they convey' (Labussière & Nadaï 2018, 27). Spatial and temporal features do not disappear here but instead they are entangled with each concern.

In bringing the themes discussed in this section together, we see three analytical registers at the core of research on socio-technical networks and energy transitions. The question at the core of this article – 'where are low-carbon places made?' – is, by proxy, tied up with the ordering of socio-technical networks, embedded components, the places they hold, and their related spatial, temporal, and material features. This understanding calls for a complementary conceptualisation of such places and therefore of place itself. The following key questions remain: What are the constitutive places of provision that help to make up socio-technical networks a product of? From where do their material, spatial, and temporal features arise? How do such places and dynamics connect with the fruition of low-carbon place-making? In the next section we discuss a relational conceptualisation of place and place-making in response to these questions and as part of introducing infrastructure junctions as a sensitising concept.

Conceptualising the 'where' of low-carbon place-making: places and infrastructure junctions

Answering 'where' questions inevitably calls for conceptualisations of place. Although there are many nuanced conceptual accounts of place, which reflect and come with their own disciplinary baggage, there exists a broader consensus that places and place-making are premised on relationality and co-constitutive socio-material processes (Harvey 1973; Lefebvre 1991; Massey 1991; 1992; 1999; 2005; Soja 1996; Castells 2002; Pierce et al. 2011). Murphy (2015, 84) claims that, viewed in this manner, 'places are not simply localized sites or containers but phenomena constituted by webs or constellations of external and internal relations which in effect "make" them'.

Massey's work provides a particularly useful means of thinking about the relationality of space and place (Massey 1991; 2005). She conceptualises places as emergent and telling of wider power-geometries of 'material practices' (Massey 2005, 9). Such material practices have spatial and temporal features, both of which inform the ongoing production, ordering, and trajectories of places as articulations of social, cultural, political, and economic 'stories-so-far' (Massey 2005, 9). Revealing the power geometries of places is about discerning these stories, underpinning material practices, constitutive connections, processes, and trajectories. It is also about discerning connections, which in combination shape the uneven development and thus fruition of places, regardless of size or scale.

The relationality that underpins Massey's conceptualisation of places as articulations of the power geometries of material practices (Massey 2005) is echoed in work that deals explicitly with place-making (Martin 2003; Friedmann 2010; Pierce et al. 2011; Marsden 2012). As Murphy (2015, 84) states, 'place-making – the process of reproducing, eliminating, and/or modifying the structures, identities, meanings, geographies, positionalities, and power relations associated with a given place – is […] an inherently relational process; one that is networked, multi-scalar, and spatial'. Accordingly, strong emphasis is placed on the contested and conflictual efforts that go into reframing and reshaping places according to particular views and motives (Martin 2003; Pierce et al. 2011; Murphy 2015).

By combining the ideas outlined in both this section and the preceding section, infrastructure junctions can be seen as places, typically owned and managed by system operators, which help to make up socio-technical networks and are dispersed across them. Moreover, the junctions are meeting points, where various practices and their material, spatial, and temporal features come together and collide in power-imbued and constitutive ways. Due to the co-constitutive connections between infrastructures and places, infrastructure junctions are also sites that shape other sites and in turn are shaped by them. In this respect, they are caught up in conflicts and attempts to reshape the trajectories of places according to different frames and ambitions, such as those to do with low-carbon transitions.

All of the following examples can be understood as forming infrastructure junctions: reservoirs, power plants, gasworks, primary substations, motorways, roundabouts, data server centres, solar farms, and satellites. Each of them is a place under the jurisdiction of system operators. Furthermore, it is possible to locate and pinpoint them on maps, on schematic diagrams, and in other discursive formats. By extending Murphy's argument concerning of 'the study of place and place-making processes' (Murphy 2015, 83) to that of infrastructure junctions, the above mentioned examples are also places and empirical starting points that afford opportunities to 'reveal novel insights into the power relations and political processes underlying transition processes'. In the next section, we introduce three infrastructure junctions that we identified in our own empirical research. The junctions elicit some shared and some unique details regarding where low-carbon places are made and what such making does (and does not) entail and support.

