Journal of Environmental Policy & Planning

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/cjoe20

Reconfiguring energy flows: energy grid-lock and the role of regions in shaping electricity infrastructure networks

Carla De Laurentis & Richard Cowell

To cite this article: Carla De Laurentis & Richard Cowell (2022) Reconfiguring energy flows: energy grid-lock and the role of regions in shaping electricity infrastructure networks, Journal of Environmental Policy & Planning, 24:4, 433-448, DOI: 10.1080/1523908X.2021.2008235

To link to this article: https://doi.org/10.1080/1523908X.2021.2008235

JOURNAL OF ENVIRONMENTAL POLICY & PLANNING
2022, VOL. 24, NO. 4, 433–448
https://doi.org/10.1080/1523908X.2021.2008235

Reconfiguring energy flows: energy grid-lock and the role of regions in shaping electricity infrastructure networks

Carla De Laurentis[a] and Richard Cowell[b]

[a]Cardiff School of Management, Cardiff Metropolitan University, Cardiff, UK; [b]School of Geography and Planning, Cardiff University, Cardiff, UK

ABSTRACT
This paper investigates how a regional perspective can offer an insightful frame to examine the distribution of agency in energy transitions, with particular reference to the widespread problem of restructuring electricity grid networks to accommodate the expansion of renewable energy. Understanding governance and agency in this sphere requires a conceptual framework that can capture the layered nature of infrastructure and the functional and territorial mismatches between network governance and other governmental arenas. Thus, this paper adopts Barry's concept of 'technological zones' and uses it to examine grid capacity challenges and prospective solutions in two Italian regions. The paper investigates how regional governments can exploit the techno-economic opportunities and fixities to develop energy network solutions in their administrative territories and shows the nature (albeit partial) and reach of regional-level agency. The findings highlight that regions should not only be seen as a layer of governance but as sites of problems – and action – which spark innovations. We argue that while the regional-level has had a modest influence in the regulation of network infrastructure in the chosen cases, regions have had a role in rendering their territory, directly or indirectly, available for infrastructural investment and in mediating potential constraints.

ARTICLE HISTORY
Received 20 January 2021
Accepted 1 November 2021

KEYWORDS
Electricity network infrastructure; regions; governance; renewable energy; grid capacity; Italy

1. Introduction

For societies to transition to more sustainable energy systems it is important not just to understand the technological possibilities, but how such change is to be realised (Meadowcroft, 2009). This means governance, which – after (Rhodes, 1996, p. 653) – can be summarised as the processes for 'authoritatively allocating resources and exercising control and coordination'. Understanding governance means grasping who can make decisions and how steering effects are exerted. Complicating this endeavour is the fact that energy systems are shaped by processes operating at and between many different spatial scales (Goldthau, 2014; Sovacool, 2014). Energy systems may have co-evolved with the territoriality of state formation, for example, in creating 'national grids', but they can be affected by governance, market and consumption processes operating at transnational levels, and at scales 'below' the central state, in households, communities and cities. A key task then, is to understand how changes to energy systems are governed across these multiple sites, each with different forms of agency and territorial jurisdiction.

Few parts of energy systems illustrate the salience of this issue better than electricity network infrastructure – transmission and distribution grids. As decarbonisation targets tighten, so electricity networks are coming under pressures to change at multiple spatial scales (Purvins et al., 2011). Within states, there is the pressure to

CONTACT Carla De Laurentis cdelaurentis@cardiffmet.ac.uk Cardiff School of Management, Cardiff Metropolitan University, Cardiff, Wales, UK

accommodate higher shares of renewable energy (hereafter RE), such as solar and wind (Funcke & Bauknecht, 2016), which are more spatially dispersed and intermittent in their production patterns than the fossil and nuclear generators that shaped earlier rounds of grid construction. Beyond the state, there is growing interest in interconnecting grids across a national border, to facilitate market extension and security of supply. Added to this, there are diverse demands for flexibility, emanating from households, communities and cities, to accommodate greater decentralised energy production, demand management and cross-vector integration [i.e. of heat, transport and electricity: Hvelplund and Djørup (2017)]. Together, these pressures raise questions about the extent to which electricity network development can move beyond traditional efficiency-driven, market-reactive capacity expansion towards more strategic re-organisation, to better facilitate sustainability transition, handle the multiplying demands for coordination and negotiate distributive questions about 'who pays?' (Brisbois, 2020). They also raise questions about governance, which are clearly socio-technical in nature. The material obduracy of grid networks, representing significant sunk investment, not only physically structures pathways to the future, but may simultaneously reproduce obdurate governance arrangements, reflecting previous technical and political agendas but with a patchy 'spatial fit' for steering future change.

A key aim of this paper is to enhance our understanding of the spatial distribution of agency to steer energy network change (Kuzemko & Britton, 2020) and, to do this, we focus our investigation on two questions. Firstly, what is the role of the region in steering electricity network development? We understand 'the region' primarily as a sub-national level of government, with significant supra-local governance capacity and cohesiveness but treat that conceptualisation critically, as a way of opening up for examination the often difficult relations between territorially-bounded government bodies and the steering of spatially-extensive infrastructures. Focusing on the region also offers an alternative spatial frame to the national and urban focus that dominates much energy transition research, thereby highlighting particular energy transition problems and possible solutions, especially the challenge of reconfiguring networks to accommodate the expansion of RE, much of which is occurring beyond cities, in rural areas with limited grid capacity. While this is challenging in many countries (Cowell et al., 2017; De Laurentis & Pearson, 2021; IEA, 2020), such problems may have specific regional manifestations with regional advocacy being used to promote innovations to solve concrete problems on the ground. This leads to our second question: what is the role of regional government in facilitating the network accommodation of more RE capacity?

To address these questions, this paper draws on research that investigated RE deployment in Italy. The Italian case exhibits the conjunction of (traditionally) centralised energy network governance, wider shifts towards constitutional decentralisation, and challenges of accommodating rapid, but spatially-concentrated RE growth. Comparative analysis of two regions – Sardinia and Apulia – is used to examine why regional agency in network development can vary across space, and the drivers of innovative responses. It also helps to address a further question about agency, and network development – to what ends is any such agency applied? Do regions engage in network development in ways that help promote more – context-responsive sub-national agendas or to facilitate national priorities (e.g. RE expansion and/or wider energy security)?

The paper reviews the practical and analytical merits of focusing on regions, and the candidate intellectual frameworks for understanding the complex relationships between electricity network development and the spatial structure of governance. We adopt Barry's concept of 'technological zones' and use it to examine grid capacity challenges and prospective solutions in two Italian regions. The examples show the layered nature of infrastructure conditions and the functional and territorial mismatches between network governance and other governmental arenas. We conclude by summarising the key findings and discussing what the cases tell us on the role of the region in steering electricity network change. Lessons to be drawn and areas for further research are also highlighted.