Researching infrastructure junctions

As part of turning our attention to infrastructure junctions, we take inspiration from Massey (2005), who started by considering places as a means of teasing out constitutive power geometries. In contrast to Massey (2005) in her book *For Space*, Pierce et al. (2011, 61) go as far as to argue that 'research on relational place-making should begin with a particular conflict over competing place frames, rather than an *a priori* site or scale'. Although we appreciate the call to identify and explore forms of conflict and how they shape the manifestation of places, we also think it important to explore forms of acceptance, agreement, and consensus. In this respect, we are inspired by the idea that ongoing forms of infrastructural maintenance, repair, and investment are just as important for low-carbon transitions and place-making as more extraordinary moments of contestation (Graham & Thrift 2007). It is for this reason that we turn to three infrastructure junctions and thus places and sites, with an eye for instances of conflict and consensus, and thinking through what these suggest about the 'where' of low-carbon place-making.

The junctions are visited through a series of vignettes, which are empirically rooted in three doctoral and post-doctoral research projects undertaken in the course of the last ten years. The projects shared a topical concern with energy transitions and their material, spatial and temporal dimensions.

The first vignette specifically draws on research undertaken in Italy and aimed at understanding the details of large-scale renewable deployment in three regions, namely Apulia, Tuscany, and Sardinia (De Laurentis & Pearson 2018). Data were obtained through documentary analysis and from 20 interviews held with experts, whom among others included government officers, civil servants, and representatives of private and public-sector companies. The interviews were supplemented by two study visits to the regions. The Apulia case was selected because it provided an opportunity to focus on places on the Italian electricity network that posed explicit grid bottlenecks, materialised constraints to system growth premised on place-oriented frames synonymous with larger-scale provision, and longer term and shared international ambitions relating to climate change.

The second vignette focuses on the proposed extension of the Rampion Offshore Wind Farm, which is part of a wider corpus of work aimed at exploring the end-of-life consenting regimes and the duration of planning consents for onshore wind generation in the UK (Windemer 2019). To date, the work has involved 24 interviews with developers, local authority planners, community members, and government policymakers, in which questions centred on exploring the end-of-life decision-making process for offshore wind. It has also seen an analysis of renewable energy and planning policies, at national (England, Scotland, Wales) and local authority scales (43 documents in total). The Rampion case is premised more specifically on a detailed review of planning files, related public comments, and online news reports. Like the previous case, this vignette informs of attempts to upscale renewable generation as part of trying to reach national and international goals. However, unlike the previous case, conflict over the meaning and use of place plays a stronger role, with contested notions of a piece of coastline fought over in ways that are shaping transitional shifts in and beyond the immediate proximity of the wind farm.

The third vignette is about the development of the Central Manchester 33 kV Primary Substation, and is derived from research focused on understanding how energy demands change in cities over time and the implications of such developments (Holmes 2019; 2021). As part of exploring this topic, 17 interviews were held with experts comprising a mix of town planners and network operators. Alongside the interviews, an analysis of over 30 documents relating to Manchester and to energy provision were undertaken. These included strategic planning publications pertaining to the city and wider city region (i.e. Greater Manchester), electricity network plans, schematic diagrams, and national and local planning and energy policy documents. Focusing on the Central Manchester Primary provided an opportunity to examine a junction that at first sight and compared with the other two examples is not so explicitly connected with the making of low-carbon places. However, as we show in this article, infrastructure junctions, beyond those to do with challenging and contested renewable deployments, are just as important for low-carbon transitions as those explicitly representative of such shifts.

In the next section we present three vignettes premised on insights garnered from each study. In accordance with the style of vignette writing, we avoid the use of extended quotes from interviews and secondary sources. Instead, we present three evocative and descriptive accounts of the conflictual and consensual power geometries of low-carbon place-making as manifested and mediated through three infrastructure junctions.

Three infrastructure junctions and low-carbon place-making

Overcoming grid bottlenecks in Apulia: multiscalar network improvements and materialising institutional alignments

The Apulia region is now a major generator of renewable energy. Prior to 2010, the region produce relatively little renewable energy. The transition hinged on overcoming a series of grid bottlenecks. These 'reverse salients' (Hughes 1983), which were acute points of pressure that were acting to limit the momentum of low-carbon transitions, emerged at an intersection between material legacies of network investment and new attempts to upscale renewable provision. The overcoming of material sticking points was a multiscalar institutional affair, involving multiple regional, national, and international actors and expertise, and a bringing together of prerogatives, aims, and ambitions.

The Italian government is an important part of the story. For some time, it has placed significant emphasis on the mobilisation of renewable sources of energy, such as wind and solar power (Ministero dello sviluppo economico 2010; Ministero dello sviluppo economico, Ministero dell'Ambiente e della Tutela del Territorio e del Mare & Ministero delle Infrastrutture e dei Trasporti 2019; Ministero dello sviluppo economico & Ministero dell'Ambiente e della Tutela del Territorio e del Mare n.d.). Reducing dependence on electricity imports has long been one of the major drivers for renewable energy in Italy, due to the lack of significant domestic fossil fuels. Earlier pressure to meet European renewable energy targets by 2020 also spurred on national support for renewable generation (European Commission 2010). In response, the Italian government introduced a system of generous uncapped incentives, which, between 2010 and 2012, stimulated impressive growth in the renewable energy sector and an unprecedented increase in PV (photovoltaic) installations and capacity.

Due to abundant natural resources, green public procurement, and relatively permissive planning regulations, the Apulia region was particularly well placed to take advantage of the favourable energy incentives offered. This mix of institutional and geographical ingredients further represented 'a big opportunity' (ARTI 2008, 12) to reverse patterns of economic underdevelopment, while also addressing multi-level energy targets.

However, the region's network was historically organised to support the long-distance transmission of electricity from other areas where conventional plants were located and from where electricity was sent to centres of demand in the north (via Bari) and to the south (the Salento region). Hence, the dramatic increases in renewable energy generation in Apulia caused network congestion challenges in the form of grid bottlenecks. These emerged, for example, in and around interregional connections between Apulia and Campania.

Reactions to the challenges took shape through several innovative responses that drew on international funds and translocal expertise. Those efforts were aimed at rebalancing and rescaling the grid, to secure supply, and maximise the uptake of renewables. The INGRID Project is synonymous with such efforts. This 39 MWh pilot plant for hydrogen-based storage for grid balancing, based in Troia Municipality in the Province of Foggia, Apulia, set out to address a sited electricity reverse flow issue. The project, which started in 2014, involved a number of national and international partners, and was led by the energy arm of the regional development agency in Apulia. Building from that experience, the region became a location for another spin-off project, STORE&GO (a Horizon 2020 project). The project explored how the renewable power used in the INGRID electrolyser could be integrated and operated within the existing gas network. Within the region, a programme of structural interventions for the development of the distribution network and smart grids, funded though EU structural and convergence funds, was initiated in 2019. The Puglia Active Network project objective was to test a smart-grid development at regional scale, and it was led by e-distribuzione (a distribution system operator) and delivered in collaboration with several local authorities in the region. This included advance automation and monitoring of medium voltage lines, predictive maintenance of primary substations, and a fleet of regional charging infrastructure for electric vehicles (EVs). Additionally, resources for infrastructure development have been allocated in regional economic planning, channelling European funding for infrastructure renewal (e.g. Apulia was allocated 15 million euros for priority spending on distributed energy for the development of the smart grid).

Grid bottlenecks, which emerge due to a concatenation of legacies of investment and current aims and ambitions rooted in regional, national, and international agencies have thus been overcome through innovative work focused on a connected rescaling and upscaling of provision. This scaling is synonymous with contemporary attempts that are taking shape across and with reference to the EU, in order to align goals of energy security, economic growth, and decarbonisation through large-scale renewable deployment.

The Rampion Offshore Wind Farm: the conflictual aesthetics of provision

The Rampion Offshore Wind Farm consists of 116 turbines, with a maximum height of 140 m, and is located off the south coast of England. It became operational in 2018 and generates enough power to serve c.350,000 homes (RWE 2023). In 2020, developers submitted a scoping request to update the existing wind farm through the development of up to 116 new turbines. Due to technological progress since the development of the original wind farm, the proposed turbines are expected to be up to 2.3 times taller, with a maximum height of 325 m. Political support for the wind farm centres on the UK Government's target of delivering 50 GW of offshore wind capacity by 2030 (HM Government 2022). This aim is linked to the wider target of achieving net zero emissions by 2050 (HM Government 2021). Other supporters emphasise that the existing wind farm has increased both tourism in the area and economic activity, which include boat tours to the site.