2. An 'infrastructural turn': what role for regions?

There are a number of reasons why regions warrant more attention in our analyses of energy transition and infrastructure development. Firstly, the sub-national level of the region is increasingly represented as important for action to promote low-carbon energy systems (REN21, 2018) and regions have emerged as sites for innovation and experimentation in RE (Dawley et al., 2015; Fornahl et al., 2012). Focusing on the regional-level draws attention to the uneven distribution of innovation processes and how these are influenced by actors, networks and institutions at this spatial level (Mackinnon et al., 2019). And, as we have noted above, key infrastructural challenges in the energy transition – notably the reconfiguration of electricity networks to accommodate growing volumes of RE capacity – are often most visible at this scale. Indeed, regional bodies seeking to base the economic development aspirations of their territory on exploiting RE often confront grid capacity issues (Cowell et al., 2017; De Laurentis, 2020).

Clearly, RE innovation processes, including RE deployment, are not just objects pursued by national governments and incumbent actors (e.g. energy companies, utilities and regulators) but also involve a host of sub-national actors and social and political interests that can mobilise different visions, instruments and responses in connection with some of the mandates that meso-level government might hold in various policy spheres (e.g. land use, planning, transport and mobility, social welfare and economic development) (Hirsch, 2020; Rutherford & Jaglin, 2015). These spheres become a means through which regional actors can influence energy infrastructure change and, concomitantly, researchers have begun devoting more attention to the understanding growing significance of the regional scale as a form of energy space (Coenen et al., 2021). However, scant attention has been given to investigating energy network infrastructure and infrastructure steering. This represents a significant gap, given that infrastructure systems can pose a major barrier in achieving achieve desired sustainability transitions (Frantzeskaki & Loorbach, 2010).

There is also merit in giving closer attention to regions as a source of more fundamental insights into the challenges of exercising agency over energy infrastructure development, and electricity networks in particular. Previous studies focusing on sub-national government, dissecting their steering powers and effects, have helped reveal the fragmentary nature of democratic control over energy systems more broadly (Muinzer & Ellis, 2017). Energy infrastructure, and its regulation, functions across territorial units that seek to govern energy relationships and deliver energy-related collective goods (Hancock et al., 2021), emphasising an inherent tension between the formal administrative arrangements of governments and the networked governance of energy infrastructure systems.

This leads to some important conceptual questions: how should the nature and distribution of (regional) agency over energy systems be understood? Concepts of 'multi-level' governance helpfully capture the complexity of the spatial arrangements of energy governance, but much criticism has been directed at the veracity of equating scale with 'levels'. As Bulkeley (2005) observes, the language of 'levels' assumes a world with hierarchies of pre-given governance levels – each distinct and neatly bounded containers – arranged like rungs on a ladder through international to national, regional and local levels. Rendered as 'levels', governance scales can become something rigid, essential and pre-given, rather than relationally constructed – i.e., 'what constitutes the regional, urban or the local is not contained within a particular physical territory … but rather socially and politically constructed as such within and between variously configured networks of actors' (Bulkeley 2005, p. 884); for energy applications Murphy (2015), Smith and Raven (2012). Efforts to understand the role of regions, as governance actors, need to be cognisant of the ways that their powers are constructed by actions in other arenas.

Furthermore, any attempt to grasp the agency of regional-level governance needs to confront the connections and disconnections between the notional territoriality of that governance power, and the territoriality of the energy systems being governed. Electricity transmission and distribution systems illustrate this point in a variety of ways. Legacies of public ownership and privatisation may carve up network ownership and control in ways that match and mismatch government structures: some being more centralised; others being more decentralised, with the latter allowing more localised ownership and control [Moss (2014) on Berlin]. Shifting structures of state power may cut across past patterns of network integration: the risks to Ireland's Single Electricity Market wrought by Brexit is one example (Muinzer, 2018). The materiality of these infrastructures is integral to these structuring effects. Moreover, the physical mass and consequences of high-voltage grid infrastructures can also make them 'sites for political contest and change' (Bridge et al., 2018), stressing the importance of investigating energy infrastructure decision-making processes – including the power and influence of different actors.

What is needed, then, is an ontological perspective that recognises the co-constructive relationship between the spatiality of infrastructures and the territorialisation of governance, which is sensitive to the diverse effects of infrastructure materiality. There are numerous contenders. Regional studies researchers have begun to explore the mutually constituting relationships between infrastructures and regional space (Glass et al., 2019). Castán Broto (2017) work on 'energy landscapes' usefully draws attention to how patterning in the way that systems of energy provision and use are arranged in the landscape co-evolves with potential transition trajectories.

Potentially most useful to our research questions here, though rather under-exploited by energy researchers, is Barry's concept of 'technological zones'. Technological zones are governance devices and within them, argues Barry (2001, 2006, 2013), steps have been taken to reduce differences between technical practices, procedures and forms, thus enabling entities like money, data and electricity to circulate smoothly. In Barry's formulation, technological zones have a number of important properties. Different technological zones may have their own geography, and should be viewed neither as spatially monolithic nor automatically aligned with national (or other) political boundaries: electricity networks are a classic example, given their potential both to reach across national borders but not necessarily serve all constituencies within the states involved. In Barry's formulation, technological zones can take a number of different forms: *metrological*, concerned with common measurement standards; *infrastructural*, concerned with common connection standards; and *zones of qualification*, which are processes of transparency and evaluation (see Table 1). However, it is arguably more useful [after Cowell (2017)], to see technological zones as composites, bundling together metrological, infrastructural and qualificatory dimensions. These dimensions together stabilise and enable the spatial extension of infrastructures and associated governance. And as Hirsch (2020) observes, knowledge is critical to the operation of all three.

The value of Barry's perspective is that it disaggregates 'infrastructures': by exposing the different elements in the operation of infrastructural systems, it makes them less of a 'black box'. This, in turn, provides a more nuanced basis for understanding the spatial distribution of agency. Certain, facets of electricity networks – transmission and distribution lines, substations – may be highly visible and subject to land use planning regulation (zones of qualification), in which sub-national governments typically play an important role. However – other facets regulating system operation, connections and systems of charging (key facets of metrological and infrastructural dimensions of technological zones) may be organised at wider spatial scales that create difficulties for sub-national actors to influence. Their technical complexity and limited visibility also problematise the scope for stakeholder and public engagement (Palm, 2021). Here we see the dilemmas that electricity network infrastructures present for sub-national actors like regional government: such infrastructure may be enmeshed in, and create diverse issues for, a specific territory, but they are often organised to facilitate flows for other, wider spaces (Barry, 2013; Goldthau, 2014). Recognising the organising effects of technological zones may point to more fundamental dilemmas for governance across space; that there is no easy way of reconciling modes of governance that seek to roll-out standardised infrastructural systems from the centre, across a

Table 1. The dimensions of technological zones (after Barry, 2006).

- *Metrological zones* – common measurement standards to make information comparable;
- *Infrastructural zones* – common connection standards so that systems of production, transmission and communication can be integrated;
- *Zones of qualification* – processes of transparency and evaluation, to ensure that the qualities of objects and practices can be assessed, against more or less common criteria.

broad territory, with those modes that seek instead to attune governance processes and outcomes to local contexts, needs and capacities (Hirsch, 2020).