Regardless of the wider aims and the benefits of the possible extension of the wind farm, planning processes and decision-making relating to renewable deployment are rarely straightforward and typically fraught. In the case of the proposed Rampion extension, the planning application has raised significant levels of opposition. Opponents have launched campaigns in the local press. Also, a petition with 2781 signatures and formal opposition from a number of local councils have been logged (UK Government and Parliament 2022). At the time of writing, the application is still ongoing.

Objections to the wind farm centre on different material, spatial, and temporal aspects of its expansion. Material features have clashed with normative aesthetic values and 'views' of the surrounding landscape. The size of the new turbines and the breadth of the proposed extension are points of contention, with each causing 'imagined' visual affronts. Indeed, opponents have argued that the extension would dominate the breadth of the local horizon, creating a combined impact across an area of 342 m^2. Such opposition reflects preferences concerning the detail and scale of visual impacts. The objections are similar to what we (the authors of this article) have seen in cases of the repowering of onshore turbines, where wind farms have been upgraded with new technology in the form of larger turbines, in some cases raising local concern about potential increases in visual impact (Windemer 2019). However, in the case of the Rampion Offshore Wind Farm it is the increase in the number and size of the offshore turbines, with infrastructure 'at sea' becoming locally foregrounded and entangled with contemporary values of place.

The proposed disruption 'at sea' is coupled with planned material changes on land. These, too, are clashing with local values and place frames. The tensions are transpiring due to the need for a subsea export cable to bring additional power to land. This requires an underground network to be developed beneath Climping Beach (also known as Atherington Beach), which is a listed Site of Special Scientific Interest. The proposed cable would also need to connect to the national grid, which would mean the need for a new substation. The wind farm developer has proposed three potential locations for the substation, all of which are locally disputed on grounds of their likely impact on the 'natural' environment. Opponents have argued that farmland and ancient woodland, situated across the South Downs National park, a site of 'natural beauty', will be negatively impacted. This opposition has come despite reassurances from developers that the effects will be temporary, as they will undertake land reinstatement strategies with landowners and farmers.

In the case of the Rampion Offshore Wind Farm, we see a clash between contested and localised ideals about what landscapes should look like and be used for, which has resulted in protracted disputes. In this case, planning applications have created key moments for opposition to surface and sited power geometries to play out. The applications and opportunities to object have their own temporal parameters. Potential increases in 'clean' energy generation cannot be achieved quickly. Hence, contested future visions of provision and place, being played out through a proposed infrastructure junction, are acting to calibrate the fruition of low-carbon place-making pertaining to national goals and ambitions.

The Central Manchester 33 kV Primary Substation: unquestioned urban futures and not so low-carbon place-making

The Central Manchester 33 kV Primary Substation was commissioned in 2007 and completed in 2009 at an estimated cost of 1.8 million GBP (IQS n.d.). Like other 33 kV substations, the primary substation provides network capacity. It facilitates the generation, transmission, distribution, and use of electricity. By so doing, it helps to bring the city and the 'demanding' practices and social sites therein to life (e.g. homes, offices, gyms, banks, tram routes, data centres) (Holmes 2021). By proxy, the substation is connected with energy transitions unfolding in the city. There has been little discussion on whether or not such investments are sustainable, although the question of their sustainability is certainly debatable.

The contestation hinges on a debate on both what sizable network interventions, such as the Central Manchester Primary, are built to support, and the detail of shorter and longer term predictions of the future and imagined demand curves. These curves are calculated with reference to specific spatial and temporal registers.

Notions of the 'city' and its projected change are, for example, embedded in the Central Manchester 33 kV Primary Substation. This is because distribution network operators (DNOs) use spatially and temporally refined econometric modelling to rationalise network investments. A review of current network planning practices and associated documents revealed that these include calculations of the city region's economic trajectory, associated development plans, and population shifts (Electricity North West 2019). Determinants of network investment hinge on, for example, an understanding 'that the Manchester region will experience the greatest year on year growth in demand' across north-west England (Electricity North West 2018, 15). This view 'correlates with the plans to create c.10,000 new homes in Greater Manchester each year and to expand the business and transport hub centred on the airport' (Electricity North West 2018, 15). These expectations are overlayed with projections of the diffusion and uptake of energy-demanding technologies across the city region, and the effects this will have on sited network assets. In this regard, heat pumps, EVs, and air conditioning units have garnered much attention (Bryson & Shaw n.d.; Electricity North West n.d.).

Whether or not materially distilled visions of Manchester's future represent and support low-carbon transitions depends on how such imaginaries are viewed. On the one hand, rationalising network investments on the grounds of supporting the uptake of EVs and heat pumps can be viewed as a positive step towards low-carbon place-making; each support shifts away from carbon-laden systems of heating and mobility. On the other hand, the unquestioned supported growth of the city, in terms of both population and economy, does not clearly align with city-region low-carbon ambitions, including the ambition of being carbon neutral by 2038 (Manchester Climate Change Partnership & Manchester Climate Change Agency 2020). As has been well established, the links between population, economic activity, and energy demand are strong (York 2007; Sorrell 2015; Holmes 2021). Thus, building more capacity to facilitate population and economic growth amounts to helping inflate sited demands and hence 'ratcheting up' the challenge of meeting such needs with low-carbon sources of generation.

The low-carbon credentials of EV's and air conditioning units are problematic (Sandy Thomas 2012; Walker et al. 2014). By planning and producing a network to facilitate the concentrated uptake of EVs in Manchester, less carbon-intensive systems of mobility and socio-technical futures are overlooked and less likely to unfold. These include, for example, other and arguably more sustainable lower-carbon futures premised on the uptake of bicycles and cycling in and around cities (Pucher & Buehler 2008; Behrendt 2020). As also argued elsewhere (Shove et al. 2014; Walker et al. 2014), the supported spread and related normalisation of cooling technologies around the globe and in places such as Manchester, which has a typically modest climate, helps to increase energy demand in arguably unsustainable ways.

The case of Central Manchester Primary shows how low-carbon transitions are caught up in calculations of future demand and embedded in network investments. Views of the 'city' have proven figurative. Whether or not these views and the rich mix of calculations used to justify investment in additional network capacity support and lead to the maximization of the potential of low-carbon place-making is a complicated topic. However, it is clear that generally accepted and unquestioned value-laden notions of the 'city' and its future are embedded in sited network investments and that these further shape the trajectory, detail, and credentials of low-carbon transitions unfolding in Manchester.

Discussion: infrastructure junctions – conflict, consensus, and low-carbon place-making

What do the examined three infrastructure junctions reveal about where low-carbon places are made? They show that low-carbon place-making is thoroughly tied up with the 'contextual' ordering of infrastructural hardware and thus the power geometries of socio-technical networks, which are cross-cut with spatial, temporal, and material dynamics. This contextuality is, as Murphy (2015, 76) writes with regard to 'context', 'fundamentally a relational rather than a territorial phenomenon, constituted through connections, flows, locations, and scales that often transcend the boundaries of nation-states, cities, and/or other commonly deployed geographical units'. In turn, we (the authors of this article) see multiple contextual energy transitions taking place simultaneously, with different pieces of networked hardware, infrastructural legacies, and other places, be they those under the influence of system operators or others (e.g. Manchester, Apulia, the Sussex coast, Italy, Europe), clashing and interacting in co-constitutive ways. In this section, we bring together the three vignettes as part of working though this contextual multiplicity and its implications. We draw attention to forms of conflict and consensus, arguing that it is just as important to study infrastructure junctions to see what is contested as it is to glimpse what is agreed upon and even what is accepted unquestioningly with seemingly little debate. We argue that the tensions and tacit agreements mediated and manifest through infrastructure junctions help to shape the detail and speed of low-carbon transitions from one place to the next.