There is a further, insufficiently explored question. To the extent that regions have any such agency in steering energy network development, *to what ends is that put?* Previous research warns us not to assume that notionally 'decentralised', sub-national actors automatically push to cultivate more locally-integrated energy systems that would enhance local spheres of autonomy (Hodson & Marvin, 2017). This matters because a further facet of technological zones is that although they might be described as 'obdurate', they are always potentially problem-prone and in flux (Barry, 2006). When faced with problems – for example, the diverse pressures on networks arising from RE expansion – it is important to investigate whether sub-national actors like regions work to smooth the operation and evolution of nationally-integrated systems, facilitate their reproduction or to pull them towards more regional, contextually-embedded agendas. Hence attention needs to be devoted to the various ways in which these problems are solved. This includes the multiplicity of contingent relations that might emerge to unpack the nature and reach of the regional-level agency.

In this review, we have examined potential frameworks for our prime goal: to enhance our understanding of the spatial distribution of agency to steer network change. We have also argued for the analytical salience of focusing on regions and using technological zones as a framing concept to obtain a better understanding of agency in energy network infrastructure. We now apply this framework to our Italian case study, to show how grid infrastructure bottlenecks have affected RE expansion and the role of regional government in exploiting the techno-economic opportunities and fixities to develop solutions.

3. Methods

The paper draws from research conducted between 2014 and 2018 that examined the spatial unevenness and variation of RE deployment in different European territories. The paper presents evidence from Italy and two of its regions, Apulia and Sardinia. Data were obtained via documentary analysis, from 20 expert interviews (see Appendix 1) undertaken with government officers, civil servants, private and public-sector companies at national and regional levels engaged in RE activities in Italy; and two study visits to Sardinia and Apulia. The paper uses a comparative case study research design (Yin, 2014) as this is useful to tease out contextual conditions such as social, cultural and institutional forces and their variation across territories (Farole et al., 2011; Wirth et al., 2013), thus 'resulting in stronger evidence (…) and a wider applicability of result(s)' (Sovacool, 2014, p. 13). Data generated from the research, both in the form of interview transcripts and documents collated, were subject to thematic analysis, that identified:

- Renewable deployment and opportunities sought for renewable resource exploitation;
- Regional responses to pressures, targets and existing grid network constraints on RE deployment;
- RE support and geographical scale of relevance;
- Barriers to RE deployment and policy strategies adopted to address them.

The following section presents the findings and teases out the challenges and opportunities that have emerged around energy network infrastructure change in Italy, and the regions of Apulia and Sardinia. Both regions are rich in renewable energy resources. Apulia that forms the 'heel' of the country and Sardinia, one of the two big islands situated in the Mediterranean, and represent interesting cases for the paper as they have faced particular problems around infrastructure saturation that have hindered the scope and desire to shape rate and level of RE development within their territory (see Figure 1). The two regional cases are used here to explore and address the questions discussed in the introduction.

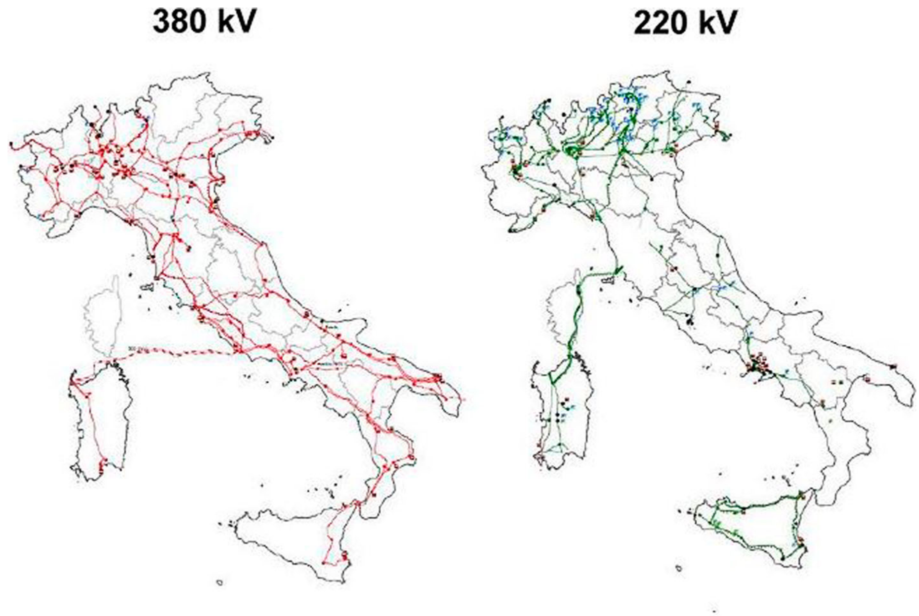

Figure 1. Italy's Transmission electricity infrastructure (2015). Source: TERNA (2017).

4. Electricity networks as technological zones: the Italian example

4.1 Italian energy network infrastructure

Italy has faced the challenge of coping with rapid RE expansion in the context of an infrastructural system geared primarily to the centralised provision of fossil fuel. Imported gas is the largest single source of generation and has proved difficult to dislodge (most growth in electricity generating capacity in the early 2000s came from gas-fired production). Italy's lack of significant domestic fossil-fuels resulted, historically, in the use of natural renewable resources in order to increase the security of supply: principally hydropower, but also geothermal. Nonetheless, the Italian government has for some time placed a significant emphasis on the mobilisation of RE sources (MISE, 2010, 2013, 2019). Reducing dependence on imports is one major driver, but so, too, has been pressures from European and international regulatory frameworks seeking to tackle climate change. In response, Italy introduced a system of generous, uncapped incentives that, between 2010 and 2012, stimulated impressive growth in the RE sector and an unprecedented increase in PV installation and capacity. However, this solar and wind 'rush' has created problems for the grid network, as we elaborate below.

Unfolding alongside RE expansion, constitutional reform provided a new framework for sharing regulatory competencies between the Italian State and the 20 administrative Regions, with political autonomy and elected parliament and government. Energy production, transportation and distribution are subject to concurrent legislation between state and regions (Art.117 Italian Constitution). The national government provides an overarching framework for RE development, including setting economic incentives, with regions having greater policy authority for climate change and energy efficiency policies as well as infrastructure planning, development and consenting processes. Italian regions have also a high degree of autonomy in relation to the planning and development of their own innovation and industrial support programmes. We can see here the layered nature of governance for the electricity technological zone, especially for the zone of qualification dimension.

After the process of liberalisation began, transmission and generation ownership was fully unbundled with the establishment of an independent national transmission system operator (TERNA), in 2005, a listed company with the largest shareholder being a joint-stock company controlled by Cassa Depositi e Prestiti. TERNA owns and operates the largest high-voltage network in Europe, with more than 63,500 km of transmission lines (IEA, 2016). As Italy's primary transmission and dispatching operator of electricity in Italy, TERNA covers grid planning, development and maintenance activities (transmission system operator) and ensures the stability, security and quality of the electricity service (independent System Operator) in a monopoly regime and on the basis of a government concession. Terna now owns 98.6% of Italy's national grid, with the remaining being owned by municipal companies and electricity producers. TERNA moved from dispatching the electricity system with 800 production plants (15 years ago) to around 800,000 distributed generation plants (mostly solar PV) currently. This requires a consistent effort in terms of the network upgrade, which is planned every 10 years in the Transmission Grid Development Plan, and presented every two years for Ministerial approval.

The Authority for Energy, Networks and the Environment regulates, controls and monitors the electricity and gas markets and water services in Italy. Whereas TERNA has sole responsibility for the transmission system, in 2019 there were about 125 electricity distribution companies. These are of uneven size, with e-distribuzione serving around 85% of the Italian market. The next three largest distributors are UnaReti (3.9%), Areti (4.49%) and Ireti (1.89%), serving major Italian cities – Rome, Milan and Turin. These are joint-stock companies whose main shareholders are national or local public bodies. Distribution operators manage the medium and low voltage lines and connect not only final customers but also producers. Traditionally distribution systems have been designed to distribute electricity top-down from generation connected to the transmission level to end consumers; they are increasingly required to provide enough capacity to cope with fluctuating demand and power flows.

Reaching the Italian share of the EU's 2020 RE targets required a sustained acceleration of development, especially wind and solar (MISE, 2010). RE projects and the related network infrastructure have been considered of national importance, with the national government designating appropriate ways to pursue them, including a principle of priority of connection and access to the grid to electricity from renewable sources. The increase in the penetration of variable RE sources that occurred in Italy between 2009 and 2012, has triggered changes both at transmission and distribution levels.

Upgrades, completed and planned, include energy connections between the Northern (where the demand for electricity is greater) and Southern Italy (where renewable production is concentrated); better connections between the mainland and the islands and improvement of international inter-connections. While the cornerstone of the 2021–2024 TERNA's Development plan is to upgrade regulated activities – to boost system security and resilience and resolve grid congestion – TERNA is also branching out to include non-regulated activities such as: energy solutions for grid infrastructure and smart grid; connectivity, particularly through optical fibre assets maximisation and a programme of industrial cables and transformers development (TERNA, 2020). This represents an expansion of grid operation logics, beyond traditional investment in new line capacity, to more innovative approaches to system capacity issues [contra Mostyn et al., 2018, in Palm (2021)].

Given the significant number of distribution networks operating in the Italian electricity distribution sector, there is not a formal ex-ante requirement for business plans. Yet distribution networks are required to plan upgrades and investments in areas such as automation and control systems for medium voltage smart grids and pilot projects concerning the installation of batteries. Moreover, the significant number and heterogeneity of Italian distribution operators, together with a regulatory framework lacking a unified approach (Benedettini & Pontoni, 2013), have influenced and shaped the level of investments in distribution infrastructure networks. However, the launch of a large-scale roll-out plan of smart metres led initially in 2001 by the major incumbent e-distribuzione (also in charge of metering activities), and then made mandatory by the regulator for all the electricity distributors, allowed new services for customers such as time of use tariffs, remote contract management, and network management (e.g. loss monitoring and identification of criticalities in the networks). The second generation of smart metres with increased functionalities and enhanced performance has been rolledout since 2017. While smart metres facilitate new, market-based and infrastructural interfaces between network operators, energy suppliers and consumers, such developments largely by-pass intermediate levels of government.

The discussion above shows that certain dimensions of the Italian electricity technological zone – those that concern system operation and marketisation – tend to be dominated by a few dominant, incumbent actors, principally TERNA and the regulator. However, the zone of qualification for developing networks exhibits a more complex, distributed scope for the agency. Under the present constitutional framework, Italian energy issues involving larger-scale infrastructure are governed under 'concurrent legislative powers', which extends to include regional involvement in administrative matters. Hence, the authorisation for any given project requires the agreement of the region concerned, including energy infrastructure renewal works that are deemed of national interest (and not just for those of regional and local interests). The development and construction (or upgrade) of transmission lines and substations, for example, require permits mandated by state, regional and local legislations to ensure environmental protection and compatibility with existing infrastructure. While the process will depend on the nature and location of the facility to be developed and the permits required, it highlights that infrastructure requirements have institutional concomitants that encompass regional steering. There have also been attempts at the national level to enhance and streamline permitting procedures for infrastructure projects of national interest (including transmission lines). In this pursuit of cross-national standardisation there is an issue for the agency at lower levels.

As discussed, regions, as a meso-level government, under the present constitutional framework, play an important but delimited formal role in energy planning governance. However, there are benefits in paying attention to the various elements that make up the electricity technological zone, especially where innovative solutions are required to network capacity problems, as this can allow to show the nature and reach of the regional-level agency. To explore this issue further, in the next two sessions, we unpack the spatial mismatch of Italian infrastructure networks and investigate the emerging techno-economic opportunities that allowed the emergence of new relations and participation in infrastructure renewals with varying spatial reach.

4.2 Spatial mismatch in electricity infrastructure networks

Italy's expanded RE capacity is often concentrated in regions that are distant from the main consumption centres and where grid development has lagged behind the spread of production facilities. This creates local over-production problems with high risks to the balance and security of the grid and the distribution network, to which a growing proportion of generation from renewables is connected. Network and congestion problems have been felt differently across Italian regions. Frequent network congestion translates into the curtailment of wind and solar power. While across Italy, curtailment rates have been low, in some areas, they have reached higher percentages. The most affected transmission lines are those located in Southern Italy (e.g. Apulia) between Andria-Foggia, Campobasso-Benevento and Benvenuto-Montecorvino, with critical areas in the distribution networks concentrated in the major islands and in the South, along transmission lines between Apulia and Campania (TERNA, 2017).

Apulia is the second biggest electricity-producing region in Italy and a net electricity exporter. The region's electricity network was historically configured for the long-distance transmission of electricity flows from the Brindisi area, where conventional plants are located, to the north and to the South of the country. This has had an important impact on the grid, amplifying congestion and transportation needs. Apulia's regional network capacity relies especially on 150 kV lines, which do not allow the dispatch of all the power produced. Moreover, small municipalities show high electricity reverse flow in primary substations, with Troia, a municipality of 7000 inhabitants, among the highest (62%). The very rapid development of electricity production capacity from renewable sources in the region created congestion and load management problems. Pending connection requests in Apulia by 2014 represented almost 50% of the entire national figure (BURP, 2014). Against the two upgrades to the grid network necessary in the north and in the centre of Italy, Apulia alone required twelve (including new inter-regional inter-connections and the development of 380 kV high-voltage collection stations).

Sardinia presents a confined and weakly-meshed transmission and distribution system with a single 380 KV interconnection that cuts across the region. The electricity network is connected to mainland Italy via Tuscany (in operation since 2011) and to Corsica, with the current Corsican connection approaching life expiry. Sardinia exports over 25% of net electricity production to the mainland. There are also calls to phase out coal by 2025: this adds to an already challenging situation as (at the time of writing) coal fuels almost half of the thermoelectric plants. Such peculiarities have reduced the opportunities for the connection and further export of RE, making the energy infrastructure subject to a more severe level of control from the transmission operator and more liable to limiting dispatch orders (RSE, 2011). These physical constraints have represented a limiting factor for RE deployment, with the regional energy plan identifying a maximum capacity limit of 1500 MW of wind power that the current regional infrastructure could accept (Regione Sardegna, 2012).

In both Apulia and Sardinia, higher shares of RE have amplified the need for transforming the electricity network – both at transmission and distribution levels, and while some upgrades have been completed, the bulk of improvement is still awaiting the authorisation required. These investments – and the delays that often characterise their completion – highlight the importance of spatial infrastructure planning and the political decision-making and steering of infrastructure renewal, though its organisation at different spatial levels also show fragmentation within the zone of qualification. As suggested by Brisbois (2020), there are questions on how far regional governments are willing or able to override the actions of municipalities in their consenting role. Apulia struggled to exercise spatial control over RE expansion, to foster greater coordination with grid capacity, in the face of resistance from municipalities keen to maximise economic returns from RE development. In Sardinia, according to Osti (2018), many wind farms and large-scale PV panels were installed by external multinational companies attracted by the opportunity to make an easy profit, with local authorities unable or unwilling to stop them.

Nevertheless, grid capacity issues and constraints at the regional-level, as noted above, can influence regional aspirations and can be influenced by the conditions which shape the interests, ideas and actions of the regional governments. Apulia's RE agenda has been a straightforward one of facilitating RE expansion, to diversify rural economies, and avoid nuclear power. This general expansionism is coupled with a recognition of grid capacity constraints and a desire to assert some spatial coordination over lower-level decisions. In Sardinia, RE development has not been seen as an instrument to enact any particular goal (c.f. Osti, 2018). The energy plan drawn up by the regional government has placed greater emphasis on switching to gas as well as RE and storage expansion; but in reality, it continued to issue an approval for coal-fired co-generation, showing ambivalence about the future direction of energy transitions. Furthermore, the maximum capacity limit identified by the regional government provided a compelling argument around grid limitations together with an opportunity for dissenting voices to raise concerns around the uptake of RE and infrastructure renewal. The opportunities for RE expansion as a basis for increased electricity export to the mainland are muted (such initiatives are left to TERNA).

Before discussing what this means for the distribution of agency, we move next to present the opportunities explored within the regions to overcome network obduracy and bottlenecks.

4.3 Techno-economic opportunities to fix grid capacity issues

The complexity of infrastructure conditions and the contextual conditions of infrastructural renewal have provided important settings for innovative solutions to emerge in the two regions, encompass the planning role allocated to regional governments by the constitution but also economic development funding. In Apulia, a number of infrastructure solutions to upgrade the transmission and distribution networks have been implemented. These include the construction and modernisation of TERNA-owned substations, the upgrade to 380 kV lines to address capacity requirements, inter-regional connectors between Apulia and neighbouring Campania and demand management solutions. These interventions were driven by TERNA and highlight how line upgrades are often represented as a conventional way to release more RE capacity. This also echoes the tendency for grid operators to drive demand-side management (DSM) without much external government engagement (Kelly & Marvin, 1995). Yet, agency, at different spatial levels, has often been used to respond to RE intermittency in other ways. These include projects aimed at testing and piloting innovative solutions that involve collaborative work with regional bodies. In Apulia, these included the INGRID Project, a 39 MWh pilot plant for hydrogen-based storage for grid balancing, based in Troia, an area with high electricity reverse. This EU FP7-funded project, 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 this experience, the region become again the location of a spin-off project, the Store and Go project, a Horizon 2020 project, which explored how the renewable power used in the INGRID electrolyser can 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 via European structural and convergence funds to support RE integration was initiated in 2019. The Apulia Active Network project led by e-distribuzione, and delivered in collaboration with a number of local authorities in the region, has aimed at testing a smart grid development at the regional scale, including advance automation and monitoring of medium voltage lines, predictive maintenance of primary stations and a fleet of regional charging infrastructure for electric vehicles. Also included are customers demand management and response innovations that allow greater awareness of the use of electricity (in homes and small businesses) and to organise more efficiently the use of appliances, heating and cooling devices. Resources for infrastructure development have also been allocated in regional economic planning, channelling European funding for infrastructure renewal (e.g. Apulia allocated 15 Million Euros priority spending on distributed energy for the development of smart grid). The Apulian regional government also participated in infrastructure governance round tables and signed a Memorandum of Understanding (MoU) with TERNA to connect new RE power plants to the grid, to help mitigating the environmental impact of grid interventions, and thus smooth the operation of the zone of qualification dimension of the technological zone.

Sardinia's infrastructure challenges have also provided the opportunity for the national transmission operator to introduce a number of innovations to solve the island's infrastructure bottlenecks. The commitment by TERNA since 2011 for various large-scale interventions to increase interdependence with the mainland and to start storage applications above the laboratory-experimental level, have made Sardinia a 'high-tech hub' for energy experimentation. These included experimentation with storage applications and to test the use of Synchronous Compensators that enhance system stability, reducing the number of plants considered essential for the security of the grid in Sardinia. The Storage Lab introduced by TERNA, in 2012, in the area of Codrongianos, where TERNA owns the site, aimed at piloting some of the main storage technologies currently available on the market and test their performance in terms of system regulation and security, in collaboration with national research institutes (Osti, 2018). The Codrongianos station has also hosted two Synchronous Compensators to enhance system security of the HVDC connection to Italy mainland. TERNA is also committed to strengthen the interconnections between Sardinia and Italy mainland to increase electricity exchange capacity and thus support the development and better use of renewable energy flow via the renovation and upgrading of the link between Sardinia and Corsica and the planned Tyrrhenian Link, starting construction in 2021, to connect Sicily with Sardinia and the Italian peninsula via a double underwater cable.

Although Sardinia has been chosen as an experimentation and demonstration site, the links with regional and other local bodies are minimal, and lower than in Apulia. National actors, especially the transmission provider, have been more active in the region. As suggested, the major infrastructure projects that dominated RE discourses in the region have mainly focussed on the opportunities offered by its position in the Mediterranean and the interconnections between the region and neighbouring countries, with the regional government playing a role in facilitating dialogue across different parties involved in infrastructure renewal (e.g. the regional government and TERNA have started consultations with local and regional authorities for the development of the Tyrennian Link).

Furthermore, the regional government and Sardinia Research, the public research organisation in the region, sought to promote the emergence of a RE cluster – with priority areas such integration and management of RE sources and analysis and monitoring of micro-networks electrical mobility and integration – yet the cluster initiative only attracted a limited number of actors (35 among regional businesses, universities, research bodies and local authorities), representing a much smaller initiative than the New Energy Cluster initiative launched in Apulia that attracted 392 organisations. This may reflect Osti's observation (Osti, 2018), that Sardinia's energy transition has been shaped by limited local involvement and Sardinia consumers who are on average poorer than Italians, leaving the island highly dependent on external funds. Indeed, while national players like TERNA push for increasing electrification, the Regione Sardinia has focussed primarily on full island methanisation (Osti, 2018).

Support for smart grid experiments should be seen in this context. The Sardinian regional government used Regional Operating Plans (plans that identify how European funds are allocated within the region) to support two villages (Benetutti and Berchidda) in experimenting with the smart grid to upgrade the low tension gird and promote demand response applications. Here, the low voltage grid is owned by the municipalities; yet in the Benetutti smart project, we see the involvement of the Sardinia's regional agency for research and technological development; in Berchidda, private companies have a greater role and a different technological model is been applied (Osti, 2018). While this emphasises the experimental role of these initiatives, it also highlights the competition between the two municipalities.

In summary, both regions have established themselves as sites for experimentation and explored investment opportunities and long-term strategic infrastructure upgrades, and we have discussed the conditionalities that made these innovations 'work'. Community actors' participation in influencing the energy grid has been limited, in both regions. There are difficulties for new entrants to get access to energy grids, offering unequal power to current incumbents in infrastructure energy networks. This is important and explains the weak role of civil society in Italy's energy transition, which is mostly limited to the north of Italy and 'historical hydroelectric cooperatives' (Magnani & Osti, 2016).

We move next to highlight lessons learnt from the cases and draw some conclusions from how grid capacity challenges and prospective solutions in two Italian regions have opened up questions of a regional agency.

5. Discussion and conclusions

The paper sought to investigate the role of the region in steering electricity network change, suggesting that the regional-level can offer an opportunity to analyse how the different material and socio-technical relations of energy network infrastructure come together in different ways, in order to enhance our understanding of the spatial distribution of agency more widely. The paper highlighted (i) how RE deployment has been affected by the conditions of the established infrastructure networks and by the way these become intimately connected through the materially embedded transmission and distribution networks in the two regions; (ii) the emerging techno-economic opportunities to fix these spatial mismatches between RE development and grid capacity; and (iii) how these have led to the creation of new relations and opportunities for participation in infrastructure renewal and innovations with varying spatial reach.

What do the case studies tell us about the emerging relationship between regions, energy network infrastructure, and the distribution of agency? At first sight, it would appear that the partial shift of responsibilities in Italian energy policy from the central ministries to the regional administrations, in terms of infrastructure steering, might be limited to the coordination between the national and the regional levels, as set by the Constitution. This coordination involves matters concerning energy planning, including some forms of energy infrastructure steering (for the siting of RE projects and consenting for new network infrastructure capacity) and via the decentralisation of planning procedures. Unquestionably, the national level has played a dominant role not only in the promotion of RE deployment but also in the regulation of network infrastructure (e.g. in terms of price signals, capacity markets and the technical rules/codes for planning and operating connections to the grid), which emphasises increasing the security of the Italian energy system and driving an agenda for grid modernisation set around the transformation of the electric energy mix.

However, regions – as a meso-level government, under the present constitutional framework – can play an important – albeit limited – role in energy planning governance by showing the importance of the distribution of power across multiple sites and tiers of government, and how this might affect legitimacy and control over infrastructure renewal.

Firstly, there have been problems in Italy around the distribution of power in infrastructure planning due to the uncertain distribution of competencies and fragmented regulatory frameworks (Corsatea, 2016). In this context, the relationships that network operators and regions have managed to establish have been useful to facilitate network improvement projects (e.g. Apulia and TERNA's MoU), by smoothing procedures within the zone of qualification dimension of the technological zone. While infrastructure planning consent is shared across different spatial levels, regional governments and transmission operators can help facilitate consultations with local and regional authorities for grid upgrades (e.g. the Tyrennian Link).

Moreover, both regions, as layers of governance by constitution, also participated in administrative matters for the provision of permits mandated by state, regional and local legislation. This is important as it shows that the regional-level, in Italy, can contribute to spatial infrastructure planning, another element contributing to the qualificatory dimensions of technological zones.

Secondly, the emergence of techno-economic opportunities to overcome grid capacity problems for RE has allowed the creation of new relations and participation in infrastructure renewals with varying spatial reach, suggesting that there might be a role for regional governments in facilitating the network accommodation of more RE capacity. This role can be explained by looking at regions as sites of problems – and action – which spark innovations. Physical and material bottlenecks have provided opportunities not only just to facilitate conventional grid network capacity expansion but also to experiment with new socio-technical advancements (as highlighted in both regions in terms of storage and smart grid implementation). We see differences emerging across the two regions in the way in which regions exercise agency to mediate potential constraints.

Often that agency is exercised in simple, external ways. We observed regional actors facilitating the identification and operation of sites that could benefit from innovative solutions to solve infrastructure bottlenecks and to actively participate in addressing these (highlighting a further form that zones of qualification could take). However, Apulia regional government and regional intermediary organisations (such as the regional development agency) have also participated in these experiments by providing resources, networks and socio-technical expertise. Infrastructure challenges presented in Sardinia also allowed the testing of new technological solutions; yet a lack of a critical mass of energy actors and entrepreneurial capacity limited the participation of regional actors, which meant that innovative solutions were led primarily by national transmission operators.

Thirdly, regional actors both in Apulia and Sardinia have also allocated resources and channelled European funding towards infrastructure renewal, especially smart grid. This highlights that European-funded projects are another important tool in modernising grids, with Italy among the highest performers within the European Programmes, particularly Horizon 2020, and stresses how the narrative of infrastructure renewal can form parts of the economic development strategies of regional governments. This confirms that regional agency also lies in discretionary regional economic development spending. While a denser network of regional, national and international organisations can facilitate regional participation in innovative solutions, as the Apulian case shows, so does the spatial organisation of the network operators themselves. As discussed, some developments and experimentation occurred in TERNA's owned facilities, removing one role for government bodies.

Adopting a technological zone lens shows that, while network infrastructure organisation and the diverse institutions that underpin its operation are often configured at the national level (e.g. what region can do in relation to the power devolved by the national level), governance and control of the spatially-extensive infrastructures in the two regions can be viewed neither as spatially monolithic nor automatically aligned with national political boundaries. This can have wider relevance in analysing energy governance and examining the distribution of agency in energy transitions. The paper highlighted how infrastructure systems, as technological zones, need to negotiate spatial vulnerabilities that require adjustments to the different qualities of technological zones – and the three dimensions – they exhibit. This raises questions around the boundaries of technological zones and their multi-layered nature. Moreover, while the sensitivity to contextual conditions helps gain a better understanding of agency at the sub-national level, the scope that the technological zone concept offers for disaggregating 'network infrastructure' is helpful in better specifying the uneven scope for the agency. When it comes to the 'metrological' and 'infrastructural dimensions' of electricity networks, our research confirms the challenges that many stakeholders face in engaging effectively. The detailed, complex nature of the technical rules governing system operation concentrates power in incumbent industry actors, and represents daunting information asymmetries for other stakeholders like regional governments (Lockwood et al., 2017). The unequal power of the different players is reproduced because without a formal role (in terms of legitimacy and power), it is difficult for public bodies – and other actors – to justify investing in acquiring sufficient knowledge or skills to engage (Brisbois, 2020; Osti, 2018; Palm, 2021). It is little wonder, perhaps, that the activities of regional government that we observed focus mostly on helping to secure economic development funding and facilitating site availability and project consents, utilising established powers within the zone of qualification dimension.

In conclusion, we contend that regional-level agency from the regional government can help in channelling resources and investment to solve constraints to RE expansion linked to infrastructure governance and inheritances by mediating between local sites of investments and wider geographies of energy, but the scope of this agency is partial in scope and reach. However, our analysis of how the two Italian regions have engaged with problems of insufficient grid capacity leads us to one final point about the spatial distribution of agency in energy transitions. This is that one cannot easily separate debates about the appropriate allocation of powers between government arenas from debates about the framing of the problem (Cowell & Webb, 2021). In this case, this is whether the problem is mostly one of building and connecting more large-scale capacity in a largely unchanged grid or whether it requires much more emphasis on DSM and other local flexibility solutions. Important questions for further research, therefore, are (i) how far and under what conditions do sub-national actors acquire the agency to work for a reframing of the problem alongside an extension of their powers? (ii) Might the opportunities for regional government bodies to engage in more innovative capacity management projects, as we observed in Apulia and Sardinia, help cultivate technical learning that could facilitate their access to other regulatory venues within the electricity network technological zone?

Acknowledgements

Financial support for the research underpinning this paper has come from a Doctoral Study jointly sponsored by the Engineering and Physical Sciences Research Council (EPSRC) in the UK and the Welsh School of Architecture in Cardiff University and a Short-Term Scientific Mission sponsored by the COST ACTION TU1104- SMART ENERGY REGIONS and is gratefully acknowledged.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Ethical approval and consent to participate

The research conducted during this study was approved by the Ethics committee of the Welsh School of Architecture of Cardiff University, reference n. EC 1504.231. All research participants signed consent to participate.

Funding

This work was supported by the Economic and Social Research Council [grant number ES/T008253/1]; Engineering and Physical Sciences Research Council.

Notes on contributors

Carla De Laurentis is a lecturer in the Cardiff School of Management, Cardiff Metropolitan University. Her research interest focuses on the geography of innovation and how energy networks influence technological innovation and renewable energy deployment.

Richard Cowell is Professor of Environmental Planning, in the School of Geography and Planning, Cardiff University. He has thirty years' experience of researching the relationship between planning and environmental sustainability, with particular interest in the dynamics of integrating environmental concerns into policy and decision-making.

References

Barry, A. (2001). *Political machines: Governing a technological society*. Athlone.

Barry, A. (2006). Technological zones. *European Journal of Social Theory*, *9*(2), 239–253. https://doi.org/10.1177/1368431006063343

Barry, A. (2013). *Material politics: Disputes along the pipeline*. Wiley Blackwell.

Benedettini, S., & Pontoni, F. (2013). Italian regulation of electricity distribution and its impact on efficiency, investments and innovation: A qualitative assessment. *Competition and Regulation in Network Industries*, *14*(4), 365–384. https://doi.org/10.1177/178359171301400403

Bridge, G., Özkaynak, B., & Turhan, E. (2018). Energy infrastructure and the fate of the nation: Introduction to special issue. *Energy Research & Social Science*, *41*, 1–11. https://doi.org/10.1016/j.erss.2018.04.029

Brisbois, M. C. (2020). Decentralised energy, decentralised accountability? Lessons on how to govern decentralised electricity transitions from multi-level natural resource governance. *Global Transitions*, *2*, 16–25. https://doi.org/10.1016/j.glt.2020.01.001

Bulkeley, H. (2005). Reconfiguring environmental governance: Towards a politics of scales and networks. *Political Geography*, *24*(8), 875–902. https://doi.org/10.1016/j.polgeo.2005.07.002

BURP. (2014). *Bollettino Ufficiale Regione Puglia n. 51 del 15/04/2014 'Analisi di Scenario della produzione di energia e fonti energetiche rinnovabili sul territorio regionale. Criticita' di sistema e iniziative conseguenti*. Regione Puglia.

Castán Broto, V. (2017). Energy landscapes and urban trajectories towards sustainability. *Energy Policy*, *108*(C), 755–764. https://doi.org/10.1016/j.enpol.2017.01.009

Coenen, L., Hansen, T., Glasmeier, A., & Hassink, R. (2021). Regional foundations of energy transitions. *Cambridge Journal of Regions, Economy and Society*, *14*(2), 219–233. https://doi.org/10.1093/cjres/rsab010

Corsatea, T. D. (2016). Localised knowledge, local policies and regional innovation activity for renewable energy technologies: Evidence from Italy. *Papers in Regional Science*, *95*(3), 443–466. https://doi.org/10.1111/pirs.12136

Cowell, R. (2017). Decentralising energy governance? Wales, devolution and the politics of energy infrastructure decision-making. *Environment and Planning C: Politics and Space*, *35*(7), 1242–1263. https://doi.org/10.1177/0263774X16629443

Cowell, R., Ellis, G., Sherry-Brennan, F., Strachan, P. A., & Toke, D. (2017). Sub-national government and pathways to sustainable energy. *Environment and Planning C: Politics and Space*, *35*(7), 1139–1155. https://doi.org/10.1177/2399654417730359

Cowell, R., & Webb, J. (2021). Making useful knowledge for heat decarbonisation: Lessons from local energy planning in the United Kingdom. *Energy Research & Social Science*, *75*(2), 102010. https://doi.org/10.1016/j.erss.2021.102010

Dawley, S., Mackinnon, D., Cumbers, A., & Pike, A. (2015). Policy activism and regional path creation: The promotion of offshore wind in North East England and Scotland. *Cambridge Journal of Regions, Economy and Society*, *8*(2), 257–272. https://doi.org/10.1093/cjres/rsu036

De Laurentis, C. (2020). Mediating the form and direction of regional sustainable development: The role of the state in renewable energy deployment in selected regions. *European Urban and Regional Studies*, *27*(3), 303–317. https://doi.org/10.1177/0969776420904989

De Laurentis, C., & Pearson, P. G. J. (2021). Policy-relevant insights for regional renewable energy deployment. *Energy, Sustainability and Society*, *11*(1), 19. https://doi.org/10.1186/s13705-021-00295-4

Farole, T., Rodriguez-Pose, A., & Storper, M. (2011). Human geography and the institutions that underlie economic growth. *Progress in Human Geography*, *35*(1), 58–80. https://doi.org/10.1177/0309132510372005

Fornahl, D., Hassink, R., Klaerding, C., Mossig, I., & Schröder, H. (2012). From the old path of shipbuilding onto the new path of offshore wind energy? The case of Northern Germany. *European Planning Studies*, *20*(5), 835–855. https://doi.org/10.1080/09654313.2012.667928

Frantzeskaki, N., & Loorbach, D. (2010). Towards governing infrasystem transitions: Reinforcing lock-in or facilitating change? *Technological Forecasting and Social Change*, *77*(8), 1292–1301. https://doi.org/10.1016/j.techfore.2010.05.004

Funcke, S., & Bauknecht, D. (2016). Typology of centralised and decentralised visions for electricity infrastructure. *Utilities Policy*, *40*(C), 67–74. https://doi.org/10.1016/j.jup.2016.03.005

Glass, M. R., Addie, J.-P. D., & Nelles, J. (2019). Regional infrastructures, infrastructural regionalism. *Regional Studies*, *53*(12), 1651–1656. https://doi.org/10.1080/00343404.2019.1667968

Goldthau, A. (2014). Rethinking the governance of energy infrastructure: Scale, decentralization and polycentrism. *Energy Research & Social Science*, *1*, 134–140. https://doi.org/10.1016/j.erss.2014.02.009

Hancock, K. J., Palestini, S., & Szulecki, K. (2021). The politics of energy regionalism. In K. J. Hancock & J. E. T. Allison (Eds.), *The Oxford handbook of energy politics*. Oxford University Press.

Hirsch, S. L. (2020). Governing technological zones, making national renewable energy futures. *Futures*, *124*, 102648. https://doi.org/10.1016/j.futures.2020.102648

Hodson, M., & Marvin, S. (2017). Intensifying or transforming sustainable cities? Fragmented logics of urban environmentalism. *Local Environment*, *22*(sup1), 8–22. https://doi.org/10.1080/13549839.2017.1306498
Hvelplund, F., & Djørup, S. (2017). Multilevel policies for radical transition: Governance for a 100% renewable energy system. *Environment and Planning C: Politics and Space*, *35*(7), 1218–1241. https://doi.org/10.1177/2399654417710024
IEA. (2016). *Energy policies of IEA countries – Italy 2016 review*. International Energy Agency.
IEA. (2020). *Global energy review 2020*. International Energy Agency.
Kelly, A., & Marvin, S. (1995). Demand-side management in the electricity sector: Implications for town planning in the UK. *Land Use Policy*, *12*(3), 205–221. https://doi.org/10.1016/0264-8377(95)00004-W
Kuzemko, C., & Britton, J. (2020). Policy, politics and materiality across scales: A framework for understanding local government sustainable energy capacity applied in England. *Energy Research & Social Science*, *62*, 101367. https://doi.org/10.1016/j.erss.2019.101367
Lockwood, M., Mitchell, C., Hoggett, R., & Kuzemko, C. (2017). The governance of industry rules and energy system innovation: The case of codes in Great Britain. *Utilities Policy*, *47*(C), 41–49. https://doi.org/10.1016/j.jup.2017.06.008
Mackinnon, D., Dawley, S., Steen, M., Menzel, M.-P., Karlsen, A., Sommer, P., Hansen, G. H., & Normann, H. E. (2019). Path creation, global production networks and regional development: A comparative international analysis of the offshore wind sector. *Progress in Planning*, *130*, 1–32. https://doi.org/10.1016/j.progress.2018.01.001
Magnani, N., & Osti, G. (2016). Does civil society matter? Challenges and strategies of grassroots initiatives in Italy's energy transition. *Energy Research & Social Science*, *13*, 148–157. https://doi.org/10.1016/j.erss.2015.12.012
Meadowcroft, J. (2009). What about the politics? Sustainable development, transition management, and long term energy transitions. *Policy Sciences*, *42*(4), 323–340. https://doi.org/10.1007/s11077-009-9097-z
MISE. (2010). *Piano di azione nazionale per le energie rinnovabili (direttiva 2009/28/CE)*. Ministero dello Sviluppo Economico.
MISE. (2013). *Strategia Energetica Nazionale*. Ministero dello Sviluppo Economico.
MISE. (2019). *Piano Nazionale Integrato per l'energia e il clima*. Ministero dello Sviluppo Economico.
Moss, T. (2014). Socio-technical change and the politics of urban infrastructure: Managing energy in Berlin between dictatorship and democracy. *Urban Studies*, *51*(7), 1432–1448. https://doi.org/10.1177/0042098013500086
Muinzer, T. (2018, November 28). Electricity bills could rise if Brexit threatens Northern Ireland's unique energy agreement with Ireland. *The Conversation* [Online]. https://theconversation.com/electricity-bills-could-rise-if-brexit-threatens-northern-irelands-unique-energy-agreement-with-ireland-106269
Muinzer, T. L., & Ellis, G. (2017). Subnational governance for the low carbon energy transition: Mapping the UK's 'energy constitution'. *Environment and Planning C: Politics and Space*, *35*(7), 1176–1197. https://doi.org/10.1177/2399654416687999
Murphy, J. T. (2015). Human geography and socio-technical transition studies: Promising intersections. *Environmental Innovation and Societal Transitions*, *17*, 43–71. https://doi.org/10.1016/j.eist.2015.03.002
Osti, G. (2018). The uncertain games of energy transition in the island of Sardinia (Italy). *Journal of Cleaner Production*, *205*, 681–689. https://doi.org/10.1016/j.jclepro.2018.08.346
Palm, J. (2021). Exploring limited capacity in the grid: Actors, problems, and solutions. *Frontiers in Energy Research*, *9*, 663769. https://doi.org/10.3389/fenrg.2021.663769
Purvins, A., Wilkening, H., Fulli, G., Tzumas, E., Cellli, G., Mocci, S., Pilo, F., & Tedde, S. (2011). A European supergrid for renewable energy: Local impacts and far-reaching challenges. *Journal of Cleaner Production*, *19*(17-18), 1909–1916. https://doi.org/10.1016/j.jclepro.2011.07.003
Regione Sardegna. (2012). *Piano d'azione regionale per le energie rinnovabili Sardegna Documento di indirizzo sulle fonti energetiche rinnovabili Cagliari*. Regione Autonoma della Sardegna.
REN21. (2018). *Renewables 2018 Global status report*. Renewable Energy Policy Network for the 21st Century.
Rhodes, R. W. A. (1996). The new governance: Governing without government. *Political Studies*, *44*(4), 652–667. https://doi.org/10.1111/j.1467-9248.1996.tb01747.x
RSE. (2011). *Energia eolica e sviluppo locale Territori, green economy e processi partecipativi*. Ricerca Sistema Energetico – RSE SpA.
Rutherford, J., & Jaglin, S. (2015). Introduction to the special issue – urban energy governance: Local actions, capacities and politics. *Energy Policy*, *78*, 173–178. https://doi.org/10.1016/j.enpol.2014.11.033
Smith, A., & Raven, R. (2012). What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, *41*(6), 1025–1036. https://doi.org/10.1016/j.respol.2011.12.012
Sovacool, B. K. (2014). What are we doing here? Analyzing fifteen years of energy scholarship and proposing a social science research agenda. *Energy Research & Social Science*, *1*, 1–29. https://doi.org/10.1016/j.erss.2014.02.003
TERNA. (2017). *Piano di sviluppodella Rete ElettricaNazionale 2017*. Terna S.p.A. – Rete ElettricaNazionale.
TERNA. (2020). *The 2021–2025 industrial plan: Driving energy*. Rome.
Wirth, S., Markard, J., Truffer, B., & Rohracher, H. (2013). Informal institutions matter: Professional culture and the development of biogas technology. *Environmental Innovation and Societal Transitions*, *8*, 20–41. https://doi.org/10.1016/j.eist.2013.06.002
Yin, R. K. (2014). *Case study research design and methods* (5th ed). Sage Publications.

Appendix 1: List of organisations interviewed

Ministero per l'Innovazione e lo Sviluppo Economico (MISE)
ENEL Green Power (Enel Group subsidiary for renewable sources)
Graziella Green, Renewable Energy Electricity producer
ENEA, National agency for new technologies energy and sustainable economic development
CNR (National Research Council) institute of geosciences and earth resources
ENEL Research Centre (Global Generation Division)
Horizon 2020 Representative for Italy in the area of Secure, Clean and Efficient Energy
TERNA, Italian Transmission Operator
Scuola Superiore Sant Anna, Innovation and Renewable Energy Research Group
Regione Sardegna (Regional Government)
Confindustria Nord Sardegna, Manufacturing and services association
Economic Department, Sassari University
Elianto, Renewable Energy Electricity Producer
Sardegna Ricerche, Cluster Renewable Energy
ARTI, Agenzia regionale per la tecnologia e l'innovazione (Apulia Development Agency)
Regione Puglia-Regional Government
Vestas, Wind Energy-Manufacturer
Tara Renewable Energy, Energy efficiency and smart buildings
CREA, Centro Ricerche Energia e Ambiente, Lecce University
Foggia University, Economics Department