In terms of a shared heritage and commonalities, there is a connection between the overcoming of bottlenecks in Apulia, attempts to extend the Rampion Offshore Wind Farm, and investment in the Central Manchester 33 kV Primary Substation. All are synonymous with a technocentric logic of provision and attempts to address climate change premised on the seemingly ever-increasing larger-scale generation, transmission, distribution, and consumption of electricity. This logic is not of either junction on its own or of any other place in and of itself. It is synonymous with a contemporary paradigm of international and marketised provision, based on the transmission of energy across vast distances and borders, from typically bespoke and dedicated sites of generation, to spatially detached but also physically and institutionally networked places of consumption.

Apulia produces more electricity than needed by the region. The Rampion extension promises to do the same, likewise feeding national and international networks of demand. Due to ongoing processes of urbanisation (United Nations 2014), electricity demand is increasingly materialising in cities, including Manchester, where we (the authors of this article) see a generally accepted 'ratcheting up' of electricity consumption, due to the largely unquestioned and supported growth of population and economy, and the uptake of technologies, including air-conditioning units and EVs, as part of sited network investments. Thus, there is a need for large-scale renewables across rural land and at sea to support the orthodoxy of ever-growing electricity consumption.

There is a shared foregrounding of translocal demands, urbanisation, the functioning of national and international markets, and attempts to meet spatially disaggregated targets relating to climate change. Ebbs and flows of demand across the noted spatial registers play figurative roles, as do attempts to reach specific goals, which in the case of Manchester is to become a zero carbon city by 2038 (Manchester Climate Change Partnership & Manchester Climate Change Agency 2020), and is net zero across the UK and Europe by 2050 (HM Government 2021). In more material terms, the sheer size and scale of infrastructure connected with each case reflects a shared logic of provision. This logic is not about local, decentralised, and community-oriented networks of energy provision and consumption (Johnson & Hall 2014). On the contrary, it arguably confounds such shifts, making them less likely to transpire. It is also not about focusing on demand reduction, but quite the opposite: it is about extension and growth, and is synonymous with an overshadowing of opportunities for demand reduction by a preoccupation with socio-technical solutions, premised on unabated consumption (CREDS 2021).

However, how bottlenecks in Apulia were overcome, the proposed extension of the Rampion Offshore Wind Farm, and the Central Manchester 33 kV Primary Substation are not simply part of a unified history and future-oriented logic of 'always' larger-scale provision and consumption. On the contrary, the cases revealed the inevitable contextual specificities of struggles that are both shaped by and shape infrastructure junctions and the disaggregated power geometries of low-carbon transitions.

In Apulia, profligate natural and geographically derived resources (e.g. wind and sunlight), combined with aims to make Italy energy secure and the country and Europe greener, conflicted with materialised legacies of network investment, which helped to disclose sited bottlenecks and challenges. These 'reverse salients' were rooted in histories of network investment, demand, and previous notions of the future pertaining to the Apulia region in particular and Italy in general. The remnants of past power geometries thus cast long and prescriptive shadows into the present, which have helped to configure much-discussed path dependencies (Goldthau & Sovacool 2012). In the discussed case, these localised challenges were overcome through transnational governance and innovative modes of intervention, crafted around specific assets (e.g. substations, switchgears, cables) and the threats they posed to ambitions rooted in other 'larger' places. However, the figurative permeations of locality and specific socio-material places were not defeated in that instance. Rather, responses and investment in higher voltage hardware represented processes of ongoing contextualisation, whereby aims and objectives common to Italy and Europe were mediated through network assets that came to set new contextual limits, thereby setting the stage for future challenges and conflicts.

Conflict is also at the heart of the Rampion case. However, it is not so much about past legacies and limits of investment conflicting with current transnational ambitions aimed at addressing climate change as about the proposed network extension at the wind farm clashing with aesthetic judgments and feelings concerning the local countryside, a beach, and the horizon. The sheer material size of the proposed turbines and their number are currently rubbing up against and irritating normative notions of the landscape and what it should look like and be used for. This conflict is playing out through a planning process, with its own temporal features (e.g. periods to raise objections, time frames to respond). Whether or not the wind farm will be extended remains unclear. Either way, the result will be an outcome of a contextual struggle over a place caught up in contested notions of both its and other places' futures. Indeed, due to the networked connections between infrastructure junctions and the fruition of low-carbon places, what happens at Rampion impacts wider attempts to achieve decarbonisation in, for example, cities, including Manchester. As with the bottlenecks in Apulia, local solutions to conflicts over place will spill over and have consequences for the fruition of transitions elsewhere.

Switching attention to the Central Manchester 33 kV Primary Substation means the grounds of conflict and consensus shift. As in Apulia, there has been a clash between legacies of network investment and current aims and ambitions. Unlike in Apulia, these aims and ambitions pertain to a city region, namely Greater Manchester. They are underpinned by anticipated and unquestioned economic and population growth, and by the development of buildings and uptake of particular technologies in the city. The UK's and other European countries' ambitions concerning climate change are backgrounded. Whether future visions of the city and demand therein, as materialised through networks investment, are low carbon is questionable. What is clear is that investments in network assets, such as the Central Manchester 33 kV Primary Substation, proceed largely unquestioned, unlike the proposed extension of the Rampion Offshore Wind Farm. Typically falling under the category of 'generally permitted development', they are not subject to public consent. They therefore fly under the radar, avoiding public contestation and debate. Nevertheless, as an infrastructure junction, investments such as the Central Manchester 33 kV Primary Substation shape the form and speed of energy transitions, favouring certain urban futures over others.

The infrastructure junctions examined in this article thus share some features, while remaining unique and of their own contexts. These infrastructural contexts are telling of the conflictual, consensual, and unquestioned power geometries of low-carbon place-making, what is fought over, which values and visions of places and futures win out over others, through forms of struggle and agreement, and whether tacit or not. In the next section, we consider the significance of this understanding for future research.

Conclusions

In melding a relational conceptualisation of place and place-making with an understanding of infrastructures as socio-technical networks, we have turned conceptual and analytical attention in this article to 'infrastructure junctions', for two reasons. First, the 'how' and 'when' of low-carbon transitions has tended to take precedence in research over questions of 'where' transformational shifts are made (Bridge et al., 2013). Second, where the 'where' of low-carbon transitions and place-making have been in focus, geographical scales and units, such as cities, regions, and nation states, have tended to take precedence over the sited components that help to make up socio-technical networks (Bolton & Foxon 2015). This has been the case even though such networked components are caught up in, shaped by, and shape low-carbon transitions and places in the making.

To demonstrate the value of switching attention to infrastructure junctions, we have examined three such junctions in this article. With an eye for material, spatial, and temporal features, we have discerned different instances of conflict and consensus, which are equally telling of the power geometries of low-carbon place-making, where and when this happens, and what purposes are (and are not) served.

When bringing the cases together, we discerned a broader, translocal consensus, located in a technocentric approach premised on ever larger-scale systems of provision and consumption. We have argued that this broader consensus, which is materialised through practices of infrastructural investment, means that problematic patterns of consumption are accepted and normalised, and opportunities to kerb demand are foreshadowed. We have also revealed differences between the junctions, with different forms of conflict and consensus either played or playing out and mediated through them in ways that act to recontextualise the form and speed of energy transitions continually. We have argued that instances of conflict are just as important as forms of consensus regarding the making and calibration of low-carbon transitions from one place to the next.

With regards to future research, we hope others will join us in focusing attention on the ordering of infrastructure junctions and the related implications for energy transitions and the fruition of low-carbon places. Key questions to be addressed are: What do infrastructure junctions and their spatial, temporal, and material features suggest about the form and speed of low-carbon transitions? What versions of low-carbon place-making are succeeding? What spatial scales and time frames are foregrounded and served? How are these spatial scales and time frames connected with the ordering and capacities of materialised assets? How are legacies of investment impacting current aims and ambitions? Addressing such questions will necessarily involve exploring the contexts of 'junctions' and tracing constitutive processes and collisions between practices that betray the power geometries of provision, consumption, and low-carbon places in the making. Moving in this direction promises to produce critical knowledge and practical insights into where, how, when, and for whom low-carbon places are made.

